frontiers | Research Topics

Public health and health research data: Availability, needs and challenges

Edited by
Carla Sofia e Sá Farinha, Andreia Silva Costa and Paulo Jorge Nogueira

Published in
Frontiers in Public Health

ISSN 1664-8714
ISBN 978-2-8325-4224-8
DOI 10.3389/978-2-8325-4224-8

About Frontiers

Frontiers is more than just an open access publisher of scholarly articles: it is a pioneering approach to the world of academia, radically improving the way scholarly research is managed. The grand vision of Frontiers is a world where all people have an equal opportunity to seek, share and generate knowledge. Frontiers provides immediate and permanent online open access to all its publications, but this alone is not enough to realize our grand goals.

Frontiers journal series

The Frontiers journal series is a multi-tier and interdisciplinary set of open-access, online journals, promising a paradigm shift from the current review, selection and dissemination processes in academic publishing. All Frontiers journals are driven by researchers for researchers; therefore, they constitute a service to the scholarly community. At the same time, the *Frontiers journal series* operates on a revolutionary invention, the tiered publishing system, initially addressing specific communities of scholars, and gradually climbing up to broader public understanding, thus serving the interests of the lay society, too.

Dedication to quality

Each Frontiers article is a landmark of the highest quality, thanks to genuinely collaborative interactions between authors and review editors, who include some of the world's best academicians. Research must be certified by peers before entering a stream of knowledge that may eventually reach the public - and shape society; therefore, Frontiers only applies the most rigorous and unbiased reviews. Frontiers revolutionizes research publishing by freely delivering the most outstanding research, evaluated with no bias from both the academic and social point of view. By applying the most advanced information technologies, Frontiers is catapulting scholarly publishing into a new generation.

What are Frontiers Research Topics?

Frontiers Research Topics are very popular trademarks of the *Frontiers journals series*: they are collections of at least ten articles, all centered on a particular subject. With their unique mix of varied contributions from Original Research to Review Articles, Frontiers Research Topics unify the most influential researchers, the latest key findings and historical advances in a hot research area.

Find out more on how to host your own Frontiers Research Topic or contribute to one as an author by contacting the Frontiers editorial office: frontiersin.org/about/contact

Public health and health research data: Availability, needs and challenges

Topic editors

Carla Sofia e Sá Farinha — New University of Lisbon, Portugal

Andreia Silva Costa — ISAMB & ESEL, Portugal

Paulo Jorge Nogueira — New University of Lisbon, Portugal

Citation

e Sá Farinha, C. S., Costa, A. S., Nogueira, P. J., eds. (2024). *Public health and health research data: Availability, needs and challenges*. Lausanne: Frontiers Media SA.

doi: 10.3389/978-2-8325-4224-8

Table of contents

frontiers | Frontiers in Public Health

TYPE Editorial
PUBLISHED 15 December 2023
DOI 10.3389/fpubh.2023.1340663

OPEN ACCESS

EDITED BY
Tafadzwa Dzinamarira,
University of Pretoria, South Africa

REVIEWED BY
Enos Moyo,
University of KwaZulu-Natal, South Africa

*CORRESPONDENCE
Paulo Jorge Nogueira
paulo.nogueira@ensp.unl.pt

RECEIVED 18 November 2023
ACCEPTED 27 November 2023
PUBLISHED 15 December 2023

CITATION
Nogueira PJ, Costa AS and Farinha CS (2023) Editorial: Public health and health research data: availability, needs and challenges. *Front. Public Health* 11:1340663. doi: 10.3389/fpubh.2023.1340663

Editorial: Public health and health research data: availability, needs and challenges

Paulo Jorge Nogueira[1,2,3,4]*, Andreia Silva Costa[3,4] and Carla Sofia e Sá Farinha[5]

[1]National School of Public Health, New University of Lisbon, Lisbon, Portugal, [2]Comprehensive Health Research Center, New University of Lisbon, Lisbon, Portugal, [3]Institute of Environmental Health, Faculty of Medicine, University of Lisbon, Lisbon, Portugal, [4]Centro de Investigação, Inovação e Desenvolvimento em Enfermagem de Lisboa, escola Superior de Enfermagem de Lisboa, Lisbon, Portugal, [5]Center for Environmental and Sustainability Research, Faculty of Sciences and Technology, New University of Lisbon, Caparica, Portugal

KEYWORDS

public health data, COVID-19 pandemic, healthcare policy, data analysis in healthcare, cyberinfrastructure in health, global health strategy

Editorial on the Research Topic
Public health and health research data: availability, needs and challenges

The criticality of data in the COVID-19 era

In the era of COVID-19, the availability and quality of public health data have become more critical than ever. This pandemic has highlighted the essential role of reliable data in informing health policy and public health management. The works of Ortiz-Prado et al. (1) and Zhang et al. underscore the importance of accessible and high-quality health data in formulating effective health strategies, especially during crises. Johannesson et al. emphasize the need for comprehensive and coordinated data collection and sharing systems, transcending national boundaries to tackle global health challenges effectively.

Integrating data for comprehensive health overview

The pandemic has illuminated significant challenges in managing health emergencies, particularly in resource-limited settings. Naz et al. stress the importance of integrating data from multiple sources, including governmental and private sectors, to create a comprehensive health overview, which is a necessity in low- and middle-income countries (LMICs). The study by Gao et al. demonstrates how cyberinfrastructure can augment traditional medical infrastructure, supporting adaptable policies and responses to public health emergencies.

Case studies and insights

- Ortiz-Prado et al. (1) advocate for measures that foster freedom of expression and sharing of scientific knowledge, which are vital for the growth and development of countries.
- Zhang et al.. highlight the necessity of cooperation to increase access to essential medications, contributing to universal health care goals.
- Ouedraogo et al. shows that despite non-communicable diseases (NCDs) being a major cause of mortality, they are often underfunded in health budgets.
- Lyons and Bhagwandeen discuss how access and availability of public healthcare services affect migrants and refugees during public health emergencies.
- Lv et al. and Gavurova et al. focus on using data for improved decision-making and developing tools for health-related project selection processes.
- The Role of Data in Public Health Management.
- The UNITE Summit 2023 Health Care Think Tank symbolizes the growing engagement in transforming health data management. This initiative aims to define key initiatives to tackle major challenges in health data management.
- Wang et al. provide an analysis of the global, regional, and national burden of digestive diseases, providing a critical perspective for public health initiatives based on the Global Burden of Disease Study 2019.
- Abdulla et al. give insights into the intersection of infectious diseases and nutritional challenges, highlighting food insecurity among tuberculosis patients in Eastern Ethiopia.
- Mutale et al. evaluate a protocol-driven primary care model in rural Zambia aimed at reducing all-cause mortality, emphasizing integrated healthcare approaches.
- Junker et al. propose the development of a high-frequency mental health surveillance prototype in Germany, underlining the importance of data infrastructure in public health.
- Panag et al. perform a comparative analysis of national surveillance reporting for Mpox virus in various countries, stressing the need for standardized reporting in global public health.
- and, Shen and Wang discuss regulating China's health code system for future pandemic preparedness, reflecting on digital health strategies and public health policy.

Conclusion: harnessing the true power of data in public health

This Research Topic, "Public Health and Health Research Data: Availability Needs and Challenges," has demonstrated unequivocally that the true power in data lies not merely in its existence, but in its strategic availability, analysis, and application in public health decision-making. The COVID-19 pandemic has served as a critical catalyst, underscoring this reality and emphasizing the urgent need for robust, accessible health data systems.

Throughout this Research Topic, studies such as those by Ortiz-Prado et al. (1), Zhang et al., and others, have provided compelling evidence of how data availability and quality directly impact the effectiveness of health strategies and responses, particularly in crisis situations. The case studies highlighted reveal that comprehensive, coordinated data collection and sharing systems are not just beneficial but essential for addressing global health challenges.

We have seen that in resource-limited settings, the integration of data from diverse sources, including governmental and private sectors, is crucial for creating a comprehensive health overview, as emphasized by Naz et al.. Additionally, the role of cyberinfrastructure, as shown by Gao et al., in augmenting traditional healthcare systems, presents new avenues for public health management and resilience against future emergencies.

As we move forward, it is imperative to foster collaboration across sectors and embrace a One Health perspective that recognizes the interconnectedness of human, animal, and environmental health. This comprehensive approach is vital for refining health data systems and effectively responding to current and future public health challenges.

In conclusion, this Research Topic has not only highlighted the current shortfalls in health data management but also pointed toward potential solutions and innovative technological pathways. The insights gained here advocate for a more inclusive approach to data gathering and utilization at all levels—governmental, private, and grassroots. The lesson is clear: the true power of data in public health emerges when it is made available, analyzed thoroughly, and utilized strategically to inform and guide public health policies and interventions. The future of public health lies in harnessing the full potential of data, ensuring that it becomes a cornerstone of public health decision-making and policy development in our increasingly interconnected world.

Author contributions

PN: Writing – original draft, Writing – review & editing. AC: Writing – review & editing. CF: Writing – original draft, Writing – review & editing.

Funding

The author(s) declare that no financial support was received for the research, authorship, and/or publication of this article.

Acknowledgments

We are grateful to the authors who contributed to our Research Topic.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Ortiz-Prado E, Izquierdo-Condoy JS, Vasconez-Gonzalez J, Garcia-Bereguiain MA. Upholding academic freedom: a call to protect freedom of expression and science in Ecuador and beyond. *Front Public Health*. (2023) 11:1259110. doi: 10.3389/fpubh.2023.1259110

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 18 April 2023
DOI 10.3389/fpubh.2023.1178654

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon,
Portugal

REVIEWED BY
Helen Roberts,
Food and Rural Affairs,
United Kingdom
Joseph Heskin,
Chelsea and Westminster
Hospital NHS Foundation Trust,
United Kingdom
Paula Vasconcelos,
Directorate-General of Health (DGS),
Portugal

*CORRESPONDENCE
Nityanand Jain
✉ nityapkl@gmail.com

SPECIALTY SECTION
This article was submitted to
Public Health Policy,
a section of the journal
Frontiers in Public Health

RECEIVED 03 March 2023
ACCEPTED 17 March 2023
PUBLISHED 18 April 2023

CITATION
Panag DS, Jain N, Katagi D, De Jesus Cipriano Flores G, Silva Dutra Macedo GD, Rodrigo Díaz Villa G, Yèche M, Velázquez Mérida SY, Kapparath S, Sert Z and Reinis A (2023) Variations in national surveillance reporting for Mpox virus: A comparative analysis in 32 countries.
Front. Public Health 11:1178654.
doi: 10.3389/fpubh.2023.1178654

Variations in national surveillance reporting for Mpox virus: A comparative analysis in 32 countries

Deepkanwar Singh Panag[1], Nityanand Jain[1]*, Dimitra Katagi[2], Gabriela De Jesus Cipriano Flores[3], Gabriela Dias Silva Dutra Macedo[4,5], Gonzalo Rodrigo Díaz Villa[6], Mathieu Yèche[7,8], Saydi Yusveni Velázquez Mérida[9], Sreerag Kapparath[10], Zilfi Sert[11] and Aigars Reinis[1,12]

[1]Faculty of Medicine, Riga Stradinš University, Riga, LV, Latvia, [2]Faculty of Medicine, School of Medicine, University of Patras, Rio, Greece, [3]Faculty of Medicine, Universidad Peruana Cayetano Heredia, Lima, Peru, [4]Faculty of Medicine, Universidade da Região de Joinville (UNIVILLE), Joinville, Brazil, [5]Pontifícia Universidade Católica do Paraná (PUCPR), Rua Imaculada Conceição, Prado Velho, Curitiba - PR, Brazil, [6]Faculty of Medicine, Universidad de los Andes, Las Condes, Chile, [7]ICM, Paris Brain Institute, Hopital de la Pitie-Salpetriere, Sorbonne Universite, INSERM U1127, CNRS UMR7225, Paris, France, [8]Département de Biologie de l'École Normale Supérieure (ENS), PSL Research University, Paris, France, [9]Faculty of Human Medicine "Manuel Velasco Suárez", Universidad Autónoma de Chiapas, Tapachula, Chiapas, Mexico, [10]Faculty of Medicine, Tbilisi State Medical University, Tbilisi, Georgia, [11]Faculteit der Bètawetenschappen, Vrije Universiteit Amsterdam, Amsterdam, Netherlands, [12]Joint Laboratory, Pauls Stradinš Clinical University Hospital, Riga, Latvia

Objectives: Case Reporting and Surveillance (CRS) are crucial to combat the global spread of the Monkeypox virus (Mpox). To support CRS, the World Health Organization (WHO) has released standardized case definitions for suspected, probable, confirmed, and discarded cases. However, these definitions are often subject to localized adaptations by countries leading to heterogeneity in the collected data. Herein, we compared the differences in Mpox case definitions in 32 countries that collectively reported 96% of the global Mpox caseload.

Methods: We extracted information regarding Mpox case definitions issued by the competent authorities in 32 included countries for suspected, probable, confirmed, and discarded cases. All data were gathered from online public sources.

Results: For confirmed cases, 18 countries (56%) followed WHO guidelines and tested for Mpox using species specific PCR and/or sequencing. For probable and suspected cases, seven and eight countries, respectively were found to have not released definitions in their national documentations. Furthermore, none of the countries completely matched WHO's criteria for probable and suspected cases. Overlapping amalgamations of the criteria were frequently noticed. Regarding discarded cases, only 13 countries (41%) reported definitions, with only two countries (6%) having definition consistent with WHO guidelines. For case reporting, 12 countries (38%) were found to report both probable and confirmed cases, in line with WHO requirements.

Conclusion: The heterogeneity in case definitions and reporting highlights the pressing need for homogenization in implementation of these guidelines. Homogenization would drastically improve data quality and aid data-scientists, epidemiologists, and clinicians to better understand and model the true disease burden in the society, followed by formulation and implementation of targeted interventions to curb the virus spread.

KEYWORDS

case definitions, differences, epidemiology, Monkeypox, mpox, reporting, surveillance

1. Introduction

In the domain of public health, Case Reporting and Surveillance (CRS) is a quintessential component in controlling the spread of communicable diseases in society. CRS enables real-time monitoring of the spread of the disease-causing pathogen not only within a specific community but also at a global level. Such surveillance allows for evaluation and prediction of the course of the disease, while contributing toward the formulation of targeted interventions to truncate the spread (1). Additionally, it enables the identification of the most vulnerable population groups (e.g., the older adult population in initial COVID-19 waves) (2), thereby facilitating moderation and diversion of the already scarce healthcare resources to those most in need.

Accordingly, the International Health Regulations (IHR) 2005, were adopted in 2007 by 196 countries and serve as a legally binding instrument that empowers the World Health Organization (WHO) as the main global surveillance system and requires the WHO to declare certain pathogens as public health emergency of international concern (PHEIC) (3). PHEIC is any hazard (radiological, chemical, and biological) that has the potential of international spread and requires an immediate and coordinated global response. The IHR 2005 require all signatory countries to develop and maintain the capacity to detect, assess, report, and respond to PHEIC(s). Despite the adoption of IHR 2005 more than a decade ago, the Centers of Disease Control and Prevention (CDC) estimates that about 2/3rd of the countries lack such capacities, thereby leaving the world population vulnerable (4). In the past, countries with potential violations of the IHR 2005 have gone by without suffering many serious consequences (5), attributable mostly to the lack of guidelines about the mandatory dispute settlement process or enforcement mechanism (5).

To aid the member countries, the WHO regularly releases interim guidelines and other relevant documentation for proper recording, isolation, and reporting of suspected, probable, and confirmed cases. However, experiences from previous epidemics and pandemics have highlighted that there is a lack of standardization when it comes to the international implementation of case definitions and surveillance guidelines (6). Taking the recent example of COVID-19, Suthar et al., found that in the 25 most affected countries, only 56% of the countries followed WHO's recommended case definition for suspected cases (7). Similar findings were seen for probable and confirmed cases (7). This is not the first time such heterogeneity has been described (8, 9). In the European Union (EU), a review of maritime hygiene and disease control manuals also found variances in disease surveillance practices and called for a need for the implementation of common rules and tools (10).

Implementation and adherence to standardized case definitions allow for easy intra- and inter-country reporting and compilation of data, thereby enhancing the data quality. Such practices also allow for the maximum inclusion of population characteristics which is essential when preparing disease models. A test conducted by Krause et al., in Germany allowed the authors to analyze intra-country variations in the implementation of case definitions (11). The author's work proved to be instrumental in overhauling the case reporting system in Germany and allowed for inclusive and more realistic reporting (11). Several calls in the past have been raised for the WHO to step up and homogenize the case-reporting hierarchy, however, differences in technical and financial capabilities in the lower- and middle-income countries (LMICs) often limit this exercise (6).

The latest biological PHEIC to be classified is the Monkeypox Virus (Mpox), a zoonotic virus endemic to the rainforests of central and western Africa (12). The virus has spread rapidly in the Global North and has been detected in more than 100 countries as of 30th January 2023. In response, the WHO released standardized case definitions (13) and two separate forms for case investigation (CIF) and case reporting (CRF) (14). The CIF is meant for in-depth epidemiological investigations while the CRF is a minimum dataset capturing the key epidemiologic parameters of monkeypox cases. Currently, the WHO mandates member states to submit the CRF for probable and confirmed cases under Article 6 of the IHR 2005 (13).

Given the possibility of differences in the implementation of WHO recommendations based on previous experiences, we henceforth, undertook the present study whereby we investigated how different countries adopted WHO's Mpox guidelines and recommendations in terms of case definitions and case notification. We believe the results obtained in the present study would be useful to the international community at large, given the current spread of Mpox. Highlighting such discrepancies at earlier stages of the disease spread could potentially aid in proper implementation, capacity building, and updating of the respective national guidelines.

2. Methods

In the present study, we investigated data from 32 countries. These countries were included based on the following criteria: (i) most affected countries (the countries with the highest Mpox caseload); (ii) publicly available information on Mpox case definitions; (iii) release of such definitions by the country's competent authority and (iv) access to the information. We additionally, excluded countries that are considered endemic and/or had been known historically to be the source of outbreaks. Accordingly, we included 17 out of 20 of the most affected countries along with 15 other countries with relatively low Mpox caseloads. The other three countries in the top 20 most affected countries—Nigeria, Democratic Republic of Congo, and Ecuador were not included due to historically known outbreaks in the first two and no case definition information found for the latter.

Information regarding Mpox case definitions for suspected, probable, confirmed, and discarded cases were collected and gathered from online public sources. Additionally, we collected information regarding which of the Mpox cases are required to be notified to the Health Officers/National Reporting Systems (NRS) by healthcare practitioners. For the data that was not available in English, for the following languages, the data was validated by the authors (native language speakers)—Dutch, French, Greek, Portuguese, Spanish, and Turkish. For other languages, we used bi-directional online language conversion (using Google Translate)—first from the language of the official document to English and then in the reverse direction (for

accuracy). A list of sources used for each of the investigated countries along with full case definitions and their translations are provided in Supplementary File.

The investigated Mpox guidelines and documents were "current and in effect" in the respective countries as of January 2023 (based on available and accessible online data; there may be newer versions which are not immediately available online). The sources were last checked for updates on 25th January 2023. The study design was restricted to observational, cross-sectional, qualitative comparison (including descriptive statistics) and inferential statistical analysis was not undertaken due to the nature of the collected data. The STROBE checklist was used for reporting the data. Since the data analyzed are available publicly, ethical approval did not apply to the present study.

3. Results

3.1. Spread of Mpox across the investigated countries

Since May 2022, more than 81,000 cases of Mpox have been confirmed as of 31st January 2023 in the investigated 32 countries, representing almost 96% of the total cases reported globally (Figure 1). The United States of America (USA) reported the highest caseload (35.2%) followed by Brazil and Spain (12.6 and 8.8%, respectively). Together, these three countries account for more than 55% of all confirmed cases globally. Furthermore, nine of the 32 included countries reported Mpox-related deaths (70 deaths combined), accounting for 63% of all reported Mpox-related deaths worldwide. The highest number of deaths were recorded in the United States (27) followed by Brazil and Peru (15 each). India and Belgium each reported 1 Mpox-related death.

3.2. Case definitions for laboratory confirmed cases

The WHO's guidelines for the classification of confirmed Mpox case requires the detection of unique sequences of the Mpox DNA using either (i) polymerase chain reaction (PCR) or (ii) sequencing (Table 1). Furthermore, PCR conducted on blood samples is not considered diagnostically sufficient and should not be used as a stand-alone first-line diagnostic tool. The primary sampling for PCR should be done from the skin lesion material or other specimen such as an oral or nasopharyngeal swab. We observed that all countries required molecular testing with PCR as a pre-condition for classification of cases as "Mpox positive." Noticeably, 11 countries also accepted generalized Orthopoxvirus detection by Nucleic Acid Amplification Tests (NAATs) which may or may not be followed up by Mpox specific sequencing. Furthermore, only 18 out of 32 countries mentioned sequencing as a criterion for confirmed cases. Australia and Sweden also accepted isolation of virus in culture (represents one of the most precise techniques to demonstrate active reproduction of the virus) as a criterion for confirmed cases. Germany, on the other hand, accepted positive electron microscopy results as an additional criterion.

3.3. Case definitions for probable cases

According to WHO, an individual is classified as a probable case of Mpox if the individual meets the clinical criteria along with one or more of several additional criteria (Table 2). The clinical criteria require that an individual present with either an unexplained acute rash, mucosal lesions, or lymphadenopathy. There are five additional criteria described by WHO for the probable case definition—(i) epidemiologic link to a probable or

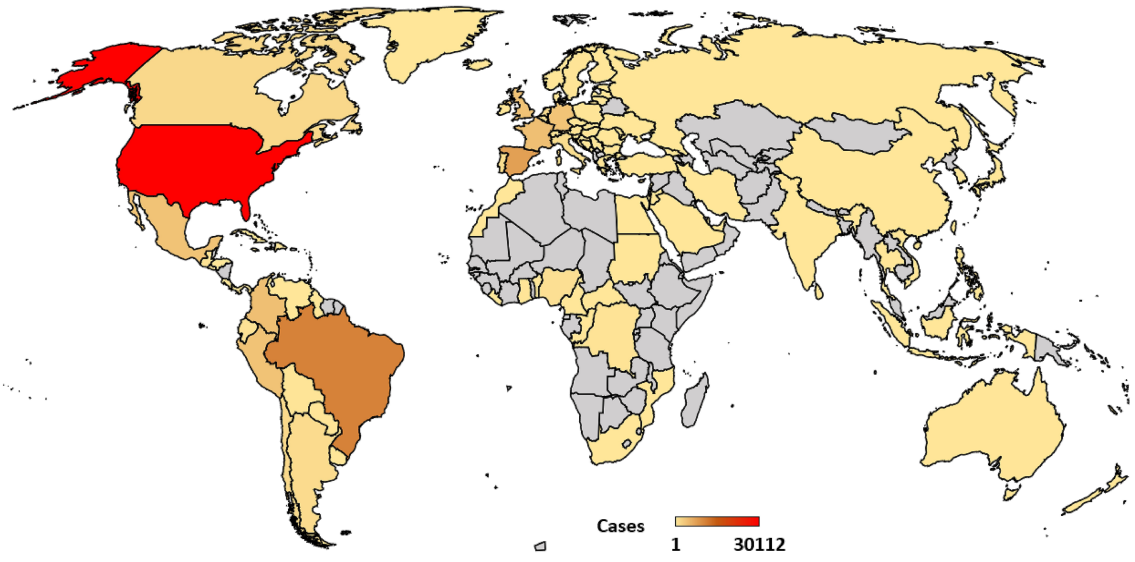


FIGURE 1
Geographical distribution of Mpox caseload as of January 31, 2023 (confirmed cases only). Data source—United States Centers for Disease Control and Prevention (U.S. CDC; https://www.cdc.gov/poxvirus/monkeypox/response/2022/world-map.html; accessed February 1, 2023). Note that the map is only for illustrative purposes and the authors remain neutral regarding territorial disputes.

10.3389/fpubh.2023.1178654

TABLE 1 Criteria for defining Mpox confirmed case in the investigated countries.

Country	Detection of unique sequences of Mpox DNA using		Isolation of Mpox in culture
	Polymerase chain reaction (PCR)	Sequencing	
World Health Organization (WHO)	X	X	
Argentina[1,2]	X		
Australia[3]	X	X	X
Austria[3,4]	X	X	
Belgium[5]	X		
Brazil[2]	X	X	
Canada	X	X	
Chile[6]	X		
Colombia[7,8]	X		
Costa Rica	X	X	
Cyprus[4]	X	X	
Denmark	X		
France[9]	X		
Germany[9,10]	X	X	
Greece[4]	X	X	
India	X	X	
Ireland	X		
Italy[6]	X	X	
Jamaica[6]	X	X	
Mexico	X	X	
Netherlands[8]	X		
New Zealand[3]	X		
Peru[3,7]	X		
Poland[4]	X	X	
Portugal	X	X	
South Africa[6]	X	X	
Spain[9]	X		
Sweden[3]	X	X	X
Switzerland	X		
Turkiye[7]	X		
UAE[6]	X	X	
United Kingdom	X		
United States	X	X	
Total	32/32 (100%)	18/32 (56%)	2/32 (6%)

[1]Argentina also accepts detectable PCR results for Orthopoxvirus if patient belongs to the Eurasian-African group.
[2]Argentina and Brazil require patients to meet criteria for suspected case along with laboratory confirmation to be classified as confirmed case.
[3]Australia, Austria, New Zealand, Peru, and Sweden does not specify PCR in guidelines but require patients to perform any Nucleic Acid Amplification Test (NAAT) or molecular testing.
[4]Austria, Cyprus, Greece, and Poland also accept a positive PCR result for Orthopoxvirus if it is followed by sequencing showing Mpox in a person who developed symptoms after March 01, 2022, onwards.
[5]Belgium also accepts Orthopoxvirus specific PCR assay positive result in patients with symptom onset after March 1, 2022.
[6]Chile, Italy, Jamaica, South Africa, and UAE require patients to meet criteria for either suspected or probable case along with laboratory confirmation to be classified as confirmed case.
[7]Colombia, Peru, and Turkiye requires patients to meet criteria for probable case along with laboratory confirmation to be classified as confirmed case.
[8]Colombia and Netherlands accept Orthopoxvirus specific PCR without follow-up sequencing.
[9]France, Germany, and Spain, in addition to Mpox specific PCR, also accept Orthopoxvirus specific PCR.
[10]Germany also accepts results of Electron microscopy as criterion for confirmed case.

confirmed case in the 21 days prior to symptom onset; (ii) identified as gay, bisexual, or other man who has sex with men; (iii) multiple or casual sexual partners in the 21 days prior to symptom onset; (iv) detectable levels of anti-orthopoxvirus (OPXV) IgM or IgG antibody titers; and (v) positive test result for orthopoxvirus infection.

TABLE 2 Criteria for defining Mpox probable (or likely) case in the investigated countries.

Country	Clinical Criteria			Additional Criteria (must fulfill one or more along with clinical criteria)					
	Unexplained acute skin rash[1]	Mucosal lesions[2]	Lymphadenopathy	Epidemiological link[3]	Travel to endemic regions[4]	Identifies as gay, or MSM community member	Multiple sexual partners[5]	Detectable IgM or 4x rise in IgG[6]	Positive for OPXV infection[7]
World Health Organization (WHO)	X	X	X	X		X	X	X	X
Australia[a]	X	X	X						X
Austria[b]	X	X	X	X	X		X		X
Belgium[c]	X		X	X	X	X	X		
Brazil[d,e]	X	X		X			X		
Canada[e,f]	X	X		X					
Chile[d,g,h]	X		X	X	X				
Colombia[i]	X	X	X	X	X		X		
France[e,g,j]	X	X	X	X					
Germany[k]	X	X	X	X					
India[d,e,f,h]	X		X	X					
Ireland[l]	X	X	X	X	X				
Italy[d,e,l,m]	X		X	X	X		X		X
Jamaica[d,e,f,l]	X		X	X	X				
Mexico[l]	X	X	X						
Netherlands[l,n]	X	X	X	X		X	X		
New Zealand[e]	X	X		X	X	X	X		
Peru[e,f,o]	X		X	X			X		
Poland[e,l]	X		X	X	X	X	X		X
Portugal[d,e,m,p]	X	X	X	X	X		X		
South Africa[d,e,l,m]	X		X	X	X		X		X
Spain[l]	X		X	X	X	X	X		
Switzerland[d,q]	X			X					
UAE[d,r]	X		X	X	X		X		
United Kingdom	X	X		X		X	X		

(Continued)

10.3389/fpubh.2023.1178654

TABLE 2 (Continued)

Country	Clinical Criteria			Additional Criteria (must fulfill one or more along with clinical criteria)					
	Unexplained acute skin rash[1]	Mucosal lesions[2]	Lymphadenopathy	Epidemiological link[3]	Travel to endemic regions[4]	Identifies as gay, or MSM community member	Multiple sexual partners[5]	Detectable IgM or 4x rise in IgG[6]	Positive for OPXV infection[7]
United States[s]								X	X
Total	24/25 (96%)	13/25 (52%)	19/25 (76%)	22/25 (88%)	13/25 (52%)	6/25 (24%)	14/25 (56%)	1/25 (4%)	6/25 (24%)

[1]The skin rash may include single or multiple lesions in the ano-genital region or elsewhere on the body.

[2]Mucosal lesions may include single or multiple oral, conjunctival, urethral, penile, vaginal, or ano-rectal lesions. Anorectal lesions can also manifest as ano-rectal inflammation (proctitis), pain and/or bleeding.

[3]The person has been exposed to a probable or confirmed monkeypox case in the 21 days before symptom onset. For countries with animal to human transmission, known contact with wild animals (dead or alive) and/or sick animals in the 21 days before the onset of symptoms is included as epidemiological criteria.

[4]The person has traveled to Mpox endemic African regions in the 21 days before symptom onset [Benin, Cameroon, the Central African Republic, the Democratic Republic of the Congo, Gabon, Ghana (identified in animals only), Ivory Coast, Liberia, Nigeria, the Republic of the Congo, Sierra Leone, and South Sudan].

[5]The person has had multiple and/or casual sexual partners in the 21 days before symptom onset.

[6]The person has detectable levels of anti-orthopoxvirus (OPXV) IgM antibody (during the period of 4–56 days after rash onset); or a 4-fold rise in IgG antibody titer based on acute (up to day 5–7) and convalescent (day 21 onwards) samples; in the absence of a recent smallpox/monkeypox vaccination or other known exposure to OPXV. Note that serology is not first line diagnostic modality for Mpox and should be used for retrospective case classification when PCR skin lesion testing was not possible or for research purposes.

[7]The person has a positive test result for orthopoxviral infection done on a sample other than blood specimen (e.g., OPXV-specific PCR without Mpox-specific PCR or sequencing).

[a]Australia also accepts detection of orthopoxvirus by electron microscopy from clinical specimens in the absence of exposure to another orthopoxvirus. Additionally, in clinical criteria, Australia also mentions history of fever (>38°C), headache, myalgia, arthralgia, fatigue, and back pain.

[b]Austria in clinical criteria additionally accepts fever (>38.5°C), myalgia, arthralgia, cephalgia, back pain, painful lymphadenopathy (localized or generalized), and fatigue (prodromal stage). Additionally, contact with rodents or non-human primates in or from affected areas that allows animal-to-human transmission and occupational exposure to smallpox viruses are also considered as criteria in the case definition.

[c]Belgium also considers following symptoms for Mpox infection—fever (usually high >38.5°C), headache, back ache, and fatigue.

[d]Brazil, Chile, India, Italy, Jamaica, Portugal, South Africa, Switzerland, and UAE requires probable cases to meet the definition of suspected cases.

[e]Brazil, Canada, France, India, Italy, Jamaica, New Zealand, Peru, Poland, Portugal, and South Africa also consider prolonged and close exposure without respiratory protection and contact with contaminated materials, such as bedding and bath linen or utensils for common use belonging to a probable or confirmed case within the last 21 days of symptom onset as criteria for probable case. Healthcare workers meeting suspected case definition and improperly using personal protective equipment who got in contact with probable or confirmed case are also considered as probable case.

[f]Canada, India, Jamaica, and Peru considers travel history to or residence in a location where monkeypox is reported in the last 21 days of symptom onset as criteria for epidemiological link.

[g]Chile and France for epidemiological criteria requires contact with confirmed cases only.

[h]Chile and India additional clinical symptoms included in case definition include headache, sudden onset of fever (>38.5°C), myalgia, back pain, and asthenia (weakness).

[i]Colombia also considers following symptoms in clinical criteria—fever, sore throat, myalgia, and headache. Additionally, Colombia considers contact with live or dead animal potential reservoirs of the virus in African region as epidemiological criteria. It also considers travel to countries with confirmed outbreak as another criteria.

[j]France additionally considers fever (>38°C) and odynophagia as clinical criteria. In epidemiological criteria, France also considers unprotected contact <2 m for ≥3 h with probable or confirmed symptomatic case.

[k]Germany refers to probable cases as "Clinically-epidemiologically confirmed disease." Clinical criteria also include fever, and disease-related death.

[l]Ireland, Italy, Jamaica, Mexico, Netherlands, Poland, Spain, and South Africa considers following clinical symptoms in probable case definition–-acute illness with fever (>38.5°C), headache, myalgia, arthralgia, back pain, and asthenia.

[m]Italy, Portugal, and South Africa also considers any hospitalized person due to Mpox-like illness as probable case.

[n]Netherlands also considers a female partner of a man who (also) has sex with men as epidemiological criteria. Netherlands refers to probable cases as "Likely case."

[o]Peru also considers following clinical symptoms in clinical criteria—fever, fatigue, muscular pain, vomiting, diarrhea, shaking chills, throat pain, and headache.

[p]Portugal also considers sudden onset fever (≥38.0°C), asthenia, myalgia, back pain, and headache as clinical symptoms. Portugal uses definition of high-risk contacts for all epidemiological contacts.

[q]Switzerland considers either fever (or flu like symptoms) with acute rash or fever or rash with epidemiological link as definition for suspected and probable case.

[r]UAE considers acute rash interchangeable with fever (>38.5°C) and requires at least two or more of the following clinical symptoms to be present in the patient—headache, myalgia (muscle pain/body aches), back pain, and asthenia.

[s]United States characterizes probable case as case with no suspicion of other recent Orthopoxvirus exposure (e.g., Vaccinia virus in ACAM2000 vaccination) and no laboratory evidence of infection with another non-variola orthopoxvirus. Further, demonstration of orthopoxvirus DNA by molecular testing of a clinical specimen or orthopoxvirus using immunohistochemical or genomic sequencing testing methods is required for probable case definition.

10.3389/fpubh.2023.1178654

Seven of the investigated countries (Argentina, Costa Rica, Cyprus, Denmark, Greece, Sweden, and Turkiye) did not report case definitions for probable cases. Among the remaining countries, presence of unexplained rash in any age group patient after March 1, 2022, and high-risk contact with confirmed or probable case were noted as the most common criteria (Table 2). More than half of the countries also included an additional criterion (when compared with WHO's guidelines) of travel to endemic regions in Africa in the last 21 days of symptom onset. Only the United States uses serological criteria for probable cases. For countries with animal to human transmission, WHO states that known contact with wild animals (dead or alive) and/or sick animals in the 21 days before the onset of symptoms should be included in the epidemiological criteria. Austria and Colombia were the only two countries to issue guidelines in this regard.

Interestingly, only six countries—Belgium, Netherlands, New Zealand, Poland, Spain, and United Kingdom—included identification of patient as gay or MSM (men who have sex with other men) community member as a criterion in the case definition of probable cases. Netherlands also considers a female partner of a man who (also) has sex with men as epidemiological criteria. Both Poland and New Zealand also included prolonged and close exposure without respiratory protection and contact with contaminated materials, such as bedding and bath linen or utensils for common use belonging to a probable or confirmed case within the last 21 days of symptom onset as criteria for probable case. Healthcare workers meeting suspected case definition and improperly using personal protective equipment who got in contact with probable or confirmed case were also considered as probable case in these two countries.

Australia additionally accepts electron microscopy results for defining probable cases (while Germany used the technique for confirmed cases). United States, on the other hand, accepts immunohistochemistry and genomic sequencing results for probable case definitions. Application of diagnostic electron microscopy (EM) can provide initial results within minutes and can successfully aid in excluding majority of differential diagnosis (15). However, it must be followed by more specific tests since EM cannot identify different viral species.

3.4. Case definitions for suspected cases

The WHO defined a suspected case as an individual fulfilling either of the two criteria. The first criteria included epidemiological contact with a confirmed or probable Mpox case in the 21 days before the onset of signs or symptoms and who presents with any of the following—acute onset of fever (>38.5°C), headache, myalgia (muscle pain/body aches), back pain, profound weakness, or fatigue. The second criteria included clinical criteria (unexplained acute skin rash, mucosal lesions, or lymphadenopathy) and testing criteria (exclusion of other common causes of acute rash or skin lesion and testing for Mpox in case of co-infections).

We found that eight countries did not report case definitions for suspected cases (Austria, Colombia, Germany, Ireland, Mexico, New Zealand, Peru, and Poland). Austria previously defined suspected cases separately but in the updated 2023 guidelines, the country defines suspected and probable cases singly as probable cases. Similarly, Mexico removed the definition of suspected cases in the updated August 2022 guidelines. Though the exact rational is not immediately clear behind these changes, we suspect these changes would streamline the reporting process (in line with WHO recommendations) and provide for a binary classification of cases for the medical personnel.

Interestingly, New Zealand has a classification category called "Under Investigation" that is defined as a person that has been reported to a Medical Officer of Health, but information is not yet available to classify it as confirmed, probable or not a case. Among the other countries, unexplained acute skin rash and fever were found to be the most used clinical symptoms, followed by lymphadenopathy and headache (Table 3). Belgium and Brazil were the only country (in line with WHO guidelines) that recommended testing for Mpox in highly suspicious cases in whom an alternative pathogen has been identified to check for co-infections.

For epidemiological criteria, only 46% of the countries fulfilled WHO criteria. For suspected cases, United States was the only country to include contact with infected animal as one of the many possible epidemiological criteria. Interestingly, many countries did not clearly divide the criteria for suspected case in the manner prescribed by WHO. Overlapping amalgamations of the two criteria were seen in most countries (refer to Supplementary File for individual country definitions).

3.5. Notifiable cases

According to the WHO, national authorities should collect data for all cases that meet the case definitions for probable and confirmed cases. The data pertaining to suspected cases should be maintained at national level. Accordingly, we found that 12 countries (38%) followed the WHO guidelines, with seven countries asking medical practitioners to additionally notify suspected cases (Table 4). Germany, Netherlands, Sweden, and Switzerland require notification for only confirmed cases while nine countries (28%) required notification of confirmed and suspected cases. Noticeably, Netherlands, downgraded reporting of cases from group A (confirmed and probable cases) to group B1 (only confirmed cases) as of 15th December 2022.

3.6. Case definitions for discarded cases

According to the WHO, a discarded case is a suspected or probable case for which laboratory testing of lesion fluid, skin specimens or crusts by PCR and/or sequencing is negative for Mpox (should be done on a sample other than blood specimen). Thirteen out of 32 of the investigated countries (41%) reported definitions for discarded cases or reported exclusion criteria for cases to be classified as suspected, probable, or confirmed for Mpox infection. However, of these countries only Chile and Italy had definitions that were in line with WHO recommendations (Table 5). Spain and United States remained ambiguous in terms of accepted laboratory tests (e.g., Spain does not mention sequencing for confirming cases while United States additionally accepts viral isolates from culture as described in Table 1). Brazil and Costa Rica on the other hand, mentioned only suspected cases with negative laboratory investigations as discarded case.

TABLE 3 Criteria for defining Mpox suspected (or possible) case in the investigated countries.

Country	Criteria 1						Criteria 2				
	Epidemiological criteria[1]	Clinical criteria					Clinical criteria[2]			Testing criteria	
		Acute onset Fever>38.5°C	Headache	Myalgia	Back pain	Profound weakness or fatigue	Unexplained acute skin rash	Mucosal lesions	Lymphadenopathy	Exclude other causes of rash[3]	Testing for Mpox in case of co-infections[4]
World Health Organization (WHO)	X	X	X	X	X	X	X	X	X	X	X
Argentina [a]	X	X	X	X	X	X	X	X	X	X	
Australia [b,c]	X	X	X	X	X	X	X	X	X		
Belgium [d]		X	X	X	X	X	X		X		X
Brazil [d]							X	X		X	X
Canada [e]		X	X	X	X	X	X	X	X		
Chile [d]		X	X	X	X	X	X		X	X	
Costa Rica [a,c,f]	X	X	X	X	X	X	X	X	X	X	
Cyprus [c,d,g]	X	X	X		X	X	X		X		
Denmark [c]	X	X	X		X	X	X	X	X		
France [c,h]		X					X	X	X		
Greece [c,d,g]	X	X	X		X	X	X		X		
India [d,i]		X	X	X		X			X		
Italy		X	X	X	X	X	X		X	X	
Jamaica		X	X	X	X	X	X		X	X	
Netherlands		X	X	X	X	X	X	X	X	X	
Portugal [j]		X	X	X	X	X	X	X	X	X	
South Africa		X	X	X	X	X	X		X	X	
Spain [k]		X	X	X	X		X		X	X	
Sweden [l]	X										
Switzerland	X	X					X				
Turkiye [k,m]	X	X	X	X		X	X		X		
UAE		X	X	X	X	X	X		X		

(Continued)

10.3389/fpubh.2023.1178654

TABLE 3 (Continued)

Country	Criteria 1						Criteria 2				
	Epidemiological criteria[1]	Clinical criteria					Clinical criteria[2]			Testing criteria	
		Acute onset Fever>38.5°C	Headache	Myalgia	Back pain	Profound weakness or fatigue	Unexplained acute skin rash	Mucosal lesions	Lymphadenopathy	Exclude other causes of rash[3]	Testing for Mpox in case of co-infections[4]
United Kingdom [j,k]	X	X	X	X	X	X	X	X	X		
United States [c,d,n]	X	X					X	X	X	X	
Total	11/24 (46%)	22/24 (92%)	19/24 (80%)	16/24 (67%)	17/24 (71%)	18/24 (75%)	22/24 (92%)	11/24 (46%)	21/24 (88%)	11/24 (46%)	2/24 (8%)

[1]A person who is a contact of a probable or confirmed monkeypox case in the 21 days before the onset of signs or symptoms. For countries with animal to human transmission, known contact with wild animals (dead or alive) and/or sick animals in the 21 days before the onset of symptoms is included as epidemiological criteria.

[2]A person presenting since 01 January 2022 with an unexplained acute skin rash, mucosal lesions, or lymphadenopathy (swollen lymph nodes). The skin rash may include single or multiple lesions in the ano-genital region or elsewhere on the body. Mucosal lesions may include single or multiple oral, conjunctival, urethral, penile, vaginal, or ano-rectal lesions. Ano-rectal lesions can also manifest as ano-rectal inflammation (proctitis), pain and/or bleeding.

[3]Differentials include varicella zoster, herpes zoster, measles, herpes simplex, bacterial skin infections, disseminated gonococcus infection, primary or secondary syphilis, chancroid, lymphogranuloma venereum, granuloma inguinale, molluscum contagiosum, allergic reaction (e.g., to plants); and any other locally relevant common causes of papular or vesicular rash. It is not necessary to obtain negative laboratory results for listed common causes of rash illness in order to classify a case as suspected.

[4]If suspicion of monkeypox infection is high due to either history and/or clinical presentation or possible exposure to a case, the identification of an alternate pathogen which causes rash illness should not preclude testing for Mpox, as co-infections have been identified.

[a]Argentina and Costa Rica additionally considers contact with contaminated materials—such as clothing or bedding used by suspected or confirmed case, close contact without respiratory protection, and sexual intercourse with multiple partners in the past 21 days of symptom onset as epidemiological criteria.

[b]Australia considers fever >38°C or history of fever as criteria for clinical evidence along with extra symptom of arthralgia.

[c]Australia, Costa Rica, Cyprus, Denmark, France, Greece, and United States additionally considers overseas travel (especially to endemic regions) in the 21 days before symptom onset and sexual contact and/or other physical intimate contact with multiple partners (of any orientation) and/or a gay, bisexual, or other man who has sex with men in the 21 days before symptom onset as epidemiological criteria.

[d]Belgium, Brazil, Chile, Cyprus, Greece, India, and United States define acute onset rash as unexplained generalized or localized maculopapular or vesiculopustular rash with centrifugal spread, with lesions showing umbilication or scabbing and progressing through following stages—macules, papules, vesicles, pustules, and crusts.

[e]Canada defines rash as progressively developing that usually starts on the face and then spreads elsewhere on the body. The rash can affect the mucous membranes in the mouth, tongue, and genitalia. The rash can also affect the palms of hands and soles of the feet. The rash can last for 2—4 weeks and progresses through the following stages before falling off: macules, papules, vesicles, pustules, and scabs.

[f]Costa Rica also considers medical history of recent consultations for suspected STI diseases as epidemiological criteria.

[g]Cyprus and Greece also considers positive result in a test for the detection of viruses of the genus Orthopoxvirus as criteria for suspected case classification.

[h]France defines case with clinical presentation as "suspected case" but a case with clinical presentation and high-risk contact (refer to footnote point c above) as "possible case."

[i]India considers travel to affected countries in the past 21 days of symptom onset as epidemiological criteria.

[j]Portugal and United Kingdom considers fever as ≥38°C.

[k]Spain, Turkiye, and United Kingdom additionally consider arthralgia as a clinical symptom suggestive of Mpox. For United Kingdom only, chills are also an additional symptom.

[l]Sweden considers suspected case as a person sampled with suspicion of monkeypox pending test results and who has no symptoms but has fulfilled the epidemiological criteria.

[m]Turkiye defines rash as itchy lesion without specific differentiation of the type of lesion (mucosal or dermal).

[n]United States also considers contact with a dead or live wild animal or exotic pet that is an African endemic species or used a product derived from such animals as epidemiological criteria. Additionally, contact, without the use of appropriate PPE or Biosafety Level (BSL) protocols, with laboratory specimens or other items or contact without appropriate use of PPE with a person or animal with a known orthopoxvirus or Mpox virus infection are considered in the criteria.

10.3389/fpubh.2023.1178654

TABLE 4 Differences in notifiable cases based on surveillance definitions.

Notifiable cases based on surveillance definitions	Number of countries	Countries
Confirmed cases only	4	Germany[1], Netherlands, Sweden, and Switzerland
Confirmed and probable cases (WHO recommended)	12	Australia[2], Austria, Canada, Colombia, France[3], Ireland, Mexico, New Zealand, Peru, Poland[4], United States, and United Kingdom[5]
Confirmed and suspected (or possible) cases	9	Argentina, Costa Rica, Belgium, Brazil, Cyprus, Denmark, Greece, South Africa, and Turkiye
Confirmed, probable, and suspected cases	7	Chile, India, Italy, Jamaica, Portugal, Spain, and UAE

[1]Germany requires reporting of laboratory confirmed cases that can either (i) fulfill clinical criteria; (ii) have unfulfilled clinical criteria; or (iii) have unknown clinical picture.
[2]Australia requires notification of suspected cases only to the state and territory public health units and not to the national surveillance authorities.
[3]Apart from confirmed and probable cases, France requires mandatory reporting of possible (suspected) cases that are exempt from testing (criteria for exemption are—if the clinical symptoms are sufficiently suggestive, there is a context of risk of exposure to the virus, there are no signs of seriousness, and the diagnoses differentials have been ruled out).
[4]Poland requires reporting of suspicious cases (after considering other causes of symptoms and considering epidemiological connections). However, when reporting to ECDC and WHO, Poland reports confirmed, suspected, and probable cases.
[5]United Kingdom requires reporting of confirmed and highly probable cases (person with an orthopox virus PCR positive result in 2022 and where monkeypox remains the most likely diagnosis).

TABLE 5 Definition of discarded cases according to national guidelines in the investigated countries.

Country	Definition
World Health Organization (WHO)	A suspected or probable case for which laboratory testing of lesion fluid, skin specimens or crusts by PCR and/or sequencing is negative for Mpox (should be done on a sample other than blood specimen).
Austria	If the laboratory diagnostic examination of the suspected (considered same as probable) case does not provide any indication a monkeypox virus infection, the suspected case is an "excluded case" and cease any official action.
Brazil	Suspected case with negative or undetectable laboratory result for monkeypox virus (Mpox) by molecular diagnostics (real-time PCR and/or sequencing).
Chile	Suspected or probable case for which PCR and/or sequencing are negative for monkeypox.
Colombia	Probable case in which sample was taken, preserved, and processed in adequate manner for laboratory diagnosis and the result was negative.
Costa Rica	Suspected case for which laboratory tests by PCR (real-time PCR), and/or sequencing are negative in properly collected samples.
Cyprus	Upon a negative laboratory result, patients cease to be considered as outbreaks of monkeypox.
Greece	Upon a negative laboratory result, patients cease to be considered as outbreaks of monkeypox.
Italy	A suspected or probable case for which laboratory tests using PCR and/or sequencing are negative for Mpox.
Mexico	A probable case with a negative result to real-time PCR test (qPCR) or identification by sequencing that has been issued by the InDRE company.
New Zealand	A person that has been investigated and subsequently found not to meet the case definition (called as *not a case*).
Peru	A person whose cause of acute rash has been identified based on clinical diagnosis or epidemiological connection. However, to comply with the definition of probable case one must obtain and test sample for Mpox considering possible coinfection.
Spain	Suspected or probable case in which the laboratory result in samples of high quality has been negative.
United States	A case may be excluded as a suspect, probable, or confirmed case if: An alternative diagnosis can fully explain the illness OR An individual with symptoms consistent with monkeypox does not develop a rash within 5 days of illness onset OR A case where high-quality specimens do not demonstrate the presence of Orthopoxvirus or Mpox virus or antibodies to Orthopoxvirus.

4. Discussion

The current multi-country outbreak of the Mpox virus is a rapidly evolving situation, one that requires constant modifications and adaptations to the management and surveillance guidelines as the virus spreads. Subsequently, the WHO released interim guidelines for case recording and categorization for the member states with the aims of (i) identifying new clusters/outbreaks to provide appropriate clinical care; (ii) stopping human-to-human transmission by isolating identified cases and contact tracing; (iii) minimizing zoonotic transmission; and (iv) tailoring a coordinated global response by identifying risk groups and protecting frontline workers (13). Furthermore, the WHO has prepared a macro-enabled Microsoft Excel form that is available for member countries for data collection. The use of Go. Data platform has been recommended by the WHO for facilitation of local capture, analysis, and/or sharing of the Mpox data (13).

Although, the WHO states that the national public health authorities may adapt these recommendations and definitions based on local situation, these basic definitions for case classification were published considering the varied circumstances and capacities in all member states (13). Herein, we noticed that there are significant differences in terms of implementation and adaptation of these guidelines in the 32 investigated countries. In fact, most countries have adopted the guidelines based on the principles of ALARA (as low as reasonably achievable), something seen also during the COVID-19 pandemic (8). For example, the United States included human contact with infected animals (or products from such animals) as a criterion in the definition of a suspect case. The WHO states that this criterion is for countries with known ongoing zoonoses. However, past experience with Mpox outbreaks in the United States might have prompted such inclusion.

Case data aggregating databases such as Our World in Data (OWID; available from https://ourworldindata.org), European Centers for Disease Control and Prevention (ECDC), John Hopkins University, WHO, and others have all highlighted the discrepancies in their datasets, most of which could be traced to incomplete data collection at source and intra- and inter-country heterogeneity in guidelines, infrastructure, and indicators (16). These discrepancies are best appreciated when one investigates time series and/or comparative series. Probable causes of such ALARA adaptations stem from differences in the testing capabilities, resource scarcity, legislative delays in updating guidelines, economic capacity, insurance coverage, privacy laws etc. (8, 9). Although data modeling could be applied to overcome the ALARA heterogeneity, the very reliability of these models on previously collected data limits their accuracy and applicability in international comparisons.

Besides the ALARA adaptations, some points within the core WHO recommendations may require further consideration. For example, requiring only RT-PCR or sequencing for a confirmed case is both very limiting and not sufficiently targeted. While versatile, PCR is highly susceptible to contamination and can have varying sensitivities depending on manufacturer and end user. (17, 18). In addition, poor assay design (including primers) and sampling may result in false negative results by lowering the limit of detection (LOD) of the Mpox PCR (19). These challenges can be overcome by comparing PCR results with a previously validated and quantitated endogenous positive control. However, even this approach has its limits. Currently, the WHO guidelines require the use of a positive control that is easily detectable at low levels. But the guidelines do not ascertain what is an "easily detectable" limit (19). Furthermore, some PCR manuals describe LOD as copies/mL or copies/PCR reaction, neither of which are standardized metrics for certain clinical samples such as crusts and dry swabs (20). Although not the main goal of primary diagnostics (20), viral load quantification is still useful for future epidemiologic and standardization studies that determine LOD for designing future assays.

On the other hand, it is also plausible that Mpox PCR may produce false-positive results. There is a potential risk of cross-contamination between samples from positive and negative patients tested simultaneously in the laboratory (19). In an ideally set up PCR reaction, one would expect Cq (cycle of quantification) values to be low, an indication of high viral load in the sample. The mean Cq values for Mpox PCR tend to vary depending on sampling site (±standard deviation): 23 ± 4 Cq for skin lesions, 27 ± 7 Cq for anorectal swab specimens, and 32 ± 6 Cq for pharyngeal specimens (21). Sequencing, on the other hand, is limited by the associated downstream processing costs, technical expertise, and transportation of bulky equipment. In countries with limited experience, sequencing is hence, not the optimal method for diagnostic purposes. This may have led countries in Latin America (Argentina, Chile, Colombia, and Peru) not to include sequencing as a diagnostic criterion for confirmed cases. However, experience from the Ebola outbreak shows that relatively portable sequencing devices could be used to support epidemiological investigations in remote locations (22). We believe that the classification of cases based on laboratory findings alone may not be reasonable because of the possibility of false positives and false negatives (albeit in a small number of cases). Hence, for targeted and accurate testing and interpretation of results, it is important that clinical findings should also be included as additional criteria in confirmed case definitions.

Interestingly, parallels can be drawn between the initial approach to HIV (human immunodeficiency virus) and Mpox. Both viruses have been thought to be more transmissible among the gay, bisexual, and MSM communities. The stigma rising from the HIV epidemic is still prevalent in society, despite the implementation of countless public education programs and equal rights legislation (23, 24). In fact, a qualitative study published recently revealed that apart from fear of rejection from partners, family, and friends, intersectional stigma from healthcare providers and concerns about privacy and safety at healthcare services were equally important concerns in the MSM community (25). Since the onus for getting tested lies with the patients (based on symptom development), such associated negative perception about the neutrality of the healthcare system risks under-testing and under-reporting of the cases. Inclusion of specific criteria concerning one's belonging to the MSM community in the probable case definition could potentially have long-term consequences. Perhaps, we think this might have led to multiple countries not adopting or dropping this criterion in their national iterations (Table 2).

In the European countries, there has been evidence of this relationship in a number of studies. The number of HIV diagnoses in the MSM community has been negatively correlated with the level of homosexual stigma (26, 27). Four of the five European countries that retained the criterion of belonging to the MSM community scored high on the Rainbow Index (RI). RI is a scoring system ranging from 0 (few rights) to 100 (well protected) that assesses legal protection, rights, access to health care, and hate speech in European countries (28). Poland was an exception, ranking in the bottom 10 of the scoring list. Contrarily, Denmark, Portugal, and Sweden were outliers, as they did not include this criterion despite their high ranking in the RI. New Zealand, on the other hand, is known worldwide for its liberal civil rights (as evidenced by its military ranking first in the LGBT Military Index). In fact, a positive correlation between the RI and the cumulative incidence of Mpox in the European countries was recently demonstrated (29).

Beyond surveillance, in clinical settings case definitions are critical for patient screening and identification that require isolation, further confirmatory testing, and contact tracing (30). For example, a turnaround time of fewer than 24 h from receipt of the specimen for PCR testing is preferred by the United Kingdom Health Security Agency (UKHSA) (31). However, experience from the US CDC shows that the median laboratory turnaround time from specimen receipt to

reporting results was 30.7 h (32). Shorter turnaround times serve two purposes—first, to ensure that the patient receives appropriate care as quickly as possible, and second, to reduce the likelihood of nosocomial infection if the patient has not been properly isolated (33). Given that the family physicians/primary care providers are the first-to-detect Mpox infection in most cases (16), it is critical that doctors in such settings be properly trained and made familiar with both national and WHO case reporting guidelines.

Presently, the WHO recommends that for case identification, primary care clinics, sexual health clinics, emergency departments, dermatology clinics and other such primary care providers should employ a "simplified questionnaire and screening protocol based on the WHO case definition adapted to local epidemiology" (30), whereby adaption to the local epidemiology refers to situations when considering the differential diagnosis of infectious causes of the rash, fever, and lymphadenopathy (for classifying suspected cases). Furthermore, WHO has explicitly recommended member states test suspected cases for Mpox (using PCR/sequencing), a condition that has been adopted only by Belgium and Brazil in the national guidelines (Table 3).

The results from our comparisons also shed light on the near future challenges ahead. Selective adaptation of the guidelines—with some countries applying more stringent criteria (over-reporting) and others using more flexible criterion (under-reporting)—could lead to creation of artificial resource bottlenecks and discrepancies in the number of cases reported, thereby disproportionately demonstrating the true disease burden in the respective countries. Poor implementation of case definitions might superficially increase the number of suspected or probable cases that are reported to the healthcare system. However, upon confirmatory testing, this could lead to lesser test positivity rates and high rates of misdiagnosis, raising safety concerns (33). At the same time, this approach not only increases the demand of the confirmatory tests, but also balloon's state expenditure for covering/subsidizing the associated costs.

According to the CDC, Mpox specimens should be handled in Biosafety Level 2 facilities. The CDC also recommends that all laboratory personnel involved in handling Mpox specimens be vaccinated against smallpox (within the past 3 years). If vaccinated personnel are not available, laboratory work may be performed in level 2 facilities, but must follow more stringent level 3 procedures (34). These requirements could also prove to tighten the testing resources available in the countries since majority of the personnel might not be vaccinated against smallpox and Level-3 procedures could take time for adoption and standardization in a Level-2 facility. This might prove to be extremely detrimental to societies applying more stringent criteria since about half of the countries have included travel to affected country as an additional epidemiological criterion in their guidelines. Though the guidelines do not mention what is meant by "affected," it is reasonable to speculate that countries with higher reported caseloads would be considered and stigmatized. Differences in the notifiable cases (Table 4) are another example demonstrating our argument.

It is clear that the WHO guidelines need further standardization and consideration so that countries can better adapt and adjust case definitions. Indeed, publication of standardized guidelines are not enough; they merely act as a broad framework. Apart from the technical and logistical factors, attention should also be paid on access to facilities and reagents. Public opinions (religious, social, political) and education are other important factors that need to be considered. The current definitions will have implications, especially if a state considers Mpox a high-consequence infectious disease and orders a home quarantine. Unsurprisingly, analysis of the performance of COVID-19 case definitions showed that complex case definitions (multiple criteria, use of OR/AND) are doubly limited clinically. On the one hand, such definitions fail to identify those at highest risk of developing severe outcomes, while on the other hand, they fail to identify patients with common infectious symptoms such as cough and fever (33).

International coordinated collaboration and efforts are needed for sharing experiences, knowledge, and technical capabilities. This would allow for consistent reporting and surveillance recommendations, thereby harmonizing global data reporting processes and promoting a better understanding of outbreak evolution. Examples of such collaborations were seen during the COVID-19 pandemic (35). The European Observatory on Health Systems and Policies created the COVID Health System Response Monitor, a specialized tool reporting on the public health policies adopted by various countries in the WHO European region during the pandemic (36, 37). The role of non-state players and funders like Bill & Melinda Gates Foundation is equally critical for upgrading existing capabilities. While the data will be made available by the countries to the WHO and other public sources, it will also be necessary to provide incentives to legislators to facilitate the implementation of infrastructural and technological measures as well as legislation. A not-for-profit approach should be a priority, as should the provision by WHO of guarantees of fair use of the data reported. The WHO should ensure that the case of the non-authorized, third-party sharing of data is not repeated (38).

It should be noted that local adaptations of the WHO case reporting definitions are not always made on a voluntary basis, but rather out of necessity in most countries. As stated previously, WHO endorses and encourages such national iterations (13). Such an approach would certainly change the dynamics of regional and international comparisons, while ensuring effective triage of patients. It remains to be seen whether adopting separate clinical and epidemiological guidelines would facilitate and standardize the process of collecting data (33). Though similar for the majority part, United States issues two separate guidelines—clinical[1] and epidemiological.[2] For example, the definition for confirmed cases is similar in both guidelines except that in clinical guidelines, isolation of Mpox virus in culture from a clinical specimen is also accepted. Other noticeable difference was the definition of discarded cases which was available only in clinical guidelines but not in the epidemiological guidelines.

A similar scenario was observed for provincial definitions and case notification guidelines in neighboring Canada. British Columbia (B.C.) follows national Canadian case definitions and require notification of only confirmed and probable cases. Ontario, on the other hand, requires notification of confirmed, probable, suspected, and person under investigation. Person under investigation was defined as an individual awaiting NAAT results or an individual who does not fulfill the criteria for other case definitions.[3]

1 https://www.cdc.gov/poxvirus/mpox/clinicians/case-definition.html

2 https://ndc.services.cdc.gov/case-definitions/monkeypox-virus-infection/

3 https://www.health.gov.on.ca/en/pro/programs/publichealth/oph_standards/docs/smallpox_chapter.pdf

Nonetheless, our findings are constrained by certain limitations. Firstly, since the virus is currently circulating and spreading to newer countries, not all countries have released guidelines that could have helped us to get a broader picture. Secondly, the guidelines and case definitions are subject to revision as our clinical knowledge about the management of the virus evolves. As an example, in the June 2022 interim guidelines, WHO considered "hospitalized due to the illness" as a criterion for probable case, which was later dropped in the August 2022 guidelines. Yet, we noticed that Italy, Portugal, and South Africa still considered hospitalization as a valid criterion (since the national guidelines in these countries have not been updated to the August guidelines).

We assume that in the later studies, such variations would be corrected for and might not be observed. Nonetheless, we fear that these efforts would become difficult as Mpox cases decline globally. For example, the ECDC has now discontinued the publication of Mpox epidemiological reports as of 28th February 2023. Finally, we could not compare the effect of changes in case definitions with the number of reported cases. Austria and Mexico, for example, removed suspected case definitions in their national guidelines. The effects of this change are not possible to visualize since the countries notified only probable and confirmed cases. Hence, the on-ground risk–benefit analyses of these changes are hard to quantify.

5. Conclusion

The WHO's guidelines for Mpox surveillance are constantly being modified and adapted to the rapidly evolving situation. In their current form, these guidelines serve more as a broad framework than a set of prescriptive rules, as evidenced by the significant variation in implementation and adaptation of these guidelines among the member states. However, these variations could be compounded when comparing provincial guidelines. Such variations arise due to the differences in testing capacity, resource constraints, legislative delays, economic resources, cultural believes, and data privacy laws. In addition, some issues within the core WHO recommendations, such as the use of RT-PCR or sequencing alone for a confirmed case, may require further consideration. False-positive and false-negative results may occur due to the limitations of PCR and sequencing. The inclusion of clinical findings as additional criteria in case definitions would allow for targeted and accurate testing and interpretation of results.

Adequate case ascertainment and reporting based on up-to-date case definitions is the cornerstone for monitoring and forecasting the global spread of the virus. The quality of data collected can be dramatically improved, fair comparisons between countries/regions can be made, and collective international public health policy can be formulated by using standardized definitions provided by the WHO. In addition, GPs should familiarize themselves with both national and WHO guidelines when reporting cases to national reporting systems.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author/s.

Ethics statement

Ethical review and approval was not required for this study in accordance with local legislation and institutional requirements as all data presented in the present study has been collected from open sources and/or government resources with appropriate citations.

Author contributions

DP and NJ conceptualized the present study and were responsible for methodology, formal analysis, and writing the original draft. DP, NJ, DK, GJ, GS, GR, MY, SV, SK, ZS, and AR were involved in data collection, validation, investigation, and revising the final draft of the paper. Visualizations were done by NJ. Project administration and supervision was done by NJ and AR. AR was responsible for resources. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1178654/full#supplementary-material

SUPPLEMENTARY FILE
National Mpox Surveillance Guidelines.

References

1. World Health Organization Regional Office for the Eastern Mediterranean. Importance of surveillance in preventing and controlling noncommunicable diseases. (2022) Available at: https://www.emro.who.int/noncommunicable-diseases/publications/questions-and-answers-on-importance-of-surveillance-in-preventing-and-controlling-noncommunicable-diseases.html (Accessed October 1, 2022).

2. LaFaro A. The importance of COVID-19 data collection and transmission. The University of North Carolina at Chapel Hill. (2020) Available at: https://research.unc.edu/2020/10/01/the-importance-of-covid-19-data-collection-and-transmission/ (Accessed October 1, 2022).

3. Youde J. "The international health regulations," in *Biopolitical Surveillance and Public Health in International Politics*. New York: Palgrave Macmillan (2010). doi: 10.1057/9780230104785

4. Division of Global Health Protection, Global Health, Centers for Disease Control and Prevention. International health regulations (IHR). Centers of Disease Control and

Prevention (CDC). (2022) Available at https://www.cdc.gov/globalhealth/healthprotection/ghs/ihr/#one (Accessed October 1, 2022).

5. Wilson K, Brownstein JS, Fidler DP. Strengthening the international health regulations: lessons from the H1N1 pandemic. *Health Policy Plan*. (2010) 25:505–9. doi: 10.1093/heapol/czq026

6. Gostin L. The international health regulations and beyond. *Lancet Infect Dis*. (2004) 4:606–7. doi: 10.1016/S1473-3099(04)01142-9

7. Suthar AB, Schubert S, Garon J, Couture A, Brown AM, Charania S. Coronavirus disease case definitions, diagnostic testing criteria, and surveillance in 25 countries with highest reported case counts. *Emerg Infect Dis*. (2022) 28:148–56. doi: 10.3201/eid2801.211082

8. Atsawarungruangkit A, Yuan J, Kodama T, Cheng MT, Mansouri M, Han B, et al. Evolving global and national criteria for identifying a suspected case of COVID-19. *J Int Med Res*. (2020) 48:300060520938943. doi: 10.1177/0300060520938943

9. Peralta-Santos A. Assessment of COVID-19 surveillance case definitions and data reporting in the European Union. Policy Department for Economic, Scientific and Quality of Life Policies, Directorate-General for Internal Policies. (2020) Available at: https://www.europarl.europa.eu/RegData/etudes/BRIE/2020/652725/IPOL_BRI(2020)652725_EN.pdf (Accessed October 1, 2022).

10. Hadjichristodoulou C, Mouchtouri VA, Guglielmetti P, Lemos CM, Nichols G, Paux T, et al. Actions for prevention and control of health threats related to maritime transport in European Union. *Travel Med Infect Dis*. (2013) 11:238–42. doi: 10.1016/j.tmaid.2013.02.001

11. Krause G, Brodhun B, Altmann D, Claus H, Benzler J. Reliability of case definitions for public health surveillance assessed by round-Robin test methodology. *BMC Public Health*. (2006) 6:129. doi: 10.1186/1471-2458-6-129

12. Jain N, Lansiaux E, Simanis R. The new face of monkeypox virus: an emerging global emergency. *New Microbes New Infect*. (2022) 47:100989. doi: 10.1016/j.nmni.2022.100989

13. World Health Organization (WHO) Surveillance, case investigation and contact tracing for mpox (monkeypox): Interim guidance, 22 December 2022. (2022) Available at: https://www.who.int/publications/i/item/WHO-MPX-Surveillance-2022.4 (Accessed January 20, 2023).

14. World Health Organization (WHO) Mpox (monkeypox) case investigation form (CIF) and minimum dataset case reporting form (CRF). (2023) Available at: https://www.who.int/publications/m/item/monkeypox-minimum-dataset-case-reporting-form-(crf) (Accessed January 30, 2023).

15. Gelderblom HR, Madeley D. Rapid viral diagnosis of Orthopoxviruses by electron microscopy: optional or a must? *Viruses*. (2018) 10:142. doi: 10.3390/v10040142

16. Stoto MA, Woolverton A, Kraemer J, Barlow P, Clarke M. COVID-19 data are messy: analytic methods for rigorous impact analyses with imperfect data. *Glob Health*. (2022) 18:2. doi: 10.1186/s12992-021-00795-0

17. Huggett JF, Benes V, Bustin SA, Garson JA, Harris K, Kammel M, et al. Cautionary note on contamination of reagents used for molecular detection of SARS-CoV-2. *Clin Chem*. (2020) 66:1369–72. doi: 10.1093/clinchem/hvaa214

18. MacKay MJ, Hooker AC, Afshinnekoo E, Salit M, Kelly J, Feldstein JV, et al. The COVID-19 XPRIZE and the need for scalable, fast, and widespread testing. *Nat Biotechnol*. (2020) 38:1021–4. doi: 10.1038/s41587-020-0655-4

19. Huggett JF, French D, O'Sullivan DM, Moran-Gilad J, Zumla A. Monkeypox: another test for PCR. *Euro Surveill*. (2022) 27:2200497. doi: 10.2807/1560-7917.ES.2022.27.32.2200497

20. Michel J, Targosz A, Rinner T, Bourquain D, Brinkmann A, Sacks JA, et al. Evaluation of 11 commercially available PCR kits for the detection of monkeypox virus DNA, Berlin, July to September 2022. *Euro Surveill*. (2022) 27:2200816. doi: 10.2807/1560-7917.ES.2022.27.45.2200816

21. Tarín-Vicente EJ, Alemany A, Agud-Dios M, Ubals M, Suñer C, Antón A, et al. Clinical presentation and virological assessment of confirmed human monkeypox virus cases in Spain: a prospective observational cohort study. *Lancet*. (2022) 400:661–9. doi: 10.1016/S0140-6736(22)01436-2

22. Quick J, Loman NJ, Duraffour S, Simpson JT, Severi E, Cowley L, et al. Real-time, portable genome sequencing for Ebola surveillance. *Nature*. (2016) 530:228–32. doi: 10.1038/nature16996

23. Grossman AH. Gay men and HIV/AIDS: understanding the double stigma. *J Assoc Nurses AIDS Care*. (1991) 2:28–32.

24. Smit PJ, Brady M, Carter M, Fernandes R, Lamore L, Meulbroek M, et al. HIV-related stigma within communities of gay men: a literature review. *AIDS Care*. (2012) 24:405–12. doi: 10.1080/09540121.2011.613910

25. Iott BE, Loveluck J, Benton A, Golson L, Kahle E, Lam J, et al. The impact of stigma on HIV testing decisions for gay, bisexual, queer and other men who have sex with men: a qualitative study. *BMC Public Health*. (2022) 22:471. doi: 10.1186/s12889-022-12761-5

26. Pachankis JE, Hatzenbuehler ML, Hickson F, Weatherburn P, Berg RC, Marcus U, et al. Hidden from health: structural stigma, sexual orientation concealment, and HIV across 38 countries in the European MSM internet survey. *AIDS*. (2015) 29:1239–46. doi: 10.1097/QAD.0000000000000724

27. Stojanovski K, King EJ, Amico KR, Eisenberg MC, Geronimus AT, Baros S, et al. Stigmatizing policies interact with mental health and sexual Behaviours to structurally induce HIV diagnoses among European men who have sex with men. *AIDS Behav*. (2022) 26:3400–10. doi: 10.1007/s10461-022-03683-9

28. International Lesbian G, Bisexual, Trans and Intersex Association. Rainbow Europe 2020. (2020) Available at: https://ilga-europe.org/report/rainbow-europe-2020/ (Accessed March 12, 2023).

29. Kenyon C. Is Monkeypox being underdiagnosed in countries with more stigmatizing attitudes towards men who have sex with men? A simple ecological analysis. *Epidemiologia*. (2022) 3:363–8. doi: 10.3390/epidemiologia3030028

30. World Health Organization (WHO) Clinical management and infection prevention and control for Monkeypox (interim rapid response guidance). (2022) Available at: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwiN49Tt-sD6AhUQXvEDHf7FDLIQFnoECDQQAQ&url=https%3A%2F%2Fapps.who.int%2Firis%2Frest%2Fbitstreams%2F1432076%2Fretrieve&usg=AOvVaw29G3KGii2FHwcocctFaKyV (Accessed October 2, 2022).

31. UK Health Security Agency (UKHSA) Mpox (monkeypox): Diagnostic testing. (2023) Available at: https://www.gov.uk/guidance/monkeypox-diagnostic-testing (Accessed March 14, 2023).

32. Aden TA, Blevins P, York SW, Rager S, Balachandran D, Hutson CL, et al. Rapid diagnostic testing for response to the Monkeypox outbreak—laboratory response network, United States, may 17-June 30, 2022. *MMWR Morb Mortal Wkly Rep*. (2022) 71:904–7. doi: 10.15585/mmwr.mm7128e1

33. Baruch J, Rojek A, Kartsonaki C, Vijayaraghavan BKT, Gonçalves BP, Pritchard MG, et al. Symptom-based case definitions for COVID-19: time and geographical variations for detection at hospital admission among 260,000 patients. *Influenza Other Respir Viruses*. (2022) 16:1040–50. doi: 10.1111/irv.13039

34. Centers for Disease Control and Prevention (CDC). Interim biosafety guidelines for laboratory personnel handling human and animal specimens for Monkeypox testing. (2003) Available at: https://www.aphl.org/programs/preparedness/Smallpox/pdf/labbiosafetyguide.pdf (Accessed March 10, 2023).

35. Fanning JP, Murthy S, Obonyo NG, Baillie JK, Webb S, Dalton HJ, et al. Global infectious disease research collaborations in crises: building capacity and inclusivity through cooperation. *Glob Health*. (2021) 17:84. doi: 10.1186/s12992-021-00731-2

36. European Observatory on Health Systems and Policies. COVID-19 health system response monitor (HSRM). (2023) Available at: https://eurohealthobservatory.who.int/monitors/hsrm/overview (Accessed March 11, 2023).

37. Jit M, Ananthakrishnan A, McKee M, Wouters OJ, Beutels P, Teerawattananon Y. Multi-country collaboration in responding to global infectious disease threats: lessons for Europe from the COVID-19 pandemic. *Lancet Reg Health Eur*. (2021) 9:100221. doi: 10.1016/j.lanepe.2021.100221

38. Elbe S, Voelkner N. Viral sovereignty: the downside risks of securitizing infectious disease." in *The Handbook of Global Health Policy*. eds. GW Brown, G Yamey and S Wamala (Wiley Publications) (2014).

frontiers | Frontiers in Public Health

TYPE Systematic Review
PUBLISHED 25 April 2023
DOI 10.3389/fpubh.2023.1149838

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Mojtaba Vaismoradi,
Nord University, Norway
Kirti Sundar Sahu,
Canadian Red Cross, Canada
Bhavna Bharati,
KIIT University, India, in collaboration with reviewer KS

*CORRESPONDENCE
Lingli Zhang
✉ zhanglingli@scu.edu.cn

†These authors have contributed equally to this work

RECEIVED 23 January 2023
ACCEPTED 06 April 2023
PUBLISHED 25 April 2023

CITATION
Zhang M, Zou K, Liu Z, Liu D, Wang X, Shi Y, Chen Z, Cheng X, Lang B, Li H, Zeng L, Tang Y, Zhao S, Jiang Y, Choonara I and Zhang L (2023) Availability of essential medicines, progress and regional distribution in China: a systematic review and meta-analysis.
Front. Public Health 11:1149838.
doi: 10.3389/fpubh.2023.1149838

Availability of essential medicines, progress and regional distribution in China: a systematic review and meta-analysis

Miao Zhang[1,2,3,4,5†], Kun Zou[1,2,3,4†], Zheng Liu[1,2,3,4,6], Dan Liu[1,2,3,4,5], Xiuli Wang[7], Yuqing Shi[1,2,3,4,5], Zhe Chen[1,2,3,4,5], Xiao Cheng[1,2,3,4], Bingchen Lang[1,2,3,4], Hailong Li[1,2,3,4], Linan Zeng[1,2,3,4], Yong Tang[8], Shaoyang Zhao[8], Yongmu Jiang[8], Imti Choonara[9] and Lingli Zhang[1,2,3,4,10*]

[1]Department of Pharmacy, West China Second University Hospital, Sichuan University, Chengdu, China, [2]Evidence-Based Pharmacy Center, West China Second University Hospital, Sichuan University, Chengdu, China, [3]National Medical Products Administration (NMPA) Key Laboratory for Technical Research on Drug Products *In Vitro* and *In Vivo* Correlation, Chengdu, China, [4]Key Laboratory of Birth Defects and Related Diseases of Women and Children, Sichuan University, Ministry of Education, Chengdu, China, [5]West China School of Pharmacy, Sichuan University, Chengdu, China, [6]West China School of Medicine, Sichuan University, Chengdu, China, [7]Healthcare Evaluation and Organizational Analysis (HEOA) Group, West China School of Public Health and West China Fourth Hospital, Sichuan University, Chengdu, China, [8]School of Economics, Sichuan University, Chengdu, China, [9]Academic Division of Child Health, University of Nottingham, Derbyshire Children's Hospital, Derby, United Kingdom, [10]Chinese Evidence-Based Medicine Center, West China Hospital, Sichuan University, Chengdu, China

Background: Essential medicines are the backbone of healthcare and meet the priority healthcare needs of the population. However, approximately one-third of the global population does not have access to essential medicines. Although China formulated essential medicine policies in 2009, the progress of availability of essential medicines and regional variations remains unknown. Therefore, this study was conducted to evaluate the availability of essential medicines, their progress, and regional distribution in China in the last decade.

Methods: We searched eight databases from their inception to February 2022, relevant websites, and reference lists of included studies. Two reviewers selected studies, extracted data, and evaluated the risk of bias independently. Meta-analyses were performed to quantify the availability of essential medicines, their progress, and regional distribution.

Results: Overall 36 cross-sectional studies conducted from 2009 to 2019 were included, with regional data for 14 provinces. The availability of essential medicines in 2015–2019 [28.1%, 95% confidence interval (CI): 26.4–29.9%] was similar to that in 2009–2014 (29.4%, 95% CI: 27.5–31.3%); lower in the Western region (19.8%, 95% CI: 18.1–21.5%) than Eastern (33.8%, 95% CI: 31.6–36.1%) and Central region (34.5%, 95% CI: 30.6–38.5%); very low for 8 Anatomical Therapeutic Chemical (ATC) categories (57.1%), and low for 5 categories (35.7%) among all ATC groups.

Conclusion: The availability of essential medicines in China is low compared with the World Health Organization goal, has not changed much in the last decade, is unequal across regions, and lacks data for half of provinces. For policy-making, the monitoring system of the availability of essential medicines is to be strengthened to enable long-term surveillance, especially in provinces where the data has been missing. Meanwhile, Joint efforts from all stakeholders are warranted to

improve the availability of essential medicines in China toward the universal health coverage target.

Systematic review registration: https://www.crd.york.ac.uk/PROSPERO/display_record.php?RecordID=315267, identifier: PROSPERO CRD42022315267.

KEYWORDS

essential medicines, availability, China, regional distribution, systematic review

1. Introduction

Access to essential medicines is a vital component of the millennium development goals (MDGs), sustainable development goals (SDGs) and universal health coverage (UHC) (1–3). The World Health Organization (WHO) defined essential medicines as those can meet basic medical and healthcare needs, have appropriate dosage forms, guaranteed supply, can be equipped at the grass-roots level, and can be equitably accessed by the people (4). Since 1977, WHO has been updating essential medicines list every 2 years, with the latest 22nd version in 2021 (5). Currently, the list forms an integral part of national essential medicines policies in 146 countries guiding the selection of drugs based on public health relevance, efficacy, safety, and cost (6). However, studies have shown that millions of people around the world face illness, disability, and death every year because of poor access to medicines (7, 8). Approximately one-third of the global population does not have access to essential medicines. In 2012, a survey performed by WHO estimated that more than 10 million deaths around the world could be avoided every year by providing essential medicines through the effective National Essential Medicines Policy (NEMP) (9). To facilitate and promote monitoring the progress of the availability of essential medicines and the national essential medicine system (NEMS), the WHO and Health Action International (HAI) jointly developed the WHO/HAI standardized method, which provided a unified method for countries and organizations to investigate the availability, price, and affordability of essential medicines (10).

In 2009, China initialized the national essential medicine system, as one of the five key components of the "new health reform" to improve the medicine supply system and ensure the safe use of medicines in the population (11). Since the new health reform in China in 2009, several studies have been conducted to examine the availability of essential medicines in China (12–19). However, several key questions have not been fully addressed. Firstly, nationwide studies of the availability of essential medicines were lacking, as most of these studies were conducted in single or several provinces only (20). Secondly, studies of the findings on its secular trend have been inconsistent (17–19, 21–23). For example, Zhu et al. (18) and Wei et al. (19) showed that the availability of essential medicines in 2016 was lower than that in 2012. In contrast, a study found that the availability of essential medicines increased from 2010 to 2014 (17). A thorough evaluation on the secular progress and geographical distribution of the availability of essential medicines in China could enable benchmarking and provide vital evidence for policy-making on the NEMS for years to come. However, to our knowledge, no such study has been conducted in China since its 2009 health reform.

Therefore, this study was conducted to systematically evaluate the availability of essential medicines, their secular progress, and regional distribution in China in the last decade, to provide evidence and support policy-making of the NEMS to improve the availability of essential medicines toward universal health coverage.

2. Methods

This systematic review and meta-analysis was reported in accordance with the preferred reporting items for systematic review and meta-analysis (PRISMA) (24), and was registered in PROSPERO (CRD42022315267).

2.1. Search strategy

We searched literature databases of PubMed, Embase (Ovid), the Cochrane Library, Web of Science, China National Knowledge Infrastructure (CNKI), WanFang database, VIP database, and Chinese Biomedical Literature database (CBM) from their inceptions to February 2022. We also searched the websites the of WHO and International Pharmaceutical Federation (FIP) and manually checked reference lists of included studies and relevant published reviews. The search terms included: essential drug, essential medicine, China, Chinese, etc. The search strategy in PubMed is presented in Supplementary Table S1.

2.2. Eligibility criteria

Primary studies were included if they had participants of medical institutions or pharmacies, public or private, that may provide essential medicines in mainland China; outcome of availability of essential medicines (frequency and percentage); study design of the cross-sectional study, interrupted times series study, uncontrolled before-after study, and controlled before-after study. Publications in English or Chinese were included. Studies were excluded if they were duplicate publications or their full texts were not available.

2.3. Study selection and data extraction

Two reviewers (MZ and ZL) selected studies and extracted data independently. The following data were extracted: (1) general information of the study: title, first author, year of publication, and study design; (2) characteristic of studies: study area, survey

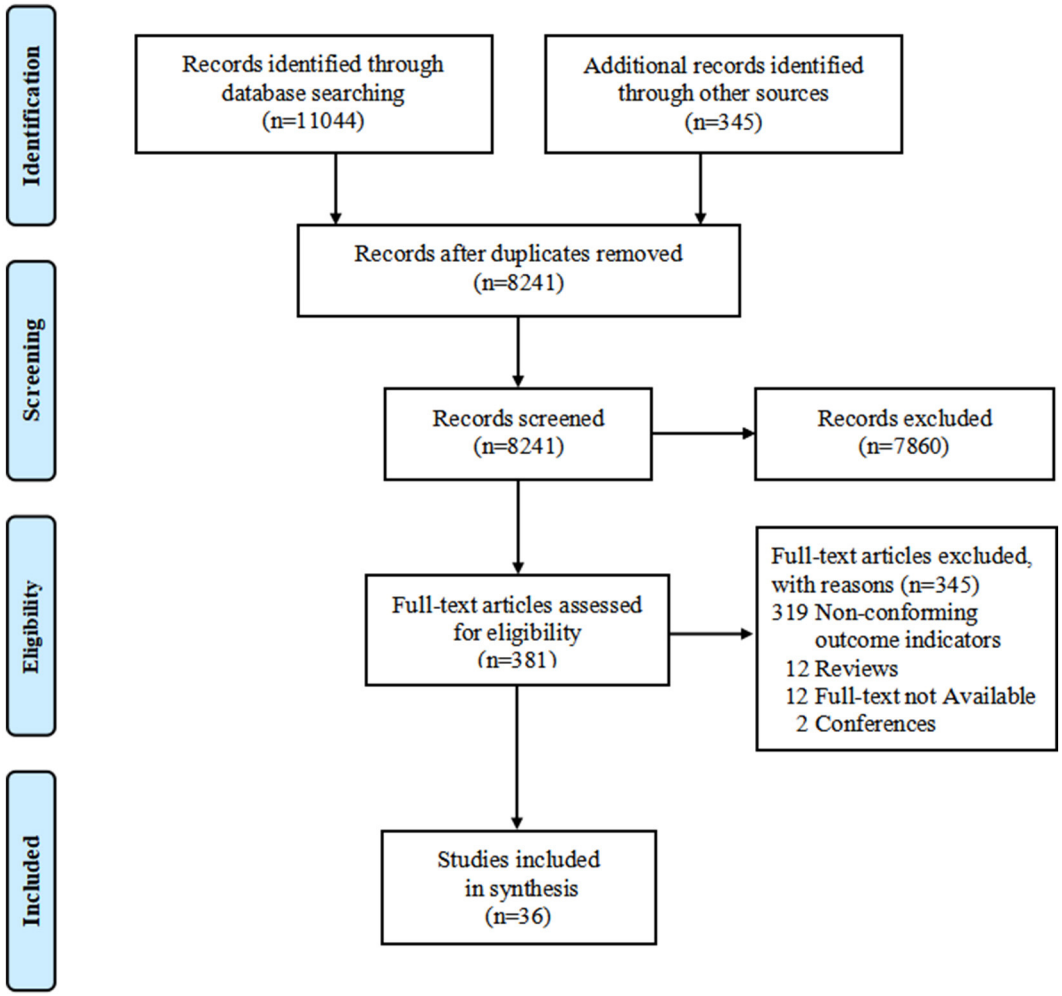


FIGURE 1
PRISMA flow chart of study selection.

time, survey method, number of essential medicines investigated, number of medical organizations, and names of investigated medicines; (3) outcome: availability rate of essential medicines. Reviewers resolved disagreements by discussion to consensus, and if necessary, by consulting a third reviewer (KZ).

2.4. Risk of bias assessment

Two reviewers (MZ and ZL) evaluated the risk of bias of cross-sectional studies independently using the Joanna Briggs Institute (JBI) Critical Appraisal Tools (25). The tool consists of nine items in terms of sampling methods, research objects, data collection, and analysis methods. Each item was determined by yes, no, unclear, and not applicable. For the overall quality rating of a study, more than 6 scores were considered as high, 4–6 scores as moderate, and <4 scores as low quality (25). The risk of bias of interrupted times series study, uncontrolled before-after study, and controlled before-after study was assessed using the Cochrane Effective Practice and Organization of Care (EPOC) criteria (26). Disagreements were resolved by discussion to consensus, and if necessary, by consulting a third reviewer (KZ).

2.5. Outcome measurement

The availability of essential medicines was calculated as the percentage (%) of the number of institutions equipped with essential medicines to the number of institutions surveyed. The availability of essential medicines was classified as very low if the percentage was <30%, low if it was 30–49%, fairly high if it was 50–80%, and high if it was more than 80% (27).

2.6. Statistical analysis

The pooled availability of essential medicines was estimated using percentage and its 95% CI. Heterogeneity was evaluated using I^2 and Chi-square (χ^2) test. If heterogeneity was significant ($I^2 > 50\%$), the random effect model was used, otherwise, the fixed effect model was used. The overall availability rates of essential medicines in China, and that from 2009 to 2014 and from 2015 to 2019 were estimated. Subgroup analyses were conducted by regions in mainland China (Eastern region including 11 provinces or municipalities, Central region including 8 provinces or autonomous regions, and Western region including

12 provinces, municipality or autonomous regions) (28), and provinces to examine its geographic distribution across China, and by Anatomical Therapeutic Chemical (ATC) Classification of medicines.

3. Results

3.1. Literature search and study selection

A total of 11,389 records were identified by the initial search. After removing duplicates and irrelevant records by screening for titles and abstracts, 381 studies were assessed for eligibility at full-text screening. Eventually, 36 studies were included in this systematic review (13, 16–23, 29–55). The study selection process is shown in Figure 1.

3.2. Characteristics of included studies

The characteristics of the included studies are presented in Table 1. The included were all cross-sectional studies, which were conducted from 2009 to 2019. Among them, 15 studies (41.7%) were conducted in the Eastern region, 8 studies (22%) in the Western region, 4 studies (11%) in the Central region, and the remaining 9 studies (25%) were conducted across several provinces or nationwide. Among them, 33 studies (92%) adopted the WHO/HAI standardized methodology, while the investigation method was unclear in 3 studies. However, they all adopted the definition of availability of essential medicines according to the WHO/HAI methods, and therefore, were also included in the analyses. All studies selected investigated medicines based on the WHO Model List of Essential Medicines (22nd List) and China National Essential Medicines List (2018) (56, 57). The median number of investigated essential medicines was 28 (ranging from 3 to 121). The list of essential medicines investigated in included studies is presented in Supplementary Table S2.

3.3. Risk of bias assessment

Among the 36 studies, 26 studies were assessed as high quality, and the remaining 10 studies were of moderate quality (Supplementary Table S3).

3.4. Availability of essential medicines in China from 2009 to 2019

A total of 36 studies reported the availability of essential medicines in China. Overall, the availability of essential medicines was 28.8% (95% CI: 27.5–30.1%) from 2009 to 2019. Detailed availability of the essential medicines by ATC is presented in Supplementary Table S4.

3.4.1. Secular trend of availability of essential medicines in China between 2009–2014 and 2015–2019

The changes of the availability of essential medicines in China during the two periods are shown in Figure 2. A total of 17 studies reported the availability from 2009 to 2014, and 23 studies from 2015 to 2019. The overall availability of essential medicines in China during the two periods was similar, which was 29.4% (95% CI: 27.5–31.3%) from 2009 to 2014 and 28.1% (95% CI: 26.4–29.9%) from 2015 to 2019. Detailed availability of the essential medicines by ATC between the two periods is presented in Supplementary Tables S5, S6.

3.4.2. Availability of essential medicines by regions

The number of studies reported the availability of essential medicines for the Eastern, Central and Western regions was 20, 9, and 13, respectively. From 2009 to 2019, the overall availability of essential medicines in the Western regions (19.8%, 95% CI: 18.1–21.5%) was lower than that in the Eastern (33.8%, 95% CI: 31.6–36.1%) and Central regions (34.5%, 95% CI: 30.6–38.5%) (Supplementary Table S3). As regards to secular trend, the availability of essential medicines in the Eastern region and the Central region reduced notably from 2015 to 2019 to that from 2009 to 2014, while increasing substantially in the Western region from 17% during 2009–2014 to 38% from 2015 to 2020 (Figure 2; Supplementary Tables S5, S6).

3.4.3. Availability of essential medicines by provinces

The variations of availability of essential medicines across provinces during the two time periods are shown in Figures 3A, B. Provincial data of the availability of essential medicines were only reported for 14 provinces, while the other 17 provinces neither conducted a survey nor reported the provincial data. Among them, 5 provinces (16.1%) had provincial data of availability of essential medicines from 2009 to 2014, and 12 provinces (38.7%) had provincial data from 2015 to 2019.

From 2009 to 2019, the three provinces with the lowest overall availability of essential medicines were Yunnan (19.4%, 95% CI: 6.3–3.2%), Shaanxi (19.8%, 95% CI: 18.0–21.6%), and Jiangsu (22.3%, 95% CI: 19.4–25.1%). More detailed availability of essential medicines in different provinces from 2009 to 2014 and from 2015 to 2019 were presented in Supplementary Tables S5, S6.

3.4.4. Availability of essential medicines by ATC categories

Thirteen categories of essential medicines were investigated from 2009 to 2014, and 14 categories were investigated from 2015 to 2019. Changes in the availability of essential medicines by ATC categories in the two periods are presented in Figure 4.

From 2009 to 2014, the number of ATC categories of essential medicines with fairly high, low, and very low availability were 1, 4, and 8, respectively, while no data was available for the genito urinary system and sex hormones. From 2015 to 2019, the number of ATC categories of essential medicines with fairly high, low,

10.3389/fpubh.2023.1149838

TABLE 1 Characteristics of included studies.

Study ID.	Study time	Study area	Region	Methods	Number of medical organizations	Number of essential medicines
Zhu et al. (29)	2013–2019	Jiangsu	Eastern region	WHO/HAI	41	12
Wang et al. (23)	2016, 2018	Jiangsu	Eastern region	WHO/HAI	56	3
Zhang et al. (20)	2019	Jiangsu	Eastern region	WHO/HAI	13	35
Wang et al. (31)	2019	Shandong	Eastern region	WHO/HAI	150	30
Dai et al. (32)	2017	China (Zhejiang, Fujian, Jiangxi, Jiangsu, Anhui, Guangdong, Henan, Yunnan, Guizhou, Sichuan, Shaanxi, Hebei, Shandong, Liaoning, Guangxi, Xinjiang, Shanghai)	Nationwide	WHO/HAI	55	42
Zhang et al. (30)	2018	China (The province was not specified)	Nationwide	Unclear	2,243	28
Dong et al. (35)	2018	Zhejiang	Eastern region	WHO/HAI	60	12
Yang et al. (33)	2018	China (Shandong, Hubei, Henan, Shaanxi, Yunnan)	Nationwide	WHO/HAI	519	12
Xu et al. (34)	2015	Anhui	Central region	WHO/HAI	143	13
Jiang et al. (36)	2017	Liaoning	Eastern region	WHO/HAI	76	25
Li et al. (16)	2016	Shaanxi	Western region	WHO/HAI	21	8
Wei et al. (19)	2012, 2016	NR (The province was not specified)	Eastern region	WHO/HAI	1725	49
Zhu et al. (18)	2012, 2016	Jiangsu	Eastern region	WHO/HAI	70	40
Yang et al. (37)	2015	Shaanxi	Western region	WHO/HAI	144	8
Sun et al. (41)	2017	Jiangsu	Eastern region	WHO/HAI	60	40
Xi et al. (39)	2017	China (Shanghai, Jiangsu, Shandong, Ningxia, Jiangxi, Henan)	Nationwide	WHO/HAI	24	50
Li et al. (38)	2016	China (Henan, Fujian, Xinjiang, Gansu, Nei Monggol, Hunan, Shaanxi, Shandong, Anhui, Zhejiang, Shanxi, Jilin, Liaoning, Guangdong, Ningxia, Jiangsu, Chongqing, Yunnan, Beijing)	Nationwide	WHO/HAI	55	121
Gong et al. (42)	2016	Hubei	Central region	WHO/HAI	34	20
Wu et al. (40)	2016	Hubei	Central region	WHO/HAI	33	16
Guan et al. (21)	2011–2016	China (28 provinces, municipalities and autonomous regions except Qinghai, Xizang, Hainan)	Nationwide	WHO/HAI	1,159	13
Song et al. (22)	2009–2011	China (Shandong, Zhejiang, Anhui, Ningxia)	Nationwide	WHO/HAI	146	NR
Su et al. (43)	2016–2017	China (31 mainland provinces, municipalities and autonomous regions)	Nationwide	Unclear	3,362	62
Liu et al. (13)	2016	Hubei	Central region	WHO/HAI	60	5
Xie et al. (44)	2015	Shanghai	Eastern region	WHO/HAI	13	30
Shang et al. (45)	2013	Beijing	Eastern region	Unclear	1,585	9
Wu et al. (17)	2010, 2012, 2014	Shaanxi	Western region	WHO/HAI	374	44
Zhang and Li (46)	2013	Jiangsu	Eastern region	WHO/HAI	60	24
Xi et al. (47)	2013	Jiangsu	Eastern region	WHO/HAI	63	30

(Continued)

TABLE 1 (Continued)

Study ID.	Study time	Study area	Region	Methods	Number of medical organizations	Number of essential medicines
Jiang et al. (48)	2012	Shaanxi	Western region	WHO/HAI	240	35
Wang et al. (49)	2012	Shaanxi	Western region	WHO/HAI	120	21
Wang et al. (50)	2011	Shaanxi	Western region	WHO/HAI	30	21
Jiang et al. (52)	2012	Shaanxi	Western region	WHO/HAI	240	38
Guan et al. (53)	2010	China (The province was not specified)	Nationwide	WHO/HAI	334	30
Yan et al. (51)	2010	Shaanxi	Western region	WHO/HAI	86	33
Li et al. (54)	2010	Zhejiang	Eastern region	WHO/HAI	17	14
Li (55)	2010	Guangdong	Eastern region	WHO/HAI	28	40

WHO/HAI, The World Health Organization/Health Action International; NR, Not reported.

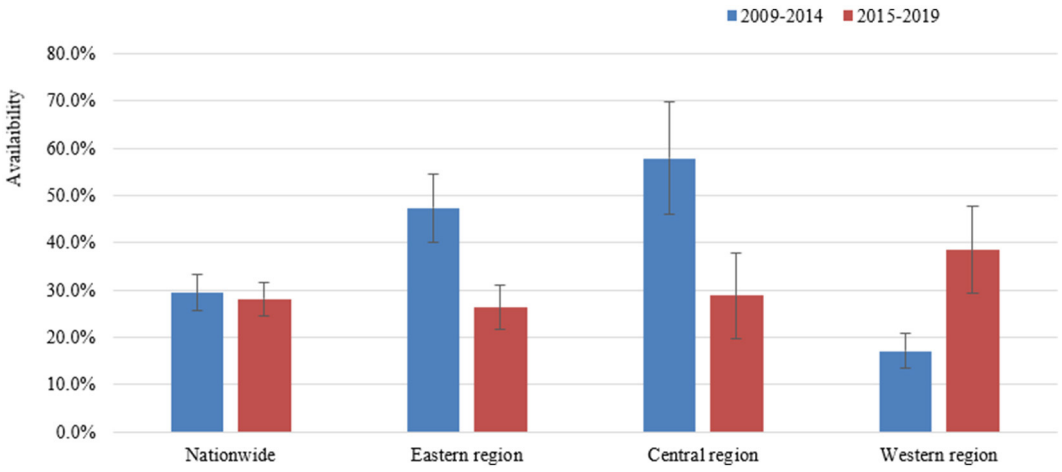


FIGURE 2
The availability of essential medicines in China.

and very low availability were 1, 4, and 9, respectively. From 2009 to 2014, the three ATC categories of essential medicines with the lowest availability were nervous system (10.6%, 95% CI: 8.1–13.4%), systemic hormonal preparations excluding sex hormones and insulins (15.9%, 95% CI: 2.8–34.6%), and sensory organs (17.2%, 95% CI: 7.0–30.5%). From 2015 to 2019, the three ATC categories of essential medicines with the lowest availability were nervous system (12.6%, 95% CI: 8.4–17.5%), antiparasitic products, insecticides and repellents (16.3%, 95% CI: 6.7–28.2%), and systemic hormonal preparations excluding sex hormones and insulins (18.3%, 95% CI: 6.6–33.5%). The three medicines with the lowest availability were similar to the national level, especially nervous system, which was very low (<30%) in all regions (Supplementary Tables S3–S5).

4. Discussion

To our knowledge, this is the first systematic review and meta-analysis that has comprehensively evaluated the secular trend, regional and provincial distribution of the availability of essential medicines in China in the last decade. There are four important findings in this study. First, the availability of essential medicines was low in China from 2009 to 2019 with little overall change between 2009–2014 and 2015–2019, and much is to be done to achieve the goal of 80% availability suggested by the WHO. Second, the availability of essential medicines in the Western region was lower than that in the Eastern and Central regions. As regards to secular trend, the availability of essential medicines in the Eastern region and the Central region reduced slightly from 2015 to 2019 compared with that from 2009 to 2014, while increasing moderately in the Western region. Third, among 14 ATC categories of essential medicines, the availability was very low for 8 categories (57.1%), and low for 5 categories (35.7%) in most recent studies. Finally, the provincial data are only available for less than half provinces (14 provinces) while lacking for the others, as they were not surveyed at all or not reported, indicating substantial research gaps and needs.

Overall, our results revealed that the availability of essential medicines was still low in China according to the WHO availability goal, which was consistent with the findings of published studies. A national study found that the mean availability of essential

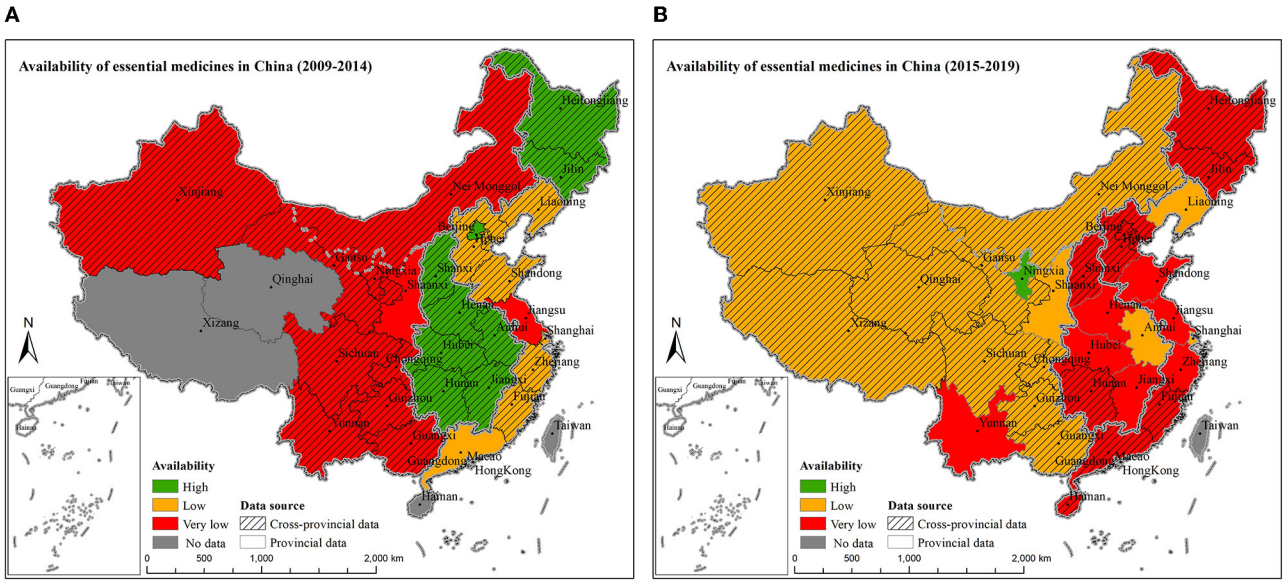


FIGURE 3
The availability of essential medicines by provinces from 2009 to 2014 **(A)** and from 2015 to 2019 **(B)**. Availability of essential medicine considered as: high > 80%, fairly high 50–80%, low 30–49%, very low < 30%. Methods for data manipulation for provinces with missing data in the map: if the province has been surveyed but the provincial data were not available, regional data (pooled estimate using meta-analysis) were used to fill in the data; if no survey has been conducted in the province at all, then it was labeled as no data. (From 2009 to 2014, provincial data were available for Beijing, Jiangsu, Guangdong, and Shaanxi; whereas, from 2015 to 2019, provincial data were available for Jiangsu, Liaoning, Shanghai, Zhejiang, Shandong, Anhui, Jiangxi, Henan, Hubei, Shaanxi, Yunnan, and Ningxia).

medicines in China was low (4.29–43.75%) (33). Another national survey found that the overall availability of essential medicines for children in China was low (<35%) (38). Internationally, Mahmić-Kaknjo et al. found that the availability of essential medicines is still suboptimal from 2003 to 2011 in low- and middle-income countries (58). It suggested that the availability of essential medicines in China is at the middle level among all low- and middle-income countries. There may be several reasons for the low availability of essential medicines in China. First, on the supply side, the low price and meager profit of essential medicines may lower the motivation of the production and distribution enterprises to produce and supply essential medicines (12, 59). Second, on the demand side, patients may be influenced by misunderstood beliefs that cheap medicines may not be as effective as those with high prices (60), which may also lead to a decrease in demand, production and supply of these cheap price essential medicines. Last, the WHO/HAI method has strict restrictions on dosage forms and specifications which may be different from that in the China market, and therefore, may underestimate the actual availability of those medicines (17).

We found the availability of essential medicine in China has changed little in the last decade. This finding was supported by several other studies. Guan et al. found that the nationwide availability was steady from 2011 to 2016 (21), and Song et al. showed that the availability of essential medicines did not change radically (22). The possible reason may be that the availability of essential medicines decreased in the Central and Eastern regions, while increasing in the Western region from 2009–2014 to 2015–2019. In addition, in this study, based on ATC categories, we found that the availability of some essential medicines has increased and that of others has decreased during the two periods. Since our study included all available studies of essential medicines across China from 2009 to 2019, it is more likely to reflect the overall trend of China. However, research on causes of the changes is lacking, as most studies on the availability of essential medicines only reflected its status quo but not examined its trend and reasons. Therefore, more studies are needed to understand why there has been little change in essential medicines over the past decade.

In our study, it is shown that the availability of essential medicines in the Western region was lower than in the Eastern region, which was consistent with findings from previous studies. Guan et al. and Su et al. both found that compared with the Eastern region, the Western region had lower availability of essential medicines (21, 43, 55). This may be related to the different economic levels of the Eastern, Central, and Western regions. Existing literature showed that, compared with the developed Eastern region, the Western region has insufficient health resources and a lack of high-quality essential medicines (61), which indicated the inequality in the allocation of health resources and the utilization of health services in China (62). Notably, we found that the availability of essential medicines increased moderately in the Western region, but reduced slightly in the Eastern region and the Central region from 2015 to 2019 compared with that from 2009 to 2014. The investigation is needed to shed light on the reasons for the unwanted changes, and tailored measures are warranted to reverse the downward trend of the availability of essential medicines in more developed regions.

Finally, none ATC categories except one reached the fairly high (>50%) availability rate in most recent years, indicating systematic challenges for the NEMS. And the three categories of

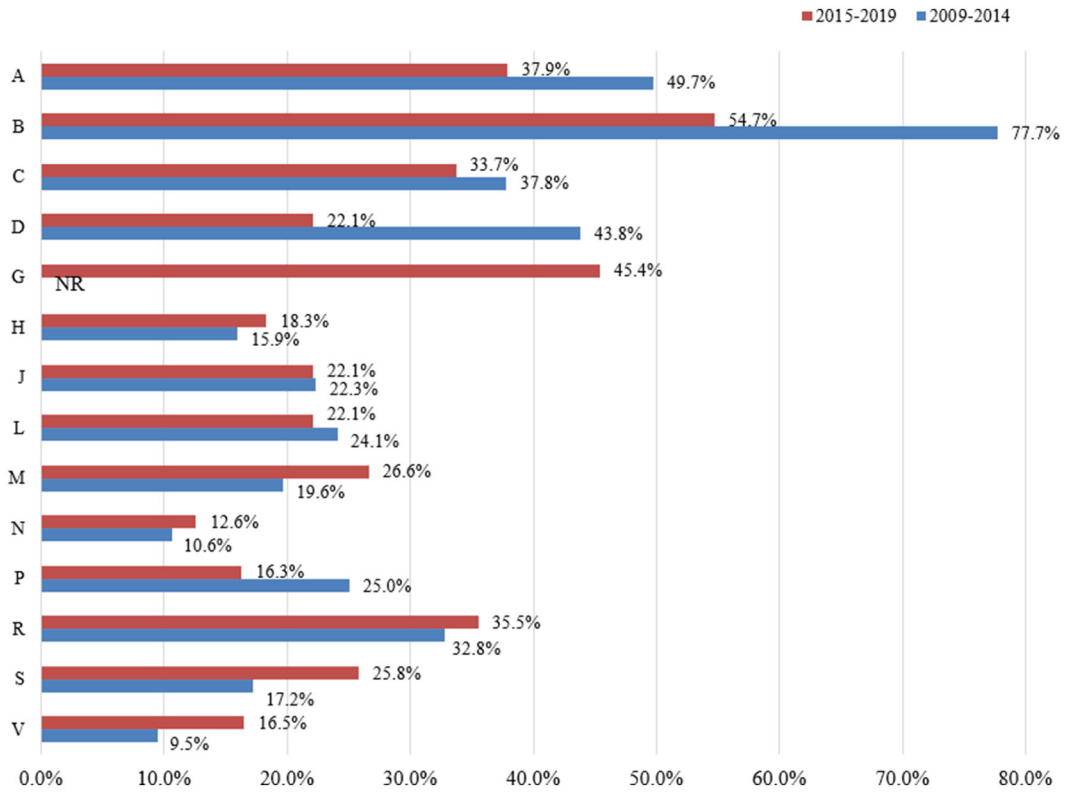


FIGURE 4
Changes in the availability of essential medicines between different categories based on ATC (2009–2014 vs. 2015–2019). G: Not reported the availability of Genito urinary system and sex hormones from 2009 to 2014. A: Alimentary tract and metabolism; B: Blood and blood forming organs; C: Cardiovascular system; D: Dermatologicals; G: Genito urinary system and sex hormones; H: Systemic hormonal preparations, excl. sex hormones and insulins; J: Antiinfectives for systemic use; L: Antineoplastic and immunomodulating agents; M: Musculo-skeletal system; N: Nervous system; P: Antiparasitic products, insecticides and repellents; R: Respiratory system; S: Sensory organs: V: Various.

essential medicines with the lowest availability were similar during two periods, which were nervous system, systemic hormonal preparations, excl. sex hormones and insulins, and antiparasitic products, insecticides and repellents. There may be several reasons for this. First, it may be related to the imperfect pricing mechanism and procurement and distribution system of these medicines (51, 52). Second, pharmacies may unable to sell some medicines due to their small sale volumes, such as antiparasitic products, insecticides and repellents, which may be related to the reduced prevalence of such diseases in the Chinese population (53). Third, some medicines for the nervous system, such as diazepam, are not available in private pharmacies, because it is under special management and patients must purchase them with psychiatrist specialists' prescriptions (17).

Our study has some strengths. First, this is the first systematic review and meta-analysis to comprehensively evaluate the availability of essential medicines in China, which is one of the critical pillars of the healthcare system. Second, methodologically, this systematic review was conducted following consolidated standards including the extensiveness of search strategies, rigor in study selection criteria, extraction of relevant information, and data analysis, which ensured the comprehensiveness and robustness of research findings. Third, the research findings shed lights on the availability of essential medicines in China in aspects of its secular trend, regional distribution, and that by ATC categories in the last decade, which may have important implications for future research and pharmaceutical policy-making toward the goal of universal access to medicines.

Our study has several limitations. Firstly, due to the limited number of included studies, we were unable to perform more detailed analysis to estimate the annual availability of essential medicines. Secondly, the accuracy of pooled estimates of availability of essential medicines may be influenced by varied types of investigated essential medicines involved in primary studies, though we have used pooled estimates based on ATC categories. Thirdly, the WHO/HAI survey methodology required medicines with a specific dosage and form, which may result in underestimates of the availability of some medicines, for other forms and dosages might be available in the pharmaceutical market in China. Finally, though we have systematically searched important databases, websites, and published reviews, there may still be gray literature that has not been included.

5. Conclusion

The availability of essential medicines in China is still low compared with the WHO's availability goal, has not changed much in the last decade, is unequal across regions, and lacks data for half of provinces. For research, more studies are

warranted, to reveal the reasons and mechanisms of the low availability of essential medicines and facilitate targeted policy-making. A unified investigation method and a standardized list of investigated essential medicines should be formulated according to the healthcare need of Chinese population to promote comparison between studies. For policy-making, the monitoring system of the availability of essential medicines is to be strengthened to enable long-term surveillance, especially in provinces where the data has been missing, as a research and policy priority to enable benchmarking and dedicated efforts for improvement. Meanwhile, joint efforts from all stakeholders including health commission, regulators on drugs, health insurance, pharmaceutical industry, and hospitals are warranted to improve the availability of essential medicines in China toward the universal health coverage target.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

LZh, KZ, IC, and DL contributed to the conception and designate the study. MZ and KZ participated in drafting and writing the review. MZ, ZL, KZ, DL, YS, ZC, XC, and BL participated in the formulation of retrieval strategies. MZ, ZL, and KZ participated in study selection, data acquisition, and quality assessment. MZ, XW, HL, YJ, YT, SZ, and LZe participated in the data analysis and drawing of tables and figures. All authors contributed to the critical revision of the manuscript and approved the final manuscript.

Funding

This work was supported by the Fundamental Research Funds for the Central University (SCU2022D006).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1149838/full#supplementary-material

References

1. World Health Organization. *Equitable Access to Essential Medicines: A Framework for Collective Action*. (2004). Available online at: https://apps.who.int/iris/handle/10665/68571 (accessed October 5, 2022).

2. Mendis S, Fukino K, Cameron A, Laing R, Filipe A, Jr., Khatib O, et al. The availability and affordability of selected essential medicines for chronic diseases in six low- and middle-income countries. *Bull World Health Organ.* (2007) 85:279–88. doi: 10.2471/blt.06.033647

3. Leisinger KM, Garabedian LF, Wagner AK. Improving access to medicines in low and middle income countries: corporate responsibilities in context. *South Med Rev.* (2012) 5:3–8. Available online at: https://dash.harvard.edu/bitstream/handle/1/10623010/3606933.pdf;sequence=1

4. World Health Organization. *Global Health Risks: Mortality and Burden of Disease Attributable to Selected Major Risks*. (2009). Available online at: https://apps.who.int/iris/handle/10665/68571 (accessed October 5, 2022).

5. World Health Organization. *WHO Model Lists of Essential Medicines*. (2021). Available online at: https://www.who.int/groups/expert-committee-on-selection-and-use-of-essential-medicines/essential-medicines-lists (accessed May 28, 2022).

6. Smith MK, Tickell S. The essential drugs concept is needed now more than ever. *Trans R Soc Trop Med Hyg.* (2003) 97:2–5. doi: 10.1016/S0035-9203(03)90001-0

7. Lozano R, Naghavi M, Foreman K, Lim S, Shibuya K, Aboyans V, et al. Global and regional mortality from 235 causes of death for 20 age groups in 1990 and 2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.* (2012) 380:2095–128. doi: 10.1016/S0140-6736(12)61728-0

8. Murray CJ, Vos T, Lozano R, Naghavi M, Flaxman AD, Michaud C, et al. Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990-2010: a systematic analysis for the Global Burden of Disease Study 2010. *Lancet.* (2012) 380:2197–223. doi: 10.1016/S0140-6736(12)61689-4

9. World Health Organization. *Regional Office for the Eastern M. Price, Availability and Affordability: An International Comparison of Chronic Disease Medicines*. (2006). Available online at: https://apps.who.int/iris/handle/10665/116493?show=full (accessed March 20, 2023).

10. World Health Organization, Health Action International. *Measuring Medicine Prices, Availability, Affordability and Price Components*. 2nd ed. (2008). Available online at: https://apps.who.int/iris/handle/10665/70013 (accessed November 11, 2022).

11. The Central People's Government of the People's Republic of China. *Opinions of the CPC Central Committee and The State Council on Deepening the Reform of the Medical and Health Care System*. (2009). Available online at: http://zqb.cyol.com/content/2009-04/07/content_2611061.htm (accessed August 7, 2022).

12. Li Y, Ying C, Sufang G, Brant P, Bin L, Hipgrave D. Evaluation in three provinces of the introduction and impact of China's National Essential Medicines Scheme. *Bull World Health Organ.* (2013) 91:184–94. doi: 10.2471/BLT.11.097998

13. Liu C, Zhang X, Liu C, Ewen M, Zhang Z, Liu G. Insulin prices, availability and affordability: a cross-sectional survey of pharmacies in Hubei Province, China. *BMC Health Serv Res.* (2017) 17:597. doi: 10.1186/s12913-017-2553-0

14. Washington, DC: World Bank. *Financing, Pricing, and Utilization of Pharmaceuticals in China: The Road to Reform Policy*. (2018). Available online at: https://openknowledge.worldbank.org/handle/10986/27598 (accessed October 13, 2022).

15. Fang Y, Wagner AK, Yang S, Jiang M, Zhang F, Ross-Degnan D. Access to affordable medicines after health reform: evidence from two cross-sectional surveys in Shaanxi Province, western China. *Lancet Glob Health.* (2013) 1:e227–37. doi: 10.1016/S2214-109X(13)70072-X

16. Li Z, Feng Q, Kabba JA, Yang C, Chang J, Jiang M, et al. Prices, availability and affordability of insulin products: a cross-sectional survey in Shaanxi Province, western China. *Trop Med Int Health.* (2019) 24:43–52. doi: 10.1111/tmi.13167

17. Wu LN, Yang CJ, Shen Q, Chang J, Zhu WW, Ye D, et al. Comparative study on the availability of drugs in public hospitals and retail pharmacies in Shaanxi Province. *Chin Pharm Aff.* (2016) 30:8–16. doi: 10.16153/j.1002-7777

18. Zhu Y, Wang Y, Sun X, Li X. Availability, price and affordability of anticancer medicines: evidence from two cross-sectional surveys in the Jiangsu Province, China. *Int J Environ Res Public Health.* (2019) 16:3728. doi: 10.3390/ijerph16193728

19. Wei GX, Wang XL, Li X, Li LY, Chen J, Shi LW. A survey on the availability, price and affordability of essential medicine for children in Eastern China. *Chin J Health Policy.* (2019) 12:72–8. doi: 10.3969/j.issn.1674-2982.2019.10.011

20. Zhang L, Zhou QY, Zhang XM, Yu Y, Wang SS, Shao R. Investigation and study on the accessibility of antibiotics in essential medicine list in medical institutions of Nanjing area. *Chin Pharm.* (2020) 31:1281–7. doi: 10.6039/j.issn.1001-0408.2020.11.01

21. Guan X, Hu H, Man C, Shi L. A survey of availability, price and affordability of essential medicines from 2011 to 2016 in Chinese secondary and tertiary hospitals. *Int J Equity Health.* (2018) 17:158. doi: 10.1186/s12939-018-0870-5

22. Song Y, Bian Y, Zhen T. Making medicines more accessible in China: an empirical study investigating the early progress of essential medicine system. *PLoS ONE.* (2018) 13:e0201582. doi: 10.1371/journal.pone.0201582

23. Wang L, Dai L, Liu H, Dai H, Li X, Ge W. Availability, affordability and price components of insulin products in different-level hospital pharmacies: evidence from two cross-sectional surveys in Nanjing, China. *PLoS ONE.* (2021) 16:e0255742. doi: 10.1371/journal.pone.0255742

24. Moher D, Liberati A, Tetzlaff J, Altman DG. Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ.* (2009) 339:b2535. doi: 10.1136/bmj.b2535

25. Moola S, Munn Z, Tufanaru C, Aromataris E, Sears K, Sfetc R, et al. Chapter 7: systematic reviews of etiology and risk. *JBI Manual Evid Synth.* (2020). doi: 10.46658/JBIRM-17-06

26. Cochrane Effective Practice and Organisation of Care (EPOC). *Suggested Risk of Bias Criteria for EPOC Reviews*. (2017). Available online at: epoc.cochrane.org/resources/epoc-resources-review-authors (accessed December 12, 2022).

27. Gelders S, Ewen M, Noguchi N, Laing R. *Price, Availability and Affordability: An International Comparison of Chronic Disease Medicines*. (2006). Available online at: http://apps.who.int/iris/bitstream/10665/116493/1/dsa560.pdf

28. National Bureau of Statistics. *Li Yin, the Chief statistician of the Social Science and Culture Department of the National Bureau of Statistics, Interpreted the 2021 Statistical Bulletin on Investment in Science and Technology Funds*. (2022). Available online at: http://www.stats.gov.cn/tjsj/sjjd/202208/t20220831_1887755.html (accessed July 20, 2022).

29. Zhu Y, Xu X, Fang W, Wang Y, Dai H, Li X. Availability, cost and affordability of selected antibiotics and antiviral medicines against infectious diseases from 2013 to 2019 in Nanjing, China. *Trop Med Int Health.* (2021) 26:518–29. doi: 10.1111/tmi.13559

30. Zhang XJ, Jiang XT, Zheng JL, Peng B, Li YZ. Analysis on the availability and allocation of essential drugs for hypertension and diabetes in primary health institutions. *Chin J Health Policy.* (2020) 13:58–65. doi: 10.3969/j.issn.1674-2982.2020.07.010

31. Wang X, Zhang AC, Wang H, Xv DL. Evaluation study on the availability and prices of paediatric essential drugs in Weifang. *Chin Pharm Aff.* (2020) 34:1085–92. doi: 10.16153/j.1002-7777.2020.09.013

32. Dai Y, Li ZP, Xv H, Zhu L, Zhu YQ, Chen H, et al. A multicenter survey of the accessibility of essential medicines for children in China. *Chin J Pediatrics.* (2020) 58:301–7. doi: 10.3760/cma.j.cn112140-20190820-00527

33. Yang C, Hu S, Ye D, Jiang M, Babar ZU, Fang Y. Evaluating price and availability of essential medicines in china: a mixed cross-sectional and longitudinal study. *Front Pharmacol.* (2020) 11:602421. doi: 10.3389/fphar.2020.602421

34. Xu R, Li S, Lv X, Xie X. Prices, availability, and affordability of national essential medicines in public primary hospitals: a cross-sectional survey in poverty-stricken rural areas in China. *Int J Health Plann Manage.* (2020) 35:545–57. doi: 10.1002/hpm.2963

35. Dong Z, Tao Q, Yan B, Sun G. Availability, prices and affordability of essential medicines in Zhejiang Province, China. *PLoS ONE.* (2020) 15:e0241761. doi: 10.1371/journal.pone.0241761

36. Jiang XT, Wang YQ, Jia SH, Gao YB, Sun LH. Evaluation of essential medicines accessibility in Liaoning Province. *Chin Pharmacol J.* (2019) 54:501–5. doi: 10.11669/cpj.2019.06.013

37. Yang C, Hu S, Zhu Y, Zhu W, Li Z, Fang Y. Evaluating access to oral anti-diabetic medicines: a cross-sectional survey of prices, availability and affordability in Shaanxi Province, Western China. *PLoS ONE.* (2019) 14:e0223769. doi: 10.1371/journal.pone.0223769

38. Li SS, Xv W, Du WW, Fu YB. Study on the availability of pediatric essential medicines in China: based on the surveys in 19 provinces. *Chin J Health Policy.* (2018) 11:12–8. doi: 10.3969/j.issn.1674-2982.2018.12.003

39. Xi X, Chen P, Yang F, Yang Y, Chen L, Mao N. Evaluating the accessibility of essential medicines in China. *J Med Econ.* (2018) 21:784–92. doi: 10.1080/13696998.2018.1474744

40. Wu G, Gong S, Cai H, Ding Y. The availability, price and affordability of essential antibacterials in Hubei province, China. *BMC Health Serv Res.* (2018) 18:1013. doi: 10.1186/s12913-018-3835-x

41. Sun X, Wei J, Yao Y, Chen Q, You D, Xu X, et al. Availability, prices and affordability of essential medicines for children: a cross-sectional survey in Jiangsu Province, China. *BMJ Open.* (2018) 8:e023646. doi: 10.1136/bmjopen-2018-023646

42. Gong S, Cai H, Ding Y, Li W, Juan X, Peng J, et al. The availability, price and affordability of antidiabetic drugs in Hubei province, China. *China Health Policy Plan.* (2018) 33:937–47. doi: 10.1093/heapol/czy076

43. Su M, Zhang Q, Bai X, Wu C, Li Y, Mossialos E, et al. Availability, cost, and prescription patterns of antihypertensive medications in primary health care in China: a nationwide cross-sectional survey. *Lancet.* (2017) 390:2559–68. doi: 10.1016/S0140-6736(17)32476-5

44. Xie N, Shen Y, Ren JM, Tang KM. Empirical study on the availability of essential medicines in public health and medical institutions of Shanghai Qingpu district. *Chin Pharm.* (2016) 27:3331–4. doi: 10.6039/j.issn.1001-0408.2016.24.05

45. Shang JX, Guo ZG, Lin QM, Li L, Chen CX, Feng L, et al. Analysis of accessibility of essential medicine in Beijing. *Chin J Health Policy.* (2016) 9:52–8. doi: 10.3969/j.issn.1674-2982.2016 02. 010

46. Zhang Y, Li X. Investigation and analysis of availability and affordability of essential medicine in Nanjing based on WHO/HAI standard survey method. *Chin Pharm.* (2015) 26:4188–92. doi: 10.6039/j.issn.1001-0408.2015.30.04

47. Xi X, Li W, Li J, Zhu X, Fu C, Wei X, et al. A survey of the availability, prices and affordability of essential medicines in Jiangsu Province, China. *BMC Health Serv Res.* (2015) 15:345. doi: 10.1186/s12913-015-1008-8

48. Jiang M, Zhou Z, Wu L, Shen Q, Lv B, Wang X, et al. Medicine prices, availability, and affordability in the Shaanxi Province in China: implications for the future. *Int J Clin Pharm.* (2015) 37:12–7. doi: 10.1007/s11096-014-0037-4

49. Wang X, Yang SM, Fang Y, Jiang MH, Wu LN. Study on the availability and price pediatric essential medicines in retail pharmacies in Shaanxi Province using WHO/HAI methodology. *Chin Pharm.* (2014) 25:678–81. doi: 10.6039/j.issn.1001-0408.2014.08.02

50. Wang X, Fang Y, Yang S, Jiang M, Yan K, Wu L, et al. Access to paediatric essential medicines: a survey of prices, availability, affordability and price components in Shaanxi Province, China. *PLoS ONE.* (2014) 9:e90365. doi: 10.1371/journal.pone.0090365

51. Yan KK, Yang SM, Fang Y, Zhao J, Liu J. Study on prices and availability of 47 kinds of drugs in Shaanxi Province. *Chin Pharm.* (2013) 24:1072–5. doi: 10.6039/j.issn.1001-0408.2013.12.06

52. Jiang MH, Wang L, Wang WJ, Wang X, Fang Y, Yang SM, et al. Comparative study on the price and availability of essential drugs in public hospital and retail pharmacy of Shaanxi Province. *Chin Pharma.* (2013) 24:308–13. doi: 10.6039/j.issn.1001-0408.2013.04.08

53. Guan XD, Xin XX, Liu Y, Wang TS, Shi LW. Empirical study on availability of essential medicine in China. *Chin Pharm.* (2013) 24:2216–9. doi: 10.6039/j.issn.1001-0408.2013.24.03

54. Li XW, Liang HJ, Zhang YL, Wu SL, Xv Y. Survey on accessibility of the essential drugs in grassroots medical facilities. *Health Econ Res.* (2012) 6:24–6. doi: 10.14055/j.cnki.33-1056/f.2012.06.023

55. Li F. *Availability of Essential Medicines Research of Community Health Servicces in Guangzhou*. Guangzhou: Guangzhou University of Chinese Medicine (2011).

56. World Health Organization. *WHO Model List of Essential Medicines (22nd List)*. (2021). Available online at: https://www.who.int/publications/i/item/WHO-MHP-HPS-EML-2021.02 (accessed June 25, 2022).

57. National Health Commission of the People's Republic of China. *National Essential Medicines List*. (2018). Available online at: http://www.gov.cn/fuwu/2018-10/30/5335721/files/e7473e46d9b24aadad3eb25127ffd986.pdf (accessed June 25, 2022).

58. Mahmić-Kaknjo M, Jeličić-Kadić A, Utrobičić A, Chan K, Bero L, Marušić A. Essential medicines availability is still suboptimal in many countries: a scoping review. *J Clin Epidemiol.* (2018) 98:41–52. doi: 10.1016/j.jclinepi.2018.02.006

59. Hogerzeil HV, Liberman J, Wirtz VJ, Kishore SP, Selvaraj S, Kiddell-Monroe R, et al. Promotion of access to essential medicines for non-communicable diseases: practical implications of the UN political declaration. *Lancet.* (2013) 381:680–9. doi: 10.1016/S0140-6736(12)62128-X

60. Mani H. Patient education is crucial for the access to essential medicine. *Lancet.* (2015) 385:230. doi: 10.1016/S0140-6736(15)60057-5

61. McLeod L, Bereza BG, Shim M, Grootendorst P. Financial burden of household out-of-pocket expenditures for prescription drugs: cross-sectional analysis based on national survey data. *Open Med.* (2011) 5:e1–9. Available online at: https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3205811/pdf/OpenMed-05-e1.pdf

62. He D, Yu H, Chen Y. Equity in the distribution of CT and MRI in China: a panel analysis. *Int J Equity Health.* (2013) 12:39. doi: 10.1186/1475-9276-12-39

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 09 June 2023
DOI 10.3389/fpubh.2023.1177618

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Mojtaba Vaismoradi,
Nord University, Norway
Seok Shin Tan,
Monash University Malaysia, Malaysia
Shailaja S. Patil,
BLDE University, India

*CORRESPONDENCE
Ibsa Mussa
ibsamussa93@gmail.com

RECEIVED 01 March 2023
ACCEPTED 11 May 2023
PUBLISHED 09 June 2023

CITATION
Abdulla JH, Gebremichael B, Maruta MB, Yuye I, Mohammed A, Debella A and Mussa I (2023) Nearly one out of every five adult TB patients suffered from food insecurity in Grawa District, Eastern Ethiopia: a multicenter facility-based cross-sectional study.
Front. Public Health 11:1177618.
doi: 10.3389/fpubh.2023.1177618

Nearly one out of every five adult TB patients suffered from food insecurity in Grawa District, Eastern Ethiopia: a multicenter facility-based cross-sectional study

Jabir H. Abdulla[1], Berhe Gebremichael[2], Melat B. Maruta[3], Ibsa Yuye[4], Abdusalam Mohammed[5], Adera Debella[6] and Ibsa Mussa [2]*

[1]Department of Family Health, Grawa Health Bureau, Grawa, Ethiopia, [2]School of Public Health, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia, [3]School of Medicine, Obstetrics and Gynecology, Menelik Hospital, Addis Ababa, Ethiopia, [4]Resource Mobilization and Health Financing, East Hararghe Zonal Health Office, Harar, Ethiopia, [5]Revenue Authority, Dire Dawa City Administration, Dire Dawa, Ethiopia, [6]School of Nursing and Midwifery, College of Health and Medical Sciences, Haramaya University, Harar, Ethiopia

Background: Despite a dramatic decline in tuberculosis mortality over the past 10 years, tuberculosis is still the leading cause of death globally. In the last 2 years, tuberculosis has affected an estimated 10 million individuals, and 1.4 million people have died worldwide. In Ethiopia, the weight of the problem is less known in the study area. As a result, the purpose of this study was to assess food insecurity and associated factors among adult patients with tuberculosis attending public health facilities in Grawa district, Eastern Ethiopia.

Methods: A multicenter facility-based cross-sectional study was conducted from 01 March to 31 March 2022, among 488 randomly selected adult tuberculosis patients on treatment follow-up at public health facilities in Grawa district, Eastern Ethiopia. Data were collected using a pretested structured questionnaire through a face-to-face interview and document review, entered into EpiData version 3.1, and analyzed using SPSS version 25. The prevalence was reported using a 95% confidence interval (CI) and summary measures. Predictors were assessed using a multivariable logistic regression analysis model and reported using an adjusted odds ratio (AOR) with 95% CI. Statistical significance was declared at a *p*-value of <0.05.

Results: Overall, the prevalence of food insecurity among the study participants was 19.5%, with a 95% CI (15.8%, 23.2%). Factors such as being male [AOR = 0.58, 95% CI: (0.34, 0.97)], being married [AOR = 2.93, 95% CI: (1.33, 6.47)], being merchant [AOR = 0.22, 95% CI: (0.04, 0.67)], having low wealth quintiles [AOR = 2.10,95%CI:(1.04–4.23)], receiving anti-TB treatment for two or fewer months [AOR = 0.48, 95% CI: (0.26–0.91)], using khat [AOR = 2.18, 95% CI: (1.29, 3.70)], and owning livestock (AOR = 0.56, 95% CI: 0.29–0.94) were significantly associated with food insecurity.

Conclusions: According to this study, nearly one out of every five adults TB patients is food insecure. Factors such as being male, being married, being merchant, having low wealth quintiles, receiving anti-TB treatment for two or less months, those who chew mKhat and having a livestock were significantly associated with food insecurity. As a result, all stakeholders and concerned entities should prioritize improving the livelihood of TB patients through social security

system programs, which are critical to the success of TB control and prevention efforts.

KEYWORDS

prevalence, food insecurity, tuberculosis, associated factors, Ethiopia

Introduction

Globally, 821 million people suffer from chronic food deprivation, and the situation has been worsening in most regions of the African continent (1). Insecurity is generally defined as a lack of regular access to enough safe and nutritious food for normal growth and development and an active and healthy life (1, 2). Food insecurity has a substantial impact on the health of populations. Meanwhile, TB continues to be a major cause of morbidity and mortality globally, and its association with access to food and nutrition has been acknowledged for a long time (3). Tuberculosis holds a prominent place in public health, in part because it is listed as among the top causes of premature death among the adult population (4). Tuberculosis is present in all countries and affects all age groups. However, it affects the world disproportionately, as the majority of TB cases and deaths occur in developing countries, where more than half of the cases are in economically productive age groups (5).

Despite a dramatic decline in tuberculosis mortality over the past 10 years, tuberculosis is still the leading cause of death globally. Malnutrition and tuberculosis are two examples of how food insecurity has an impact on mortality, treatment failure, and tuberculosis risk (6). In the last 2 years, tuberculosis has affected an estimated 10 million individuals who have contracted the disease, and 1.4 million people have died worldwide (7).

The majority of people in developing nations experience food insecurity and an unhealthy environment, which have an immediate impact on household food access, availability, and consumption (7). Inadequate food intake leads to poor nutritional status and impaired immune function. Food access, availability, and consumption in households are directly impacted by food insecurity and an unhealthy environment, which are prevalent among the majority of people in developing countries (8). Poor nutritional status and impaired immunity are affected by insufficient dietary consumption. It was detected that there is a vicious cycle between undernutrition and TB, according to which poor nutritional status increases the risk of tuberculosis (TB), which in turn can lead to undernutrition (9).

Almost half (1 million) of all TB patients worldwide are malnourished (10). The World Health Organization (WHO) recommends that all TB patients have a nutritional assessment and receive the proper nutritional therapy to reduce the incidence of undernutrition (11). A sufficient, wellbalanced diet is linked to better weight gain and quicker sputum conversion (12). Energy-dense supplements also increased lean body mass and athletic performance (13). Patients with co-infections displayed significant wasting due to these synergistic negative effects (14, 15). Moreover, behavioral factors are linked to undernutrition; for example, smoking increases the risk of undernutrition, which may be linked to decreased appetite and increased resting energy expenditure due to nicotine's effects on body metabolism (16).

On the other hand, undernutrition among TB patients was at risk for those with a low socioeconomic position, low educational status, being female, having a positive sputum smear, being unable to work functionally, and not receiving dietary counseling (17–19). Unexpectedly, TB is Ethiopia's third-leading cause of hospital fatalities and the eighth-leading cause of hospital admissions (20). Furthermore, a small number of studies revealed that a sizeable portion of TB patients are undernourished (21, 22). Poor anti-TB medication adherence has also been found to be a regular occurrence in patients who are malnourished, which may increase the chance of acquiring multi-drug resistance (MDR) type TB, one of the pressing public health issues currently facing Ethiopia and the world (11, 22).

A reduction in undernutrition in the general population could significantly lower the incidence of TB because it is a powerful predictor of active TB (23). Hence, enhancing TB patients' nutritional states is crucial to lowering the likelihood of comorbidities and accompanying mortality as well as adverse treatment outcomes. Moreover, studies demonstrating the scope and causes of undernutrition are crucial for improving early case identification and management, yet Ethiopian literature is scant. Even the already conducted studies have a more limited scope, which eventually reduces the generalizability of the conclusion (22, 24).

Ethiopia has a major share of the global incidence of TB and its related mortality and morbidity (25). With an estimated 219,186 new cases and 48,910 TB deaths, the country has been ranked among the top countries with a burden of tuberculosis (26). On the other hand, food insecurity emerges as a key problem and development challenge in Ethiopia, with the country being ranked among the top East African countries affected by hunger and undernourishment (21). Subsequently, the combined impacts of food insecurity and tuberculosis place further strain on already limited resources as affected individuals strive to meet the food demand.

Nowadays, any individual infected with TB in Ethiopia receives free treatment. As an integral part of TB care and control, the health sector should recognize and help address generalized malnutrition, food insecurity, and other socioeconomic determinants and consequences of TB (27). Understanding the level of food insecurity and its associated factors among adult TB patients is crucial in designing an appropriate intervention to address the bidirectional deteriorating effects. However, despite the high burden of TB and troubling food insecurity in Ethiopia, only a few studies have been conducted concerning food insecurity and associated risk factors among adult TB patients (24, 28). Moreover, these studies have been limited to other areas, with no consideration of eastern Ethiopia,

which is overwhelmed by the recurrent impact of drought and pose the risk of food insecurity (11, 29, 30).

Despite the commitment of various stakeholders and the government, the prevalence and determinants of food security, as well as tuberculosis, which are thought to be the direct and underlying causes of undernutrition, continue to be a problem. Moreover, there are a few studies conducted in Ethiopia that pointed out that food insecurity among Tb patients is a major widespread problem (11, 21, 31). Furthermore, there is a paucity of documented evidence regarding the problems under study generally at the county level and particularly at the study area level, so the purpose of this study was to assess factors associated with food insecurity among adult tuberculosis patients attending public health facilities in Grawa district, Eastern Ethiopia.

Methods and materials

Study design, setting, and period

A multicenter facility-based cross-sectional study was conducted from 01 March to 31 March 2022, among 488 randomly selected adult tuberculosis patients on treatment follow-up at public health facilities in Grawa district, Eastern Ethiopia. Regarding the location, Grawa is located in Eastern Ethiopia, 580 km from Ethiopia's capital, Addis Ababa. According to projections from the 2007 national census, the district will have a total population of 349,543 (179,248 men and 170,295 women) by 2020. The district has 45 health posts, 9 health centers, and 1 general hospital. From those district health facilities, six health centers and one hospital provided tuberculosis laboratory services. We used the STROBE cross-sectional checklist when writing our report (32).

Eligibility criteria

All adult tuberculosis patients who had follow-up treatment in Grawa district public health facilities during the study period were considered the source population, whereas all adult TB patients who had follow-up treatment in randomly selected public health facilities and were available during the data collection period were regarded as the study population. The study excluded adult tuberculosis patients who were critically ill and unable to provide the necessary information during data collection.

Data collection methods

An interviewer-administered, pretested, structured questionnaire adapted from the Household Food Insecurity Access Scale (HFIAS) for the measurement of food access was developed by USAID (33) and related published literature that contextualized the study objectives (34). It contains socio-demographic and economic characteristics, household-related conditions, substance use-related behavior, healthcare services, and comorbidity-related characteristics. The data were collected by six BSc Nurse Health professionals who fluently speak Afaan Oromo (the local language). Supervision was conducted by the principal investigator and two public health experts familiar with the study setting. Data collectors and supervisors were trained for 2 days on ethics, tool sampling, and data collection procedures. The data collection process was supervised on a daily basis, and timely feedback was communicated to the data collectors. First, we translated it while keeping the purpose of the questionnaire and the intent of the questions in mind. It was conducted by group members who speak both languages fluently translate it. To ensure the translation's accuracy, the questionnaire was translated back into English by someone who had not seen the original version and was unfamiliar with the questionnaire's context. The back-translated version is then compared to the original, and any meaning differences are corrected. After that, to ensure a cross-validity, we tried to interview a set of respondents in English and another set in the local language such as Afaan Oromo and Amharic, and their answers were then compared to detect differences in understanding. Finally, pretesting was conducted to identify questions that are poorly understood, ambiguous, or elicit hostile or other undesirable responses. We attempted to conduct a pretest using the already-translated questionnaire. We tried to implement all the steps in pretesting such as obtaining an evaluation of a questionnaire and testing the revised questionnaire through its paces on friends, colleagues, and so on. Moreover, when choosing a tool, reliability and validity must be taken into account. The consistency with which an instrument produces the same results across multiple trials is referred to as its reliability. The degree to which an instrument measures what it was designed to measure is known as its validity. Statistically, we performed Cronbach's alpha, which is a measure used to assess the quality of our employed instruments. The result was 0.87, which was within acceptable ranges.

Variables and their measurement

Food security

A situation in which all people at all times have physical, social, and economic access to sufficient, safe, and nutritious foods that meet their dietary needs and food preferences for an active and healthy life (35).

Food insecurity

The lack of regular access to enough safe and nutritious food for normal growth and development and active and healthy life. This may be due to the unavailability of food and/or lack of resources to obtain food (36).

Food secure

May report worrying or being anxious about household food supply, but only rarely. Otherwise, the household does not experience any other conditions of inadequate food access.

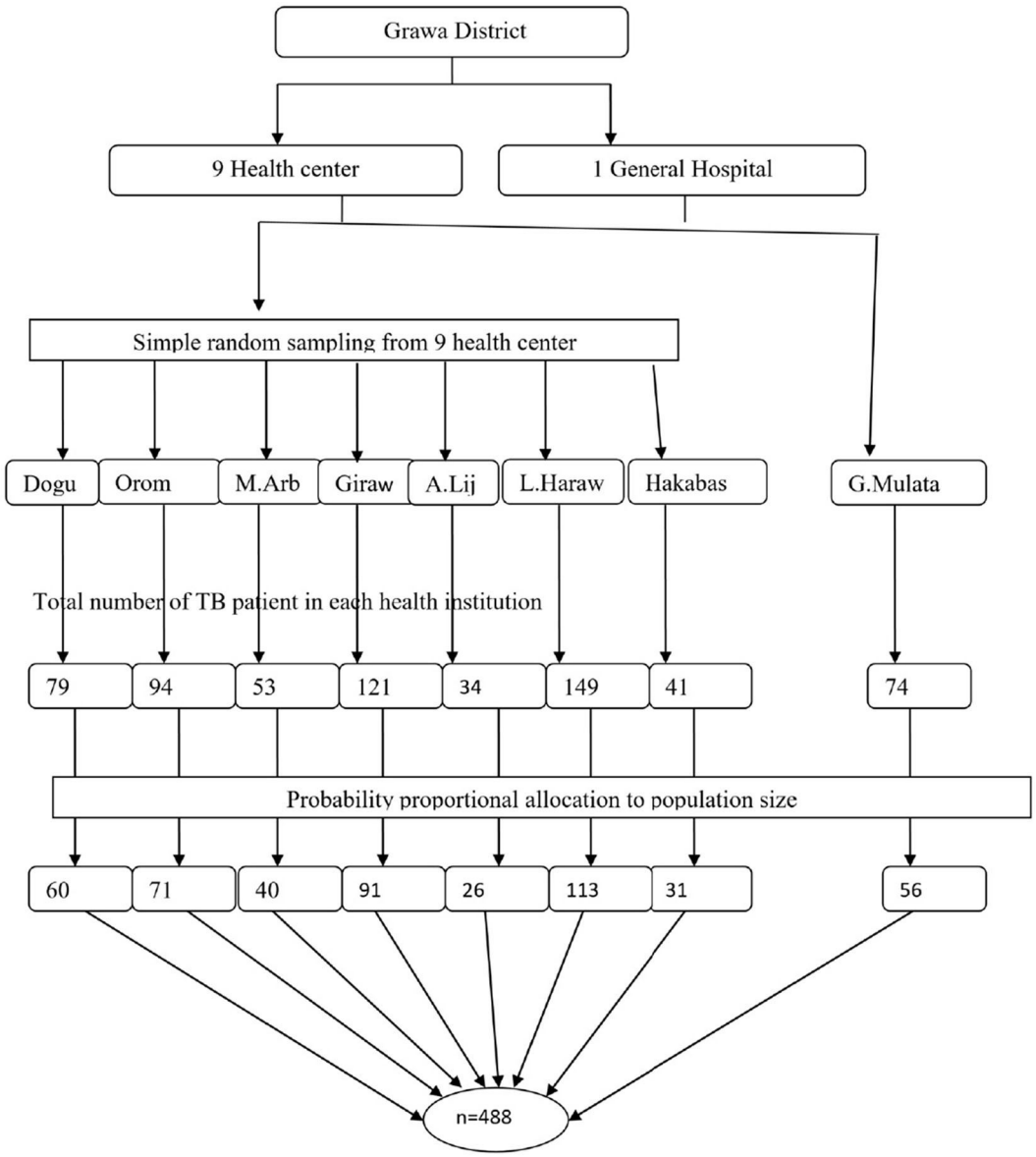


FIGURE 1
Schematic presentation of sample selection procedures of food insecurity among adult TB patients in Grawa District, Eastern Ethiopia.

Current substance use

Taking any substance such as alcohol, hashish, shisha, tobacco, and khat in the last 1 month prior to the study.

Ever substance use

Taking any substance such as alcohol, hashish, shisha, smoking cigarettes, and khat at least once in lifetime.

Bias

There were a number of biases involved while conducting this research, and the researchers took explicit measures to avoid them. One of the biases was social desirability, and to avoid it, the researchers paraphrase the questions in a way that was not socially desirable.

Sample size determination and sampling procedures

The sampling size was computed using the single population proportion formula, considering the following assumptions: 28.0% as the prevalence of undernutrition among adults with TB in southwest Ethiopia (28), a 95% level of confidence, and a 5% margin of error. A 10% non-response rate was also added to get a minimum sample size of 488.

To gather the study subjects, a multi-stage sampling technique was used. First, seven health centers from nine health centers in the Grawa district were selected by simple random sampling. Next, the total number of TB patients on follow-up treatment in each health institution was taken from the registration book of the patient to obtain a sampling frame (a list of eligible participants) before the actual data collection period. The probability-based proportional sampling technique was used to allocate the total sample size proportionally to each respective health institution. Then, each patient was given a unique code. Finally, study participants were selected using a simple random sampling technique (Figure 1).

Data quality control

The questionnaire was initially prepared in English and then translated into the local languages by a bilingual expert (Afaan Oromo). Then, it was translated back into an English version to ensure its consistency. The data collectors and supervisor received training on the data collection tool and procedures. Before the actual study data collection, a pretest was conducted among 5% of the study participants in similar settings. The investigators and experienced research supervisors provided regular supervision.

Data processing and analysis

First, the collected data were checked for completeness and consistency. Then, they were cleaned, coded, and entered into EpiData version 3.1 for further analysis. The entered data were exported to SPSS version 25 for analysis. Descriptive and summary statistics were conducted and reported using frequency tables and figures. A binary logistic regression model was fitted to check for an association between independent variables and the outcome variable. The model's fitness was checked by Hosmer–Lemeshow statistics and Omnibus tests. A multivariable analysis was performed to identify the true predictors of the outcome variables. A multi-collinearity test was carried out to check the presence of correlation between independent variables by using the standard error and co-linearity statistics, and no collinearity effects were detected. Thus, the value of the variance inflation factor (VIF) was 0.951. The direction and strength of the statistical association were measured by the odds ratio (OR) along with the 95% confidence interval (CI). A p-value of 0.05 was considered to be statistically significant in both bivariable and multivariable analyses.

Results

Socioeconomic and demographic characteristics

A total of 482 adult TB patients who were on treatment follow-up participated in the study, resulting in a response rate of 98.8%. The mean age of the study participants was 34.34 (SD ± 11.9) years, with 18 and 65 years being the minimum and maximum ages, respectively. Above half (53.5%) of the study participants were men. Most of the study participants 448 (92.9%) and 461 (95.6%) belonged to the Muslim religion and Oromo ethnicity, respectively. The majority, 411 (85.3%) of the participants, were rural dwellers. A total of 322 (62.2%) study participants had no formal education, and 311 (64.5%) of them were living with their spouses. Nearly a quarter, or 113 (23.4%), of the study participants were categorized as being in the high-wealth quintile (Table 1).

TABLE 1 Sociodemographic characteristics of adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022 ($n = 482$).

Variables	Categories	Frequency	Percentage
Age	18–30	223	46.3
	31–45	177	36.7
	≥46	82	17.0
Sex	Male	257	53.3
	Female	225	53.3
Residence	Urban	71	14.7
	Rural	411	85.3
Ethnicity	Oromo	461	95.6
	Amhara	11	2.3
	Tigre	2	0.4
	Gurage	8	1.7
Religion	Muslim	448	92.9
	Chiristian	34	7.1
Education	No formal education	300	62.2
	Primary school	82	17
	Secondary school and above	100	20.7
Occupational status	Farmer	206	42.7
	Daily laborer	57	11.8
	Civil servant	12	2.5
	Merchant	38	7.9
	Others*	169	35.1
Wealth quintiles	Low	230	47.7
	Middle	150	31.1
	High	102	21.2

*Student and housewife.

As shown in Figure 2, among 482 study participants, 311 (64.5%) were married, and 9 (1.9%) were widowed.

Household characteristics of the study participants

A total of 98 (20.3%) study subjects live alone in the household, whereas 308 (63.9%) study subjects live with four or more

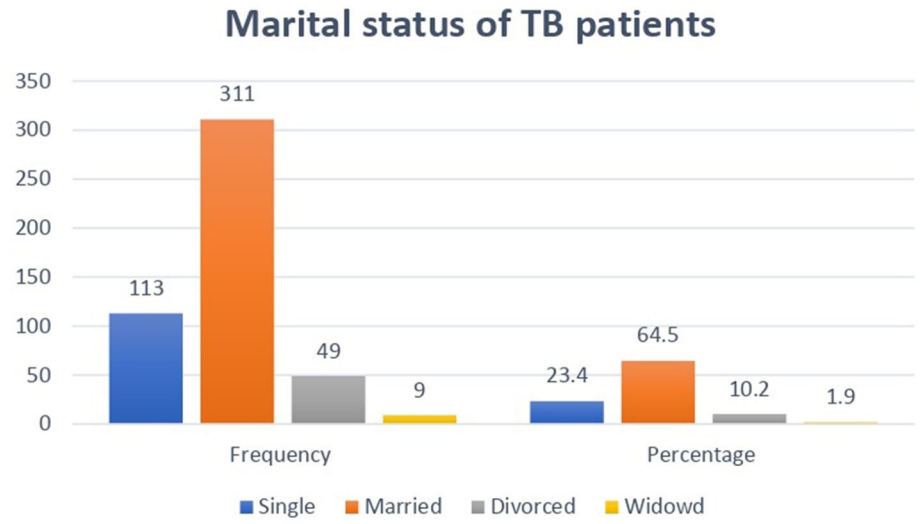


FIGURE 2
Distribution of marital status among adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022.

family members. The majority 322 (83.9%) of the households were monogamous. Nearly three-quarters 359 (74.5%) of the households had livestock, and 357 had farmland. Concerning food aid received from different organization, 22 (4.6%) households were beneficiaries of food support programs. Most of the 434 households (90%) have a latrine, and more than a quarter 134 (27.8%) of households have no window (Table 2).

Health history of adult TB patients

More than three-quarters of the study subjects 371 (76.9%) were diagnosed with and treated for pulmonary tuberculosis, while the remaining 111 (23.1%) were diagnosed and treated for extrapulmonary tuberculosis. At the time of diagnosis, more than half of the cases 256 (53.2%) had a +1-sputum smear grade. In terms of treatment duration, 358 (74.3%) of patients received anti-TB treatment for more than 2 months, and 35 (7.3%) reported skipping anti-TB medication since starting treatment. The vast majority of respondents, 405 (84.1%), had no diagnosed comorbidity. Concerning the impact of health education on treatment adherence, the majority 401 (83.2%) of study subjects reported receiving health education from health professionals since enrolling in the treatment (Table 3).

Diet and lifestyle conditions of the study participants

Almost a quarter 118 (24.5%) of study participants reported eating fruit the week before the interview, while 152 (31.5%) reported eating vegetables. More than half of the respondents, 262 (54.4%), reported using khat, and 152 (31.3%) were smoking at the time of the treatment follow-up (Table 4).

Level of food insecurity

According to the household food insecurity access scale, 94 patients were food insecure, with an overall proportion of 19.5% (95% CI: 15.8 to 23.2%). A total of 21 (22.3%), 44 (46.8%), and 29 (30.9%) TB patients with food insecurity had mild, moderate, and severe food insecurity, respectively. Nearly 72 (41.9%) patients reported being concerned about not having enough food to eat in the household, and 38 (7.9%) patients reported that household members went to bed hungry (Figure 3).

Factors associated with food insecurity among the study participants

In the bivariable analysis, predictor variables such as the sex of the patient, marital status, wealth quintiles, being an urban resident, the khat chewing condition, duration of anti-TB treatment, having farmland, and the presence of livestock in the households were significantly associated with food insecurity among TB patients. However, in the final model of multivariable logistic regression analysis, predictor variables such as being male, being married, being a merchant, having low wealth quintiles, the duration of anti-TB treatment, chewing khat, and having livestock were factors that remained significantly associated with food insecurity.

Accordingly, male counterparts were 42% less likely to experience food insecurity as compared to their female

10.3389/fpubh.2023.1177618

TABLE 2 Household characteristics of adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022 ($n = 482$).

Variables	Categories	Frequency	Percentage
Live alone in the household	Yes	98	20.3
	No	384	79.7
Number of people living in the household	Less than four	174	36.1
	Greater than or equal four	308	63.9
Have had employed family member	Yes	48	10
	No	434	90
Types of households (369)	Monogamous	307	<83.2
	Polygamous	62	16.8
Household has farmland	Yes	357	74.1
	No	125	25.9
Household has livestock	Yes	359	74.5
	No	123	25.5
Household have latrine	Yes	434	90
	No	48	10
House has window	Yes	348	72.2
	No	134	27.8
Received food support from any organization	Yes	22	4.6
	No	460	95.6

TABLE 3 Health history of adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022 ($n = 482$).

Variables	Categories	Frequency	Percentage
Type of TB	Pulmonary TB	371	76.9
	Extra pulmonary TB	111	23.1
Duration of anti-TB treatment	≤2 months	124	25.7
	>2 months	358	74.3
Sputum smear grading at diagnosis	+1	256	53.2
	+2	153	31.7
	+3	73	15.1
Have you experienced any other comorbidity in addition to TB?	Yes	77	15.9
	No	405	84. 1
Did you delayed or skipped anti-TB drug?	Yes	35	7.3
	No	447	92.7
Received health education	Yes	401	83.2
	No	81	16.8

counterparts [AOR = 0.58, 95% CI: 0.34–0.97]. Similarly, the likelihood of food insecurity was nearly three times higher among married TB patients (AOR = 2.93, 95% CI: 1.33–6.47).

TABLE 4 Diet and lifestyle conditions of adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022 ($n = 482$).

Variables	Categories	Frequency	Percentage
Have you eaten vegetables in the last week?	Yes	152	31.5
	No	330	86.5
Have you eaten fruit in the last week	Yes	118	24.5
	No	364	75.5
Have you ever drunk alcohol?	Yes	17	3.5
	No	465	96.5
Have you ever chewed Khat?	Yes	262	54.4
	No	220	45.6
Did you smoke currently	Yes	151	31.3
	No	331	68.7
Received psychological support	Yes	141	29.3
	No	341	70.7

Furthermore, merchants were 78% less likely to experience food insecurity than their counterparts [AOR = 0.22, 95% CI: 0.04–0.67]. Likewise, the odds of having food insecurity were 2.10 times higher among TB patients who were in the lowest wealth quintile [AOR = 2.10, 95% CI: 1.04–4.23]. Furthermore, when compared to those who received anti-TB treatment for more than 2 months, those who received treatment for 2 months or less were 52% less likely to be food insecure [AOR = 0.48, 95% CI: 0.26, 0.91]. TB patients who chewed khat, on the other hand, were 2.18 times more likely to be food insecure than those who did not [AOR = 2.18, 95% CI: 1.29, 3.70]. Furthermore, TB patients with livestock in their households were 44% less likely to be food insecure than those without livestock [AOR = 0.56, 95% CI: 0.29, 0.94] (Table 5).

Discussion

This study pointed out that 19.5% of the 95% CI (15.8%, 23.2%) study participants were found to be food insecure, of whom 22.3%, 46.8%, and 30.9% were mildly, moderately, and severely food insecure, respectively. Factors such as being male, being married, being a merchant, low wealth quintile, those who chew khat, duration of the anti-TB treatment, and presence of livestock in the households were identified as predictors of food insecurity.

In this study, nearly 19.5% of tuberculosis patients were food insecure. The findings from this study are in harmony with those of studies conducted in Vietnam (22%) (37) and South Africa (21%) (38). The similarities could be due to the fact that the two studies use a similar strategy for laboratory techniques and have a similar social structure. However, the current level of food insecurity is much higher than in previous studies conducted in different settings, like Sri Lanka (6%) (34). The discrepancy might be due to the variation in socioeconomic status and extended social

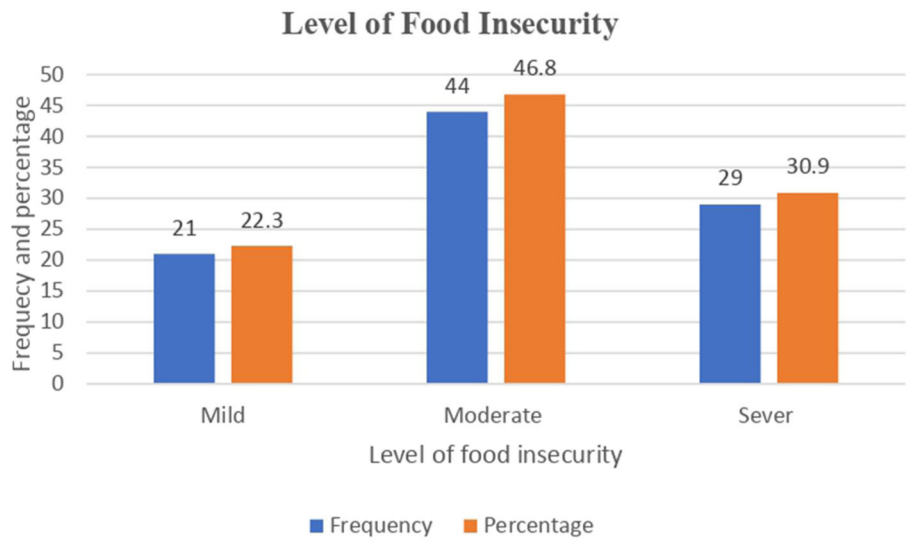


FIGURE 3
Level of food insecurity among adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022.

security programs such as food safety nets among the study areas. In addition, seasonal variability when the studies were conducted could explain the observed difference among the findings. On the contrary, this finding was relatively lower than studies conducted elsewhere, such as in Indonesia (64%) (39), southwest Ethiopia (949.3%) (28), and south India (34.1%) (39). A possible justification could be the difference in the socioeconomic status among the study participants.

This study pointed out that being male was the strongest predictor of food insecurity among TB patients. Thus, male counterparts were 42% less likely to experience food security. This finding is supported by studies conducted in different settings, such as South Africa (38), the Somali Region (31), Adama (40), and low-income countries (41). The possible justification could be attributed to the fact that men have greater access to social capital and pathways out of crisis; for instance, their income pays off previous debts and secures new farm loans, whereas women frequently face severe time constraints due to their household food-security roles. Furthermore, gender roles may be a plausible explanation for this association. The majority of rural women in developing countries face financial and land-control constraints (41, 42). This may limit their ability to purchase high-demand food and reduce production, worsening food insecurity among them.

In the final model of multivariable analysis, marital status was found to be associated with food insecurity. Thus, those study participants who married were 2.93 times more likely to experience food insecurity as compared to their counterparts. Similar findings were reported from the studies conducted in Sri Lanka (34). The possible justification could be that a married couple has children who share a few resources, which absolutely plays a pivotal role in establishing and creating food insecurity in that specific household.

The current study found that low wealth quintile were another factor that was independently associated with food insecurity. Patients with tuberculosis in the lowest wealth quintile were more likely to be food insecure than those in the highest wealth quintile. This finding is in harmony with the study done in the Kembata Tembaro zone, southern Ethiopia (43), and south India (39), which found that TB patients with a low monthly income had twice the odds of experiencing household food insecurity as their high-income counterparts. This could be due to the fact that a low income limits an individual's purchasing power for food, potentially exacerbating food insecurity. Furthermore, catastrophic health expenditure as a result of tuberculosis diagnosis and treatment can exacerbate food insecurity in low-income groups throughout the disease's course (44). Similarly, a significant association was found between food insecurity and occupation in the current study, with merchants having lower odds of experiencing food insecurity than farmers. Thus, merchants were 78% less likely to be food insecure than their counterparts. This is in line with the findings of previous studies conducted in Nigeria and Ethiopia (45, 46). This could be due to merchants' purchase and access to power. Furthermore, they have a higher income than the others, allowing them to live a normal life free of food insecurity.

Furthermore, khat consumption was found to be significantly associated with food insecurity in this study. Patients who reported chewing khat had a higher risk of food insecurity than non-chewers. Several previous studies have found that food insecurity is significantly associated with substance use habits, which is consistent with the current findings (47–50). The current study's findings of increased food insecurity among khat chewers may be due to the negative effects of khat consumption on the household economy. Khat is a major cash crop and source of income for millions of households in eastern Ethiopia (51). It is frequently blamed for worsening food insecurity by diverting money to buy khat, complicating the chewer work culture (52), and displacing food crops (53). The current study's finding

10.3389/fpubh.2023.1177618

TABLE 5 Bi-variable and multivariable logistic regression analysis of factors associated with adult TB patients undergoing treatment in public health facilities of Grawa District, Eastern Ethiopia, 2022 ($n = 482$).

Factors	Categories	Food insecurity		COR (95% CI)	AOR (95% CI)
		Yes (%)	No (%)		
Sex of the patient	Male	39 (15.2)	218 (84.5)	0.55 (0.35–0.87)	0.58 (0.34–0.97) *
	Female	55 (24.4)	170 (75.6)	1	1
Marital Status	Single	9 (8.0)	104 (92)	1	**1**
	Married	71 (22.8)	240 (77.2)	3.42 (1.65–7.10)	2.93 (1.33–6.47) *
	Divorced	11 (22.4)	38 (77.6)	3.35 (1.29–8.70)	2.02 (0.69–5.89)
	Widowed	3 (33.3)	6 (66.7)	5.78 (1.23–27.06)	3.39 (0.59–19.66)
Residence	Urban	9 (12.7)	62 (87.3)	0.30 (0.12–0.75)*	0.56 (0.27–1.27)
	Rural	85 (20.7)	326 (79.3)	1	1
Religion of the patient	Muslim	83 (18.5)	365 (81.5)	0.48 (0.22–1.02)	0.62 (0.26–1.51)
	Christian	11 (32.4)	23 (67.6)	1	1
Educational status of the patient	No formal education	60 (20.0)	240 (80.0)	1	1
	Primary school	21 (25.6)	61 (74.4)	1.38 (0.78–2.44)	1.84 (0.95–3.58)
	Secondary and above	13 (13.0)	87 (87.0)	0.60 (0.31–1.14)	0.70 (0.32–1.53)
Occupation of the patient	Farmer	119 (57.8)	87 (42.2)	1	1
	Daily laborer	50 (88.1)	7 (11.9)	0.98 (0.48–2.01)	0.69 (0.25–1.91)
	Employee	6 (50)	6 (50)	0.34 (0.04–2.66)	0.26 (0.03–2.84)
	Merchant	7 (18)	31 (82)	0.59 (0.28–1.26)	0.22 (0.04–0.67)*
	Others**	103 (61)	66 (39)	0.64 (0.37–1.10)	0.73 (0.35–1.52)
Wealth quintiles	Low	55 (23.9)	175 (76.1)	1.98 (1.04–3.75)	2.10 (1.04–4.23) *
	Middle	25 (16.7)	125 (83.3)	1.26 (0.61–2.55)	1.42 (0.66–3.03)
	High	14 (13.7)	88 (86.3)	1	1
Have had employed family member	Yes	16 (33.3)	32 (66.7)	2.28 (1.19–4.37)	1.85 (0.91–3.75)
	No	78 (18)	356 (82)	1	1
Duration of treatment follow up	≤ 2 months	15 (12.1)	109 (87.9)	0.49 (0.27, 0.88)	0.48 (0.26–0.91)*
	>2 months	79 (22.1)	279 (77.9)	1	1
Chewing Khat	Yes	63 (24)	199 (76)	1.93 (1.20–3.10)	2.18 (1.29–3.70)*
	No	31 (14.1)	189 (85.9)	1	1
Household has farmland	Yes	58 (16.2)	299 (83.8)	0.48 (0.30–0.77)	0.46 (0.24–1.09)
	No	36 (28.8)	89 (71.2)	0.48 (0.30–0.77)	0.46 (0.24–1.09)
Household have livestock	Yes	61 (17)	298 (83)	0.56 (0.34–0.91)	0.56 (0.29–0.94)*
	No	33 (26.8)	90 (73.2)	1	1

Key: *p-value <0.01, **p-value <0.001.

of an increased risk of food insecurity among khat chewers among TB patients may help researchers better understand how khat chewing affects the healthcare continuum in the study settings.

The current study also revealed that the duration of anti-TB treatment was significantly associated with food insecurity. Patients with TB who received anti-TB treatment for 2 months or less had lower odds of experiencing food insecurity compared with those who received anti-TB treatment for more than months. In contrast to the current finding, the study conducted in Burkina Faso reported no significant association between the duration of anti-TB treatment and undernutrition (54). A possible explanation for the association in the present findings could be from the perspective of the "health shocks notion," where being on treatment for a longer duration resulted in extra expenditure incurred to receive healthcare and a loss in working days, which in turn adversely affected household earnings and food security (55, 56).

Finally, this study showed that study participants who had livestock were 44% less likely to experience food insecurity as compared to their counterparts. This is supported by the studies conducted in Ghana (57). This is because livestock is critical to food systems facing these emerging global challenges. Smallholders rely on livestock for income and labor-saving, productive assets. Livestock also helps with nutrition because animal-based foods are essential, especially in reducing child stunting in developing countries (58).

Implications and limitations of study

This study plays a pivotal role in clearly showing the prevalence of food security among immune-compromised individuals such as TB patients. It also points out the factors that influence the problems under study. In this study, due to the nature of the study design, it would be impossible to determine the causal relationship between the variable and the outcome in the analysis. Moreover, the study failed to consider seasonal variability in effect which could bias the level of food insecurity.

Conclusion

According to this study, nearly one out of every five adults TB patients is food insecure. Factors such as being male, being married, being merchant, having low wealth quintiles, receiving anti-TB treatment for two or less months, those who chew mKhat and having a livestock were significantly associated with food insecurity. As a result, all stakeholders and concerned entities should prioritize improving the livelihood of TB patients through social security system programs, which are critical to the success of TB control and prevention efforts.

Data availability statement

The datasets used for this study are available from the corresponding authors upon reasonable request.

Ethics statement

Ethical approval was obtained from the Institutional Health Research Ethics Review Committee (IHRERC) of Haramaya University, College of Health and Medical Sciences. Support letters from the College of Health and Medical Sciences were submitted to the selected health facilities where the study was conducted. After getting all permission letters from responsible bodies, informed, voluntary, written and signed consent was obtained from the study participants.

Author contributions

All authors made a significant contribution to the work reported, whether that is in the conception, study design, execution, acquisition of data, analysis, and interpretation, or in all these areas, took part in drafting, revising, or critically reviewing the article, gave final approval of the version to be published, have agreed on the journal to which the article has been submitted, and agree to be accountable for all aspects of the work.

Funding

Haramaya University provided financial support for this study. However, the funding agency had no role in the collection, analysis, and interpretation of the data, as well as the writing up of the manuscript.

Acknowledgments

The authors are very thankful to Haramaya University, the heads and staff of the College of Health and Medical Sciences, the study participants, data collectors, and supervisors.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. FAO I, UNICEF, WFP, WHO. *The State of Food Security and Nutrition in the World*. (2021).

2. WHO, WHO policy on collaborative. *TB/HIV activities: guidelines for national programmes and other stakeholders*. (2012).

3. Podewils LJ, Holtz T, Riekstina V, Skripconoka V, Zarovska E, Kirvelaite G, et al. Impact of malnutrition on clinical presentation, clinical course, and mortality in MDR-TB patients. *Epidemiol Infect.* (2011) 139:113–20. doi: 10.1017/S0950268810000907

4. Dye C, Bassili A, Bierrenbach AL, Broekmans JF, Chadha VK, Glaziou P, et al. Measuring tuberculosis burden, trends, and the impact of control programmes. *Lancet Infect Dis.* (2008) 8:233–43. doi: 10.1016/S1473-3099(07)70291-8

5. Okhovat-Isfahani B, Bitaraf S, Mansournia MA, Doosti-Irani A. Inequality in the global incidence and prevalence of tuberculosis (TB) and TB/HIV according to the human development index. *Med J Islam Repub Iran.* (2019) 33:45. doi: 10.47176/mjiri.33.45

6. Feleke BE, Feleke TE, Biadglegne F. Nutritional status of tuberculosis patients, a comparative cross-sectional study. *BMC Pulm Med.* (2019) 19:182. doi: 10.1186/s12890-019-0953-0

7. Chakaya J, Khan M, Ntoumi F, Aklillu E, Fatima R, Mwaba P, et al. Global tuberculosis report—reflections on the global tb burden, treatment and prevention efforts. *Int J Infect Dis.* (2021) 113 Suppl 1:S7–S12. doi: 10.1016/j.ijid.2021.02.107

8. FAO I, UNICEF, WFP, WHO. *The State of Food Security and Nutrition in the World (SOFI). Building climate resilience for food security and nutrition* (2018).

9. Zachariah R, Spielmann MP, Harries AD, Salaniponi FML. Moderate to severe malnutrition in patients with tuberculosis is a risk factor associated with early death. *Trans R Soc Trop Med Hyg.* (2002) 96:291–4. doi: 10.1016/S0035-9203(02)90103-3

10. WHO. *Guideline : Nutritional care and support for patients with tuberculosis. World Heal Organ [Internet*]. (2013). Available online at: http://apps.who.int/iris/bitstream/10665/94836/1/9789241506410_eng.pdf (accessed April 23, 2023).

11. Gemechu F, Zemedu L, Yousuf J. Determinants of farm household food security in Hawi Gudina district, West Hararghe zone, Oromia Regional National State, Ethiopia. *J Agricult Exten Rural Develop Bull World Health Organ.* (2016) 8:12–8. doi: 10.5897/JAERD2014.0660

12. Paton NI, Chua Y-K, Earnest A, Chee CBE. Randomized controlled trial of nutritional supplementation in patients with newly diagnosed tuberculosis and wasting. *Am J Clin Nutr.* (2004) 80:460–5. doi: 10.1093/ajcn/80.2.460

13. Gebremichael E, Seyoum WM, Ishimwe B, Sataer G. Lake surface area expansion: insights into the role of volcano-tectonic processes, Lake Beseka, East Africa. *J Hydrol Reg Stud.* (2022) 41:101093. doi: 10.1016/j.ejrh.2022.101093

14. Lönnroth K, Castro KG, Chakaya JM, Chauhan LS, Floyd K, Glaziou P, et al. Tuberculosis control and elimination 2010-50: cure, care, social development. *Lancet.* (2010) 375:1814–29. doi: 10.1016/S0140-6736(10)60483-7

15. Cegielski JP, Arab L, Cornoni-Huntley J. Nutritional risk factors for tuberculosis among adults in the United States, 1971-1992. *Am J Epidemiol.* (2012) 176:409–22. doi: 10.1093/aje/kws007

16. Collins LC, Walker J, Stamford BA. Smoking multiple high- versus low-nicotine cigarettes: impact on resting energy expenditure. *Metabolism.* (1996) 45:923–6. doi: 10.1016/S0026-0495(96)90256-5

17. Indupalli AS, Sirwar SB, Shaikh B. Nutritional status of tuberculosis cases registered under tuberculosis unit of Gulbarga city north Karnataka, India. *Jama.* (2013) 2:616–9. doi: 10.21746/IJBIO.2013.03.0027

18. Guadie FF. AB assessment of nutritional status and associated factors among adult tb patients on directly observed treatment of short course in health facilities at Adama Town, East Shewa Zone, Ethiopia. *Sch Pr Pr J.* (2016) 1:23. Available online at: http://www.scholarpractitionerjournals.com/article/assessment-nutritional-status-and-associated-factors-among-adult-tb-patients-directly

19. Haddad LB, Nour NM. Unsafe abortion: unnecessary maternal mortality. *Rev Obstet Gynecol.* (2009) 2:122–6.

20. Seyoum B, Demissie M, Worku A, Bekele S, Aseffa A. Prevalence and drug resistance patterns of mycobacterium tuberculosis among new smear positive pulmonary tuberculosis patients in Eastern Ethiopia. *Tuberc Res Treat.* (2014) 2014:753492. doi: 10.1155/2014/753492

21. Endalkachew K, Ferede YM, Derso T, Kebede A. Prevalence and associated factors of undernutrition among adult TB patients attending Amhara National Regional State hospitals, Northwest Ethiopia. *J Clin Tuberc Other Mycobact Dis.* (2022) 26:100291. doi: 10.1016/j.jctube.2021.100291

22. World Health O. The World health report: 2000: health systems: improving performance. Geneva: World Health Organization (2000).

23. FAO. *Guidelines for measuring household and individual dietary diversity*. Fao. (2010). p. 1–60.

24. Dargie B, Tesfaye G, Worku A. Prevalence and associated factors of undernutrition among adult tuberculosis patients in some selected public health facilities of Addis Ababa, Ethiopia: a cross-sectional study. *BMC Nutrition.* (2016) 2:7. doi: 10.1186/s40795-016-0046-x

25. WHO. *WHO policy on collaborative TB/HIV activities: guidelines for national programmes and other stakeholders*. (2012).

26. Deribew A, Deribe K, Dejene T, Tessema GA, Melaku YA, Lakew Y, et al. Tuberculosis Burden in Ethiopia from 1990 to 2016: evidence from the Global Burden of Diseases. *Study Ethiop J Health Sci.* (2018) 28:519–28. doi: 10.4314/ejhs.v28i5.2

27. Trivedi N, Abhijit G, Singh B, Anuj A, Sachin S, Anuj M, et al. Nutritional care and support for patients with tuberculosis: A review on guidelines issued by WHO. *Pharma Res.* (2013) 10:54–74. Available online at: https://apps.who.int/iris/handle/10665/94836

28. Soboka M, Tesfaye M, Adorjan K, Krahl W, Tesfaye E, Yitayih Y, et al. Effect of food insecurity on mental health of patients with tuberculosis in Southwest Ethiopia: a prospective cohort study. *BMJ Open.* (2021) 11:e045434. doi: 10.1136/bmjopen-2020-045434

29. Mulugeta M, Tiruneh G, Alemu ZA. Magnitude and associated factors of household food insecurity in Fedis Woreda East Hararghe zone, Oromia region, Ethiopia. *Agricult Food Secur J Agricult Exten Rur Develop.* (2018) 7:1–8. doi: 10.1186/s40066-017-0140-6

30. Tesfaye W, Seifu L. Climate change perception and choice of adaptation strategies. *Int J Clim Change Strateg Manage.* (2016) 8:253–70. doi: 10.1108/IJCCSM-01-2014-0017

31. Muse AI, Osman MO, Ibrahim AM, Wedajo GT, Daud FI, Abate KH. Undernutrition and associated factors among adult tuberculosis patients in Jigjiga Public Health Facilities, Somali Region, East, Ethiopia. *Res Rep Trop Med.* (2021) 12:123–33. doi: 10.2147/RRTM.S311476

32. von Elm E AD, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. *The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies* (2019).

33. Coates J, Swindale A, Bilinsky P. *Household Food Insecurity Access Scale (HFIAS) for measurement of food access: indicator guide: version 3*. (2007).

34. Jayasuriya NANL, Derore INK. *Food Security and Nutrition Among the Tuberculosis Infected Patients. A case study among patients at the chest clinic in Sri Lanka*. (2015).

35. CLAY. *Food security:concept and measurement. Paper for FAO Expert Consultation on Trade and Food security. Conceptualizing the Linkage, Rome July, 2002*. (2002).

36. FAO. *Hunger and Food Insecurity*. (2022).

37. Nhung NT, Van NTB, Van Cuong N, Duong TTQ, Nhat TT, Hang TTT, et al. Antimicrobial residues and resistance against critically important antimicrobials in non-typhoidal Salmonella from meat sold at wet markets and supermarkets in Vietnam. *Int J Food Microbiol.* (2018) 266:301–9. doi: 10.1016/j.ijfoodmicro.2017.12.015

38. Tomita A, Ramlall S, Naidu T, Mthembu SS, Padayatchi N, Burns JK. Major depression and household food insecurity among individuals with multidrug-resistant tuberculosis (MDR-TB) in South Africa. *Soc Psychiatry Psychiatr Epidemiol.* (2019) 54:387–93. doi: 10.1007/s00127-019-01669-y

39. Ayiraveetil R, Sarkar S, Chinnakali P, Jeyashree K, Vijayageetha M, Thekkur P, et al. Household food insecurity among patients with pulmonary tuberculosis and its associated factors in South India: a cross-sectional analysis. *BMJ Open.* (2020) 10:e033798. doi: 10.1136/bmjopen-2019-033798

40. Guadie FF, Assaminew PPJ. *Assessment of nutritional status and associated factors among adult TB patients on directly observed treatment of short course in health facilities at Adama Town, East Shewa Zone, Ethiopia*. (2016).

41. Botreau HC. Gender Inequalities and Food Insecurity: Ten years after the food price crisis, why are women farmers still food-insecure?. *RelReliefWeb.* (2019) 9:1. doi: 10.1016/bs.af2s.2020.09.001

42. Negesse A, Jara D, Temesgen H, Dessie G, Getaneh T, Mulugeta H, et al. The impact of being of the female gender for household head on the prevalence of food insecurity in Ethiopia: a systematic-review and meta-analysis. *Public Health Rev.* (2020) 41:15. doi: 10.1186/s40985-020-00131-8

43. Yohannes G, Wolka E, Bati T, Yohannes T. Household food insecurity and coping strategies among rural households in Kedida Gamela District, Kembata-Tembaro zone, Southern Ethiopia: mixed-methods concurrent triangulation design. *BMC Nutrition.* (2023) 9:4. doi: 10.1186/s40795-022-00663-z

44. Division CT. *Guidance document: nutritional care and support for patients with tuberculosis in India. Ministry of Health and Family Welfare New Delhi, India* (2017).

45. Sholeye OO, Animasahun VJ, Salako AA, Oyewole BK. Household food insecurity among people living with HIV in Sagamu, Nigeria: a preliminary study. *Nutr Health.* (2017) 23:95–102. doi: 10.1177/0260106017704798

46. Tadesse Tantu A, Demissie Gamebo T, Kuma Sheno B, Yohannis Kabalo M. Household food insecurity and associated factors among households in Wolaita Sodo town 2015. *Agriculture & Food Security.* (2017) 6:19. doi: 10.1186/s40066-017-0098-4

47. Sreeramareddy CT, Ramakrishnareddy N, Rahman M, Mir IA. Prevalence of tobacco use and perceptions of student health professionals about cessation training: results from Global Health Professions Students Survey. *BMJ Open.* (2018) 8:e017477. doi: 10.1136/bmjopen-2017-017477

48. Rehm J, Samokhvalov AV, Neuman MG, Room R, Parry C, Lönnroth K, et al. The association between alcohol use, alcohol use disorders and tuberculosis (TB). a systematic review. *BMC Public Health.* (2009) 9:450. doi: 10.1186/1471-2458-9-450

49. Strike C, Rudzinski K, Patterson J, Millson M. Frequent food insecurity among injection drug users: correlates and concerns. *BMC Public Health.* (2012) 12:1058. doi: 10.1186/1471-2458-12-1058

50. Sreeramareddy CT, Ramakrishnareddy N. Association of adult tobacco use with household food access insecurity: results from Nepal demographic and health survey 2011. *BMC Public Health.* (2017) 18:48. doi: 10.1186/s12889-017-4579-y

51. Hailu T. The conceptualization of khat, its production and its socio-economic implications in Eastern Ethiopia. *Int J Educ Cult Soc.* (2019) 4:54–9. doi: 10.11648/j.ijecs.20190403.12

52. Gudata ZG, Cochrane L, Imana G. An assessment of khat consumption habit and its linkage to household economies and work culture: the case of Harar city. *PLoS One*. (2019) 14:e0224606. doi: 10.1371/journal.pone.0224606

53. Ademe BW, Coates J, Dalsgaard A, Brimer L, Lema TB. Khat production and consumption; its implication on land area used for crop production and crop variety production among rural. *Household of Ethiopia*. (2017) 5:148–54. doi: 10.12691/jfs-5-4-5

54. Musuenge BB, Poda GG, Chen PC. Nutritional status of patients with tuberculosis and associated factors in the health centre region of burkina Faso. *Nutrients*. (2020) 12:9. doi: 10.3390/nu12092540

55. Alam K, Mahal A. Economic impacts of health shocks on households in low and middle income countries: a review of the literature. *Global Health*. (2014) 10:21. doi: 10.1186/1744-8603-10-21

56. Nhung NV, Hoa NB, Anh NT, Anh LTN, Siroka A, Lönnroth K, et al. Measuring catastrophic costs due to tuberculosis in Viet Nam. *Int J Tuberc Lung Dis*. (2018) 22:983–90. doi: 10.5588/ijtld.17.0859

57. Nuvey FS, Nortey PA, Addo KK, Addo-Lartey A, Kreppel K, Houngbedji CA, et al. Farm-related determinants of food insecurity among livestock dependent households in two agrarian districts with varying rainfall patterns in Ghana. *Jama*. (2022) 6:23. doi: 10.3389/fsufs.2022.743600

58. Anita Idel VF. Livestock production and food security in a context of climate change, and environmental and health challenges. *Germanwatch eV*. (2013).

frontiers | Frontiers in Public Health

TYPE Opinion
PUBLISHED 06 July 2023
DOI 10.3389/fpubh.2023.1194499

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Bassey Ebenso,
University of Leeds, United Kingdom

*CORRESPONDENCE
Adnan Ahmad Khan
✉ adnan@resdev.org

RECEIVED 27 March 2023
ACCEPTED 26 June 2023
PUBLISHED 06 July 2023

CITATION
Naz O, Ibrahim M, Mohiuddin AF, Khan AA and Samad Z (2023) Public health data quality and evidence use in developing countries: a call to action. *Front. Public Health* 11:1194499. doi: 10.3389/fpubh.2023.1194499

Public health data quality and evidence use in developing countries: a call to action

Olan Naz[1], Muhammad Ibrahim[1], Amal Fatima Mohiuddin[1], Adnan Ahmad Khan[1,2]* and Zainab Samad[3]

[1]Research and Development Solutions, Islamabad, Pakistan, [2]Data, Evaluations and Evidence for Policy (DEEP) Unit, Ministry of National Health Services, Regulations and Coordination, Islamabad, Pakistan, [3]CITRIC Health Data Science Center, Aga Khan University, Karachi, Pakistan

KEYWORDS

health policy, health information system, data quality (DQ), national survey data, program database, evidence use in policymaking

Introduction

The COVID-19 pandemic highlighted the importance of evidence-based decision-making. However, evidence-guided policy is not the norm in many low and middle-income countries (LMICs), either because the data is not available, or considered unreliable by policymakers who may also not be able to interpret them. Policies created without evidence lead to ineffective programs, wasted resources, and persistently poor health outcomes. Non-availability of high-quality and reliable survey or program data stems both from low capacity and resources to collect and manage data. Irrespective of the reasons, poor quality of data lowers the trust in data among decision makers, who then turn to personal choices and other means (read biases) to make decisions (1–3).

Quality of the data may be poor due to endogenous or institutional causes, such as poor systems or personnel capacity to collect, collate, manage, and process (i.e., analyze and use the results of analysis) accurate data. On the other hand, there may be exogenous constraints such as cultural barriers, lack of interest or awareness of data collection methods, or from a political economy that detracts from arriving at an accurate depiction of the situation on the ground (4). While the latter is a key "logjam" point in evidence use (5), we focus on endogenous constraints as critical entry points to evidence use. Both community surveys and program data that must ideally complement each other are discussed.

Surveys collect information from communities about the health status of populations, and the impact of social and other factors (including public health programs). In Pakistan, as in many other LMICs, several surveys inform about disease priorities that are identified by funding agencies and the government. These include the five-yearly Demographic and Health Survey (DHS), the biennial Pakistan Social and Living Standards Measurement (PSLM) survey and the sporadic Multiple Indicator Cluster Surveys (MICS) that inform against key health indicators at the national or provincial (DHS, PSLM) and district (MICS) levels. Other related datasets include the census that allows the placing of specific populations, including subgroups, on geographic maps, and individual research studies that may address specific questions.

Survey data

In surveys, while some disease priorities have been consistently replicated over time, key gaps remain. For example, almost all of surveys emphasize communicable diseases and reproductive health, while non-communicable diseases such as hypertension, diabetes, cardiovascular disease, and cancer are noticeably underrepresented. Sometimes priorities change, and questions and modules are dropped or changed in serial surveys, making it difficult to follow certain indicators over time. For example, the module on reasons for non-use of family planning has been changed between two subsequent rounds of DHS in Pakistan, going from reasons for not intending to use (2006–07), to reasons for discontinuation (2012–13 and 2017–18) (6–8). Similarly, information may be incomplete or missing from different surveys. For example, clear definitions of indicators are often not represented in the tools and in some instances relevant variables get omitted.

Data collection through survey questionnaires is always potentially subject to bias (sampling, social desirability, non-response, and recall, including reliance on self-reported behaviors or preferences), illogical variables, monitoring of data collection for quality, and human errors, such as poorly trained enumerators that miss the crux of the question being asked, or simply ignore some questions completely. Sampling issues include strategic omission of certain populations such as men, or worse, systematically passing over subgroups such as working men that are absent during the daytime (9). Other sampling issues include missing out of locations due to expediency or oversight. For example, the question of cost of contraceptives are consistently left unanswered in the DHS. Finally, how surveys are conducted, can account for seemingly similar surveys such as DHS and PSLM, that use the same sampling frame and similar sample size and questions, sometimes yielding highly discrepant indicators. For example, in 2007–08 the fully immunized child percentage was 47% in the DHS and 77% in the PSLM (10).

Program data

Program data informs the supply side of service delivery (public/private facilities). Typically, government health facility services are tracked in the District Health Information Software (DHIS), while supplies are tracked in the Contraceptive Logistics Management Information System (cLMIS) and Vaccine Logistics Management Information System (vLMIS). In addition, in Pakistan, and possibly in many other countries, private sector provides 75% or more of clinical services, with a substantial portion of services being delivered by large hospital and laboratory chains that can potentially be included in the data net.

Program data fair worse on quality. Such data are often collected by busy people who consider it a secondary responsibility to their primary tasks. Not surprisingly then, data are under or misreported, and one sees data missing for entire districts for some reporting periods. Such issues are worsened by the lack of oversight on program data quality at the site of entries or any feedback from more upstream users. Part of the lack of feedback comes from the fact that much of the reporting is done manually. For example, DHIS initial inputs are through paper-based forms filled once a month, relying on providers' recall of the different types of cases seen in the previous month. Even when such data have been entered, there is seldom feedback on outliers to provide corrections. More importantly, as in surveys, various sources of program data do not match. There are huge discrepancies (sometimes over 10-fold) between DHIS record of clients served and the commodities given during those services; or even between the two systems of contraceptive supply tracking that supposedly receive the same data from the same venues. Eventually, perhaps due to frustration with data issues, different provinces have resorted to their own systems. This causes further confusion as discrepancies, sometimes even definitions, are magnified.

Triangulation of datasets

A unique problem is consistency in measurement of outcomes between program vs. survey data. For example, in the cases of family planning and childhood immunization, huge differences exist between the magnitude of services from the program data and their supposed uptake as measured in community surveys. For example, the number of intrauterine contraceptive devices given out in 2017–18 was 300% more than the women who said they had received the device in the period in DHS 2017–18, when triangulating the proportion of self-described users against population census. Similar, albeit smaller, differences were present for all types of contraceptives.

Conclusion

In Pakistan, and possibly in other LMICs, use of evidence in health decisions and confidence of policy and decision makers can be boosted by establishing an "evidence use ecosystem." The evidence use ecosystem is a comprehensive framework that involves key stakeholders in the production and utilization of evidence to improve health outcomes in a systematic and integrated way (11). The system would receive data from the public and private services and laboratory outlets. It would have dedicated personnel in government, academia or think tanks, who routinely test data for quality through basic error checks and then triangulate different sources of data—to develop and track the overall picture of health and measure the performance of programs that promote it. There should be open and non-judgmental discourse about data quality at acquisition, transmission, and storage stages, as well as for the various analyses and reporting. Policy makers would be facilitated by professionals to understand the data, identify gaps, problems, their solutions, and ways to measure such solutions. These would include innovations such as alternatives to surveys to measure community outcomes, multi-database triangulation, and the use of artificial intelligence applications to predict, track, and control errors, and to make predictions such as forecasting of personnel, supplies, and even infrastructure needs. Ideally, such a system would be decentralized to allow compensation of periodic weaknesses of one or the other component and to avoid monopolization of information by a few actors.

Author contributions

AK contributed to the conceptualization of the study, acquired funding, and provided critical input for editing and validation of the manuscript. ZS provided valuable input in editing and validation. ON designed and wrote the initial draft of the manuscript, and provided substantial input to editing and refining. MI and AM provided valuable feedback, supervision, and contributed to the editing of the manuscript. All authors have made significant contributions to this piece and have approved the final submitted version.

Funding

This work has been funded by the Bill and Melinda Gates Foundation (INV 033854). The funding agency had no role in the development of this opinion piece.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. World Health O. *Data Quality Review: Module 1: Framework and Metrics*. Geneva: World Health Organization (2017).

2. Althubaiti A. Information bias in health research: definition, pitfalls, and adjustment methods. *J Multidiscip Healthcare*. (2016) 4:211–7. doi: 10.2147/JMDH.S104807

3. Hox JJ, Boeije HR. *Data Collection, Primary vs. Secondary*. Amsterdam: Elsevier Science (2005).

4. Munyoro I. Research data collection in challenging environments: barriers to studying the performance of Zimbabwe's parliamentary constituency information Centres (PCICs). Af J Inform Commun. (2018) 21:81–95. doi: 10.23962/10539/26111

5. Dodge S, Kieffer D, Repenning NP. Breaking logjams in knowledge work. *MIT Sloan Manag Rev*. (2018) 60:47–54.

6. National Institute of Population Studies—NIPS/Pakistan, ICF. *Pakistan Demographic and Health Survey 2017–18*. Islamabad: NIPS/Pakistan and ICF (2019).

7. National Institute of Population Studies—NIPS/Pakistan, ICF International. *Pakistan Demographic and Health Survey 2012–13*. Islamabad: NIPS/Pakistan and ICF International (2013).

8. National Institute of Population Studies—NIPS/Pakistan, Macro International. *Pakistan Demographic and Health Survey 2006–07*. Islamabad: NIPS/Pakistan and Macro International (2008).

9. Kjellsson G, Clarke P, Gerdtham UG. Forgetting to remember or remembering to forget: a study of the recall period length in health care survey questions. *J Health Econ*. (2014) 35:34–46. doi: 10.1016/j.jhealeco.2014.01.007

10. Statistics PBO. *Pakistan Social And Living Standards Measurement Survey (PSLM)*. Islamabad: Pakistan Bureau of Statistics (2006).

11. Shepherd JP. *How to Achieve More Effective Services: The Evidence Ecosystem*. Cardiff: What Works Network/Cardiff University (2014).

frontiers | Frontiers in Public Health

TYPE Methods
PUBLISHED 14 July 2023
DOI 10.3389/fpubh.2023.1208515

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Isain Zapata,
Rocky Vista University, United States
Wei Zhou,
Hunan University, China

*CORRESPONDENCE
Stefan Damerow
✉ damerows@rki.de

†These authors have contributed equally to this work and share first authorship

RECEIVED 19 April 2023
ACCEPTED 23 June 2023
PUBLISHED 14 July 2023

CITATION
Junker S, Damerow S, Walther L and Mauz E (2023) Development of a prototype for high-frequency mental health surveillance in Germany: data infrastructure and statistical methods.
Front. Public Health 11:1208515.
doi: 10.3389/fpubh.2023.1208515

Development of a prototype for high-frequency mental health surveillance in Germany: data infrastructure and statistical methods

Stephan Junker†, Stefan Damerow*†, Lena Walther and Elvira Mauz

Department of Epidemiology and Health Monitoring, Robert Koch Institute, Berlin, Germany

In the course of the COVID-19 pandemic and the implementation of associated non-pharmaceutical containment measures, the need for continuous monitoring of the mental health of populations became apparent. When the pandemic hit Germany, a nationwide Mental Health Surveillance (MHS) was in conceptual development at Germany's governmental public health institute, the Robert Koch Institute. To meet the need for high-frequency reporting on population mental health we developed a prototype that provides monthly estimates of several mental health indicators with smoothing splines. We used data from the telephone surveys German Health Update (GEDA) and COVID-19 vaccination rate monitoring in Germany (COVIMO). This paper provides a description of the highly automated data pipeline that produces time series data for graphical representations, including details on data collection, data preparation, calculation of estimates, and output creation. Furthermore, statistical methods used in the weighting algorithm, model estimations for moving three-month predictions as well as smoothing techniques are described and discussed. Generalized additive modelling with smoothing splines best meets the desired criteria with regard to identifying general time trends. We show that the prototype is suitable for a population-based high-frequency mental health surveillance that is fast, flexible, and able to identify variation in the data over time. The automated and standardized data pipeline can also easily be applied to other health topics or other surveys and survey types. It is highly suitable as a data processing tool for the efficient continuous health surveillance required in fast-moving times of crisis such as the Covid-19 pandemic.

KEYWORDS

COVID-19, mental health, surveillance, automatic, smoothing, trends, prediction, spline

1. Introduction

The COVID-19 pandemic and non-pharmaceutical interventions to reduce transmission of the virus as well as the societal discourse on the pandemic had far-reaching impacts on populations worldwide. Questions about the potential consequences for mental health arose from the beginning of the outbreak (1–3). As the pandemic unfolded, it became clear that it was a long-term stressor with many phases and sometimes rapid changes in circumstances (4). Therefore, ongoing and

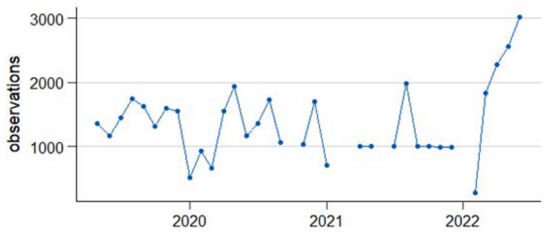


FIGURE 1
Observations per one-month period ranging from middle of the month to middle of the following month.

high-frequency monitoring of mental health and other outcomes was called for, and several public health institutions began tracking mental health indicators at regular intervals, including in the US (5), France (6), and England (7). Importantly, this type of continuous, temporally finer-grained surveillance comes with particular requirements for data processing, estimate calculation, and output for interpretation.

A nationwide Mental Health Surveillance (MHS) was in conceptual development at the Robert Koch Institute when the pandemic began in Germany (8). In line with the established concept of public health surveillance (9), the aim of the MHS is to regularly and systematically quantify core mental health indicators in order to provide information on the development of population mental health as a foundation for public health action. While this surveillance system was not yet in operation at the start of the pandemic and not initially conceived for high-frequency updates on mental health, we implemented a strategy for mental health monitoring using monthly data from a series of population-based telephone surveys of adults in Germany to meet new information needs arising in the pandemic. The particular aim of this high-frequency surveillance approach is to provide information on possible changes in population mental health almost as they unfold in order to enable policymakers and health care practitioners to respond swiftly for optimal health promotion and prevention, particularly in times of crisis.

The first survey that we used for high-frequency monitoring was the third wave of the European Health Interview Survey conducted as part of the study "German Health Update" (GEDA 2019/2020-EHIS) for Germany, which began data collection almost exactly 1 year before the outbreak of the pandemic (10). The study continued until January 2021, which was beyond the official end of GEDA 2019/2020 - EHIS. Even though the survey was not designed for monthly reporting, adjustments to sample weighting allowed for the calculation of monthly representative time-varying estimates of various health indicators, including symptoms of depression, as shown in previous reports by researchers at Robert Koch Institute (11, 12). Subsequently, data for high-frequency mental health monitoring has come from the studies "COVID-19 vaccination rate monitoring in Germany (COVIMO)" (13) as well as GEDA 2021 and GEDA 2022 (14), all of which were designed for monthly reporting given pandemic-related monitoring needs.

Data on several mental health indicators from these surveys was used to build a prototype for mental health surveillance of the adult population in Germany on the basis of graphically represented, continuously updated time series of monthly estimates. The prototype was developed to meet the following criteria:

1. Output should be updated to include the most recent available data as fast as possible, requiring a highly automated data processing and estimate calculation pipeline.
2. The results should be generalizable to the adult population in Germany.
3. It should be possible to analyze developments over time adjusted for demographic changes with regard to sex, age, and level of education.
4. It should be possible to compare sociodemographic subgroups by sex, age, and level of education, standardized and unstandardized for the respective other two characteristics.
5. The results should be as temporally fine-grained as possible.
6. Although our prototype's objective is to identify changes, it should not be overly responsive to minor and random fluctuations, as this would complicate the graphical interpretation. In other words, it necessitates the use of a technique for smoothing short-term fluctuations.
7. The results need to be in a format suitable for graphical presentation, for example via a dashboard.

In this paper, we describe the prototype comprising an automated data pipeline from data collection, data preparation, and calculation of estimates to output creation. Furthermore, the statistical methods used are described. These include a weighting algorithm, a linear and a logistic regression model used to make predictions on a standard population for a moving three-month window, and a generalized additive model (15) with smoothing splines employed to make predictions on a standard population for a weekly interval.

2. Methods

2.1. Data and software

The data used for the analyses are from telephone health surveys conducted on behalf of the Federal Ministry of Health (BMG) as part of the nationwide health monitoring program German Health Update (GEDA) (10, 14, 16, 17) and COVID-19 vaccination rate monitoring in Germany (COVIMO) (18). The number of observations per monthly period ranging from the middle of one month to the middle of the following month between April 2019 and April 2022 are shown in Figure 1.

SAS SE® software, version 17.1[1] is used for data management and data cleaning procedures as well as to perform adjustment weighting. All other data processing and some of the analysis steps are carried out in R version 4.1.2. (19), RStudio 2022.02.1.461 (20). Several

Abbreviations: COVIMO, COVID-19 Impfquoten Monitoring (COVID-19 vaccination rate monitoring); GAM, General Additive Model; GEDA, Gesundheit in Deutschland aktuell (German Health Update); MHS, Mental Health Surveillance.

1 SAS and all other SAS Institute Inc. product or service names are registered trademarks or trademarks of SAS Institute Inc. in the USA and other countries. ® indicates USA registration.

packages available for R are used. For data preparation and pipeline programming, dplyr 1.0.7 (21), rlang 0.4.12 (22), readstata13 0.10.0 (23), ISOweek 0.6–2 (24), and stringr 1.4.0 (25) are used. RStata (26) is used to transfer data back and forth between R and Stata. For analysis and prediction of the smoothing splines, mgcv 1.8.39 is used. The tool rmarkdown 2.11 (27–29) is used to structure analyses and graphs. We create the graphs with ggplot2 (30). Stata 17 (31) is used to estimate marginal predictions with confidence intervals on the basis of linear and logistic regression models.

2.2. Data pipeline

In order to meet the first criterion of promptly updating the output as soon as new data becomes available, we implemented a highly automated data pipeline. It consists of two parts, the data collection and quality assurance by the Epidemiological Data and Survey Center of Department 2 (EDC) of the Robert Koch Institute and external contractors as well as the data preparation and analysis for the purpose of mental health surveillance. In this section the work of the EDC is briefly summarized while the automated process for the MHS is laid out in more detail. At the end of the data pipeline estimation results are stored in a table format or as lists of tables, ensuring broad compatibility for further applications (criterion 7).

For the first part of the data pipeline, an external market and social research institute (USUMA GmbH) is contracted to conduct the telephone surveys, and provides the data to the EDC of the Robert Koch Institute. Figure 2 shows a simplified version of the data pipeline starting at the EDC.

Before the data is made available for analysis, the EDC performs standardized data editing and data quality assurance on the raw survey data. For example, implausible data is deleted or corrected, cases are cleaned, and new variables are generated (10). This only applies to data from the GEDA study, however. Because the COVIMO study was not integrated into the EDC's data editing and data quality assurance procedures, these were performed by the authors. Because the study is conducted using computer-assisted telephone interviews which already include filtering of questions and value range checks, data inconsistencies are rare and data editing is limited to very few cases. Weighting factors are provided by the EDC for both data sources. The data is then made available in Stata and SAS format.

After the data has been made available by the EDC, it is prepared for the specific calculations performed within the MHS. Because the aim is to update the results as fast as possible on the basis of continuously collected data, data preparation needs to be mostly automatic and flexible. Thus, several functions and scripts were developed in R to perform the following tasks: First, an object (tibble) is created encompassing all necessary metadata for the survey data files. The metadata contains information on the location of the data and information for data processing, including an identifier specifying the function used for further processing of this data file. There are automatic checks for new data or data updates in predefined folders. When new data becomes available in one of these folders, a new row is automatically added. If neither updated data nor new data is found, the data processing stops. If, however, one of the two criteria are met, the data files are prepared separately from each other by the specified function, a new metadata file is created and saved, and a list of data frames containing the data from the different surveys and survey waves is created and later unpacked to a single data frame. Data is imported in the form of Stata files. Predefined value labels are omitted as special characters or extensive value labels are error-prone in R.

To prepare the MHS survey data, data editing is done in two stages. In the first instance of data editing, variables are coded into a

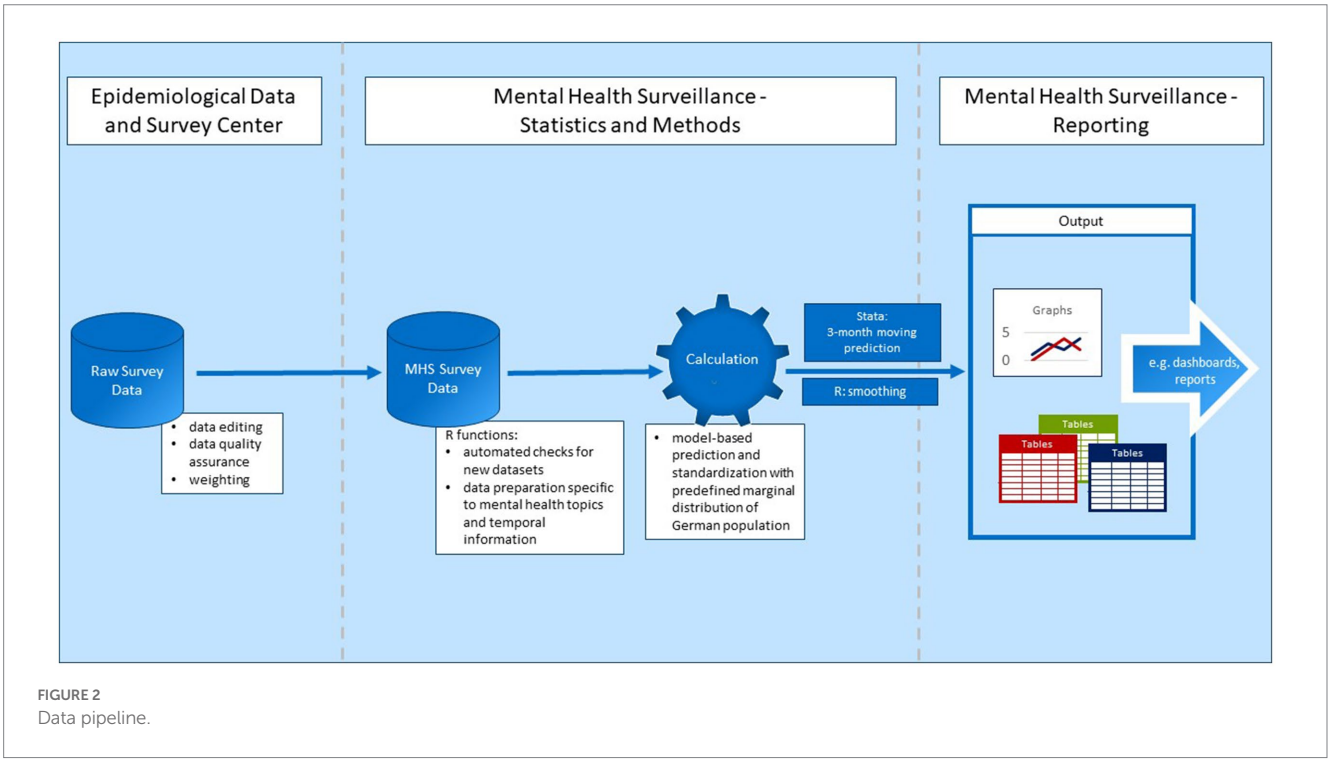


FIGURE 2
Data pipeline.

standard format within individual data frames including data from only one data file, as mentioned above. Individual data frames are used because different data sources require different forms of preparation. For example, some variables are already generated in one data file but not in the other, so this has to be done retroactively only for these data files. Also, time identifiers for the interview date differ in format between the data files. The newly created time identifiers include a standardized string variable identifying the calendar week of the interview following ISO-norm 8601 (32) and the interview month, here operationalized as middle of one month to middle of the following month (see section 2.3.2).

The second stage of data preparation begins after all data files are combined into one: this stage of data preparation includes the naming of the different levels of categorical variables and, most importantly, the creation of additional time variables. Weekly and monthly identifiers are further processed to include information on the whole time series from start to finish, including all data gaps, as date, ordered factor, and numeric variables counting the weeks and months from the start of the time series.

The next step of the data pipeline covers the calculation of adjusted predictions for each three-month period (statistical details section 2.3.2) and a smoothed curve on a weekly basis (statistical details section 2.3.3). As Stata's margin function is commonly used to estimate marginal predictions with confidence intervals, the calculation of the adjusted predictions is performed in Stata 17.1. For this purpose, every data frame contained in the abovementioned list is used to perform Stata calculations. We use the package Rstata (26) to facilitate communication and translation between R and Stata. This package enables initiation of Stata and the transfer of data frames from R to Stata. The created Stata files are then read back into R using the package readStata13. The calculation is performed with Stata do-files for linear and logistic regressions, including the calculations of margins, confidence intervals, and finally, the saving as a temporary data file. The required definitions of control variables, dependent variables, weights, and data used for predictions are managed with Stata macros which are specified in another do-file created with R. The Stata results are stored as a data frame including the predicted means and proportions (with confidence intervals) of the respective mental health indicator and the related time-identifying variables and stratification variables/levels. The estimates for the smoothed curves, on the other hand, are calculated in R because the smoothing algorithm used is included in the R package mgcv (33) and not implemented in Stata. The data frame including all data from the individual data files is used for this calculation.

The final step in the data pipeline is to save the output in the required formats. Because our major use case for further processing is the publication of the result on a dashboard, the results will eventually be saved in an SQL database with stratification by time as monthly and weekly smoothed data and the grouping parameters. At present, the dashboard is still in development, and the data is saved as an RData file. Plotting functions were programmed as add-ons to create publication-ready graphs in an R-Markdown file (27–29) using ggplot2 (30). They show the time series of three-month moving average predictions and the weekly smoothed curve for every mental health indicator stratified by sex, age group, or education standardized and unstandardized.

2.3. Statistical methods

This section details methods used for data weighting and output calculation within the semi-automated data pipeline described above. In what follows, the rationale behind these methods is briefly outlined. Subsequent sections describe different methodological steps and decisions in greater depth.

Criteria 2–5 specified above require that the prototype produce a temporally fine-grained output, representative estimates which can be compared over time, and standardized as well as unstandardized estimates for comparisons between the subgroups of interest. With the estimation of monthly weights by the EDC detailed in 2.3.1 below, fluctuations in participation between groups defined by regions, sex, level of education, and age over time can be addressed. Weighting also ensures representativity by approximating the German population and correcting for different probabilities by design.

The criterion of maximum temporal resolution and limitations of our dataset informed our first decision about the output calculation (see section 2.3.2): While producing a new estimate monthly would be desirable, our data includes too few observations in one-month periods for a direct estimation of monthly means and proportions: with a small monthly n, cell counts can simply be too low, and time series risk becoming noisy with random fluctuations. Data gaps and months with a particularly small number of observations pose added challenges. To base calculations on larger subsamples and thereby reduce the risk of random fluctuations, we opted to calculate estimates for moving three-month windows. This technique provides more observations for estimation, smooths time series by reducing random fluctuations, and still produces new estimates for every month.

Standardization between subgroups (criterion 4) as well as ensuring representativity and comparability (criteria 2 & 3) over time given the specific time windows used in analyses necessitates the use of regression modelling (see section 2.3.2) rather than a straightforward calculation of means and proportions. For standardization between the subgroups defined by one characteristic – for example sex – by the remaining two, we used predictions on a standard population (see section 2.3.4). Regression models including the sociodemographic characteristics as independent variables provided the foundation for standardization (34, 35). This procedure also ensures standardization across time when the official population distributions are changed within the EDC's weighting process. It acts as a secondary safeguard to address changes in distribution between the monthly samples, particularly when weights cannot be estimated for the exact time periods we used.

Sample means are sensitive to outliers and can be very sensitive to short-term fluctuations depending on sample size. For better separation of signal from noise (criterion 5) we considered several additional, less sensitive smoothing techniques and chose a thin plate smoothing spline because we found this method to strike a good balance between best fit and smoothing (see section 2.3.3). These choices and the methods are explained in more detail in the following sections.

2.3.1. Data weighting

Data weighting is necessary to meet criterion 2 ("The results should be generalizable to the adult population in Germany"). The EDC's data weighting procedure considers two aspects of sampling bias: (1) different selection probabilities of participants (design

weighting) and (2) different likelihoods of participaton within different population subgroups (adjustment weighting).

Despite random sampling in the sense that random phone numbers were dialed, study participants have different probabilities of having been selected into the samples at hand (selection probability). The telephone studies used here recruit participants via a dual-frame approach, using landline phone numbers and mobile phone numbers. The probability of drawing a specific phone number is a major part of the overall selection probability of each respective individual survey participant. In the mobile phone frame, the individual selection probability also depends on how many mobile phone numbers each participant has. In addition, the number of persons using the phone number called for recruitment plays into selection probability. The selection probability in the landline frame is also dependent on the probability of selecting a specific individual from each contacted household. This, in turn, is determined by household composition and household size. Design weighting compensates for the different selection probabilities of participants, in that persons with a lower selection probability represent more people from the population than persons with a higher selection probability. Due to data policy and data privacy reasons, information on sampling frame and household composition are not available to the EDC. The contracted market and social research institute therefore provides design weights calculated as described in Häder et al. (36). The weights are calculated independently for the GEDA and COVIMO studies.

Secondly, the probability of participation is not the same across participants because willingness to participate in a survey and reachability may differ according to characteristics such as region, age, sex, or level of education. With regard to the aim of assessing time trends, it is additionally important to note that the demographics of the sample might change over time or differ between time periods because participation probabilities for individuals from specific groups might vary with time, for example, due to external influences such as lockdowns and working from home. The different levels of participation may lead to biased results if these characteristics are associated with the target outcome. In adjustment weighting, the differences in willingness to participate are considered by matching the sample to the population distribution of selected characteristics. In more general terms, this means that the sample is calibrated on the basis of nonresponse in order to increase the precision of estimators. This requires variables that are captured in the survey and whose true population values are known. The population distributions are based on statistics from the Federal Statistical Office (Destatis) and the German Microcensus (37). The adjustment is carried out for each month in the GEDA19/20 survey and for each survey wave of the other surveys which approximately cover the period of one month. The adjustment weighting is performed in several iterative steps according to the so-called "raking" procedure (38), which are carried out repeatedly one after the other. The adjustment levels are described in Table 1.

It is possible that the number of observations in an adjustment level is small or zero. The calculation cannot handle empty adjustment cells because there must always be at least one observation to which the distribution can be fitted. In addition, an insufficient number of observations can lead to extreme values for the weighting factors. If the number of observations in an adjustment level for a time point is less than ten, a check is run as to whether the weighting factor values are zero or greater than a factor of ten. A weighting factor of zero cannot be used in analyses, since corresponding participants are thus practically excluded. On the other hand, participants with large weighting factors have excessive impact on the analyses. Another problem with a small number of observations in an adjustment cell is an endless iteration process in the raking procedure, which is here limited to 300 iterations. To address these problems arising from insufficient or zero observations in an adjustment cell, extreme values in the weighting factor, or an exceeded iteration limit, age groups are combined for the survey time point and adjustment level in question in order to increase the number of observations.

TABLE 1 Adjustment levels.

Level	Characteristics
1	Sex × age group (18–29, 30–39, 40–49, 50–59, 60–69, 70–79, and 80+ years of age)
2	Age group (18–29, 30–59, and 60+ years of age) × ISCED* (lower, middle with/without A-levels, high)
3	Nielsen Areas of Germany (Northwest, North Rhine-Westphalia, Center, East (North), East (South), Bavaria, Baden Wuerttemberg) × municipality size (rural, small-town, medium-town, metropolitan)
4	Federal state of Germany (combined: Schleswig-Holstein & Hamburg, Lower-Saxony & Bremen, Saarland & Rhineland-Palatinate, Brandenburg & Mecklenburg-Western Pomerania, Saxony-Anhalt & Saxony & Thuringia) × age group (18–39, 40–59, and 60+ years of age)

*UNESCO Institute for Statistics (2012) International Standard Classification of Education: ISCED 2011. UIS, Montreal, S. 8.

Missing values in any of the variables relevant for weighting are not permissible in the weighting procedure. Therefore, these must be assigned to a category or imputed. For education (ISCED), missing data are assigned to the middle category. Missing values in the self-declaration of federal state are imputed automatically, according to the distribution of federal states in Germany. Missing values in the political municipality size category are imputed based on the respective distribution in the federal state.

The adjustment weighting is performed with SAS SE software, version 17.1, using predefined syntax and macros for the raking procedure and distributional checks. It is performed after the data editing and quality assurance by the EDC.

2.3.2. Linear and logistic regressions for three-month windows

The time series that this prototype outputs encompass monthly estimates; specifically, monthly predicted mean values or proportions based on Stata's margins function for three-month windows. Periods of data collection within the surveys used for the prototype happen to begin roughly in the middle of the respective months. To optimize the number of cases per month, a monthly period is therefore defined as the middle of a month to the middle of the following month.

Linear and/or logistic regression models are fitted for each mental health indicator as the basis for prediction. In order to avoid bias due to changes in sociodemographic factors sex, age, and level of education between the monthly time periods and for the prediction of stratified values, the regression models include a list of covariates. For each individual i the linear regression model for metric mental health indicators is defined as:

10.3389/fpubh.2023.1208515

$$Y_i = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_j x_{ji} = B^T X_i^a \quad (1)$$

and the logistic regression model for binary mental health indicators is defined as:

$$\text{logit}(Y_i) = \beta_0 + \beta_1 x_{1i} + \cdots + \beta_j x_{ji} = B^T X_i^b \quad (2)$$

where $B = (\beta_0, \beta_1, \ldots, \beta_j)$ is a vector of regression parameters and X_i^a and X_i^b are vectors of auxiliary covariates. The latter includes age groups, sex, and level of education as well as their interactions. The covariates of interaction differ between the linear and logistic regression models: the linear regression (1) includes all combinations of age group, sex, and education (X_i^a), while the logistic regression (2) contains only two-way interactions (X_i^b) because otherwise, cells with zero observations are very likely to occur and prevent marginal prediction.

Some of the mental health indicators show a small prevalence of cases as defined by cutoffs, particularly within certain subgroups. For example, in one three-month period (centered on May/June 2021), 4% of men screened positive for possible anxiety disorder. Given the relatively small numbers of cases per survey month, this necessitated estimation for a three-month period rather than a one-month period in order to minimize random fluctuations (criterion 6). Following the procedure of centered moving averages (39), the observations from the previous and following month are defined as the period for the corresponding month. As the moving three-month windows overlap, regressions are separately fitted for each three-month window based exclusively on observations within it. Thus, for a survey period with M months, $t = 1 \ldots M$ separate regressions model estimates will be derived. At the beginning and at the end of a survey or due to interruptions during the survey, it is not always possible to sum up three months for each estimate in the time series. In these cases, the estimation is calculated based on two months if observations of at least two of the three months are available. The model results are then used for average predictions on a standard population as described below.

2.3.3. Smoothing

The method of moving predictions is an intuitive way to smooth a time series (criterion 6). However, this smoothing technique is still very sensitive to outliers and might lead to overfitting the data and noisy time series from which the actual trajectory is difficult to detect (40). To prevent overfitting and thus misinterpretation due to random fluctuations, another smoothing technique is applied to our time series. Another disadvantage associated with the moving three-month windows is their limited utilization the available temporal information. The temporal information used is whether an observation falls within a given three-month window or not, disregarding its placement within that timeframe.

While sample size restricts the temporal resolution of the estimates, the data contains information down to the level of weeks. When time is not segmented into periods, but treated as a continuous variable, this information can be used despite small sample size at that level. In light of continuous data collection and the requirement of automatic output creation as well as its function in facilitating the interpretability of the time series output, the following criteria for smoothing were determined:

1. The smoothing technique needs to work automatically without manual specifications.
2. To ensure the accuracy of interpretation the smoothed curve should not introduce bias by either being overfitted to the data or oversmoothing and thus failing to capture important developments. Ideally, there is an objective criterion for optimization.
3. The smoothed curve has to be as stable as possible for time points in the past when new data is added but still be locally adaptive.

Several candidate smoothing techniques were considered on the available data: polynomials, restricted cubic regression splines, and smoothing splines. Polynomials did not fulfill the criteria because the curve is not smoothed locally. A polynomial function defines the shape of the curve globally. For example, a quadratic function will always produce an (inverted) "U"-shaped curve. Thus, an adaption of the curvature at some regions of the curve always necessitates a change in the whole curve. Also, this technique requires a decision about the ideal degrees of the polynomials with every new time point as well as checks for fit to data to prevent substantial changes in the curve for the previous point in the time series when new time points are added. A way to automate the determination of the ideal degree of the polynomial is to treat it as a tuning parameter and use cross validation: the model is fitted to one part of the data, and then the prediction is evaluated on another part of the data, for example using the root mean square error. This process is iterated for a predefined choice of values. However, this process is computationally time consuming and might still lead to substantial changes for the existing time series when a time point is added. Restricted cubic regression splines are locally adaptive as the function is fitted to different parts of the curve marked by knots. The regions before the first and after the last knot are restricted to linearity as the splines often show erratic behavior in these regions. The knots between which the function is fitted need to be defined and potentially manually adapted when new data points are added (41, 42). The necessity to make choices regarding the number of knots and their placement poses a disadvantage to a process that aims to be highly automated. One possibility, however, is to use a fixed number of knots with a default placement. Stone (43) showed that five knots should be sufficient for most scenarios a recommendation for default placement of knots is provided by Harrell (44).

As another method, we considered smoothing splines. Unlike cubic regressions they do not require knots; instead, a smoothing parameter controls the smoothness. We chose a smoothing spline with the basis function of a thin plate spline over other smoothing spline approaches because it is both theoretically well-founded and particularly suited to our needs given that the approximations developed by Simon Wood (42) made thin plate regressions computationally efficient so that they can also be used for large data sets. This technique has a very good level of accuracy, though the curves produced are not as smooth as other automatic smoothers (45). The smoothing parameter can be estimated automatically and simultaneously with the whole model by either using restricted maximum likelihood (REML) or generalized cross validation (46). This is a major advantage because it enables automatic estimation and avoids any manual presetting such as defining knots or degrees of

polynomials. Thus, over-and underfitting to the data can be avoided without defining different choices of parameters for cross-validation. As generalized cross validation is prone to undersmoothing, we chose REML (46–48).

In order to determine the more suitable spline to use between restricted cubic splines and thin plate smoothing splines, we examined their behavior on recent time periods when new data was added. As mentioned in the criteria, data points added to the time series should only have a limited effect on preceding estimates. Also, the longer the calculations date back, the less pronounced the changes should be. We expected the smoothing splines to better meet this criterion because it is the ideal smoothing parameter that changes with new data, not the placement of knots, which we expected to have a higher impact. Moreover, the restricted cubic splines are restricted to linearity before and after the first and last knot, making abrupt changes more likely. We tested this hypothesis with data for a brief depression screening instrument, the Patient Health Questionnaire-2 (PHQ-2) (49). We simulated the addition of new data every week starting with a time series spanning 10 weeks (see Figure 3). For both the smoothing and the cubic spline, we see that new data changes the course of the curve. However, for the restricted cubic splines, it takes more updates for the estimates to change to fit to the later course of the curve. This is the case, for example, at the end of 2020 and the beginning of 2021 in the time series. The trend adapts with the addition of a single week of new data using smoothing splines, whereas this takes several weeks using the cubic spline (Figure 3).

To examine the overall behavior of the two techniques we also plotted the curve with the two different splines for the entire observation period (see Figure 4). Although the general trends remain consistent, the smoothing spline provides a more detailed view. This in itself is neither an advantage nor a disadvantage; however, as the smoothing spline technique provides a mechanism against under-and overfitting, it seems that the restricted cubic spline underfits or oversmooths the data. Thus, the smoothing splines meet our criteria best.

To allow for separate smooths for different sociodemographic groups, we used factor-by-curve interactions (50) or varying-coefficient models (51). The thin-plate splines were then used as part of a general additive model (GAM) (15) specified as follows in pseudo-code:

$$Y = s\left(week,\ by = interaction\left(agegroup,\ sex,\ education\right)\right) + agegroup * sex * education$$

2.3.4. Prediction and standardization

In order to obtain standardized outcomes for the mental health indicators, the results are not estimated with the actual survey data, but with a standard population. This allows for direct standardization between time periods and between subgroups defined by sex, age, or level of education. For example, estimates for different age groups are adjusted for differences in sex and level of education (criteria 3 and 4). The estimates from the linear and logistic regression models as well as the general additive models for Gaussian and binomial distributions based on the survey data described above are used for these predictions on a standard population. The standard population is derived based on the latest available German microcensus data containing the population distribution by age group, sex, and education. The time series presented below were estimated using 2018 microncensus data (52).

This standard population is the basis for weekly and three-month predictions. The predictions are then averaged over the whole population as well as within each population subgroup by sex, age group, and level of education. Therefore, this method ensures standardization for age, sex and level of education over time. Consequently, older predications will undergo changes when the standard population is updated.

For direct standardization between the subgroups, predictive margins (35, 53) are calculated. The only difference to the procedure described above is that the standard population is used for each subgroup, treating all the rows as belonging to the subgroup in question. For example, predictions for the male population treat all individuals in the standard population as if they were male and vice versa for the female population

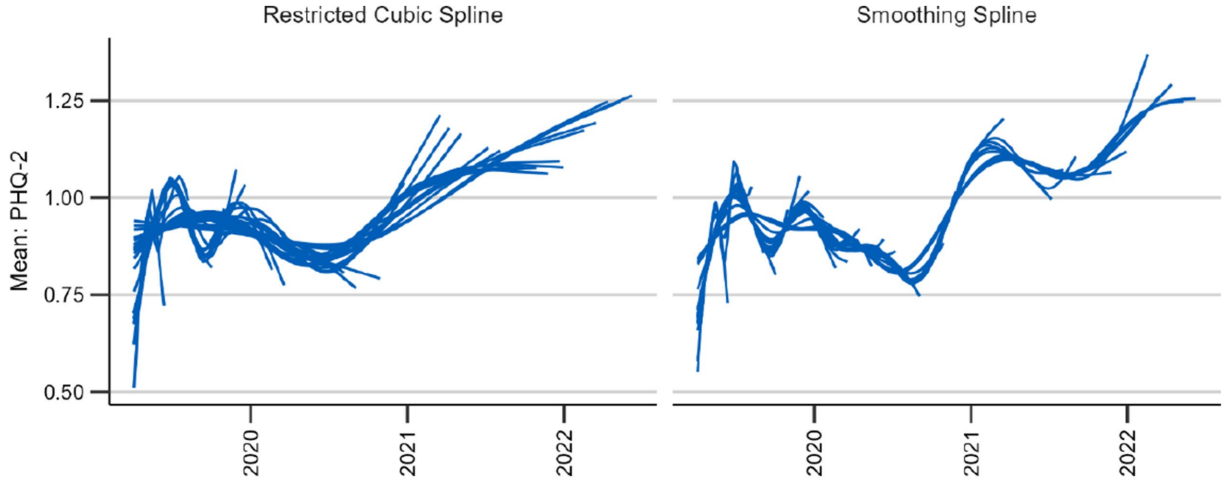


FIGURE 3
Behavior of two candidate splines with 39 updates every 4 weeks beginning after 12 weeks.

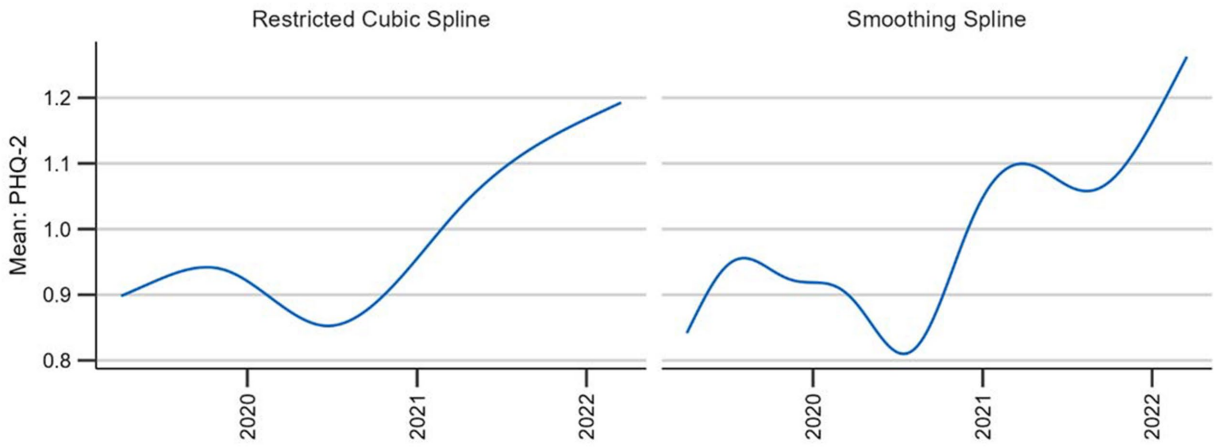


FIGURE 4
Comparison of two candidate splines across the entire observation period.

(54). The Stata command "margins" is used for both the prediction with and without standardization between subgroups because the estimation of confidence intervals is already integrated into this command. With low or high prevalence, the confidence intervals estimated by the delta method may produce lower limits beyond zero and upper limits exceeding one. This is why resulting confidence intervals are constructed by means of a logit transform (55) using the undocumented command "coef_table, citype (logit)."

For the predictions of weekly values for the smoothed curve we wrote an R function using the following formula from Graubard and Korn (53):

$$PM(r) = \frac{\sum_{i=1}^{S} w_i g\left(r, Z_i, \hat{\theta}\right)}{\sum_{i=1}^{S} w_i},$$

where g(r, Z, $\hat{\theta}$) is the predicted value which depends on $\hat{\theta}$ the survey weighted estimator for the model parameters, Z_i the S distinct values of the covariates for which the distribution in the external distribution is known, and r the value of the subgroup for which the mean or proportion is to be be predicted. When the prediction is standardized between subgroups, the weighting factor w_i represents the number of individuals in the standard population with a distinct value of Z_i. In case of an unstandardized prediction, the weighting factor only includes weights with distinct values of the covariates in subgroup r. For prediction of the whole population without stratification r can be removed from the formula.

As the calculation of confidence intervals of predictive margins with GAMs and survey design is beyond the scope of our project, only the point estimates are calculated.

2.3.5. Missings

Missings are handled differently depending on the type of variable. While only interviews with information on sex and age are included in the sample, level of education is imputed by assigning missing values to the middle category, in accordance with the weighting procedure described above. Observations with missing values in the mental health indicator are excluded from analysis. If patterns of missingness in these variables are dependent on age, sex, education, or their interactions, exclusion should not result in bias because the estimation controls for these factors.

3. Results

With the prototype described above, it is possible to provide automatic updates of time series with each survey wave and produce graphical representations of the development of mental health indicators for Germany's population [please see (56) for results]. To generate monthly estimates, data from moving three-month windows is used for the calculation of a linear or logistic regression model adjusting for age group, sex, and level of education.

This three-month window moves along one month at a time for the calculation of the next three-month estimate until the last month with observations enters the window. If only one month is missing in the three-month window, calculations are still performed; if two months are missing, no calculations are performed and there is a gap in the time series. The visual output of these three-month average predictions is intuitively understandable to non-experts and has the benefit of providing discrete estimates for specific intervals. They also include confidence intervals, which provide important information for visual inspection.

Figure 5 shows the predicted three-month averages and proportions for the time series monitoring depressive symptoms measured using the PHQ-2. Comparing these two time series, the most apparent difference is that there are fewer estimates for the proportions. This is due to empty cells which are more likely to occur with a dichotomous predictor. Using mean values therefore has the advantage of producing time series with fewer interruptions. By contrast, proportions have the advantage of being easier to interpret because they are based on a validated cutoff point indicating potential

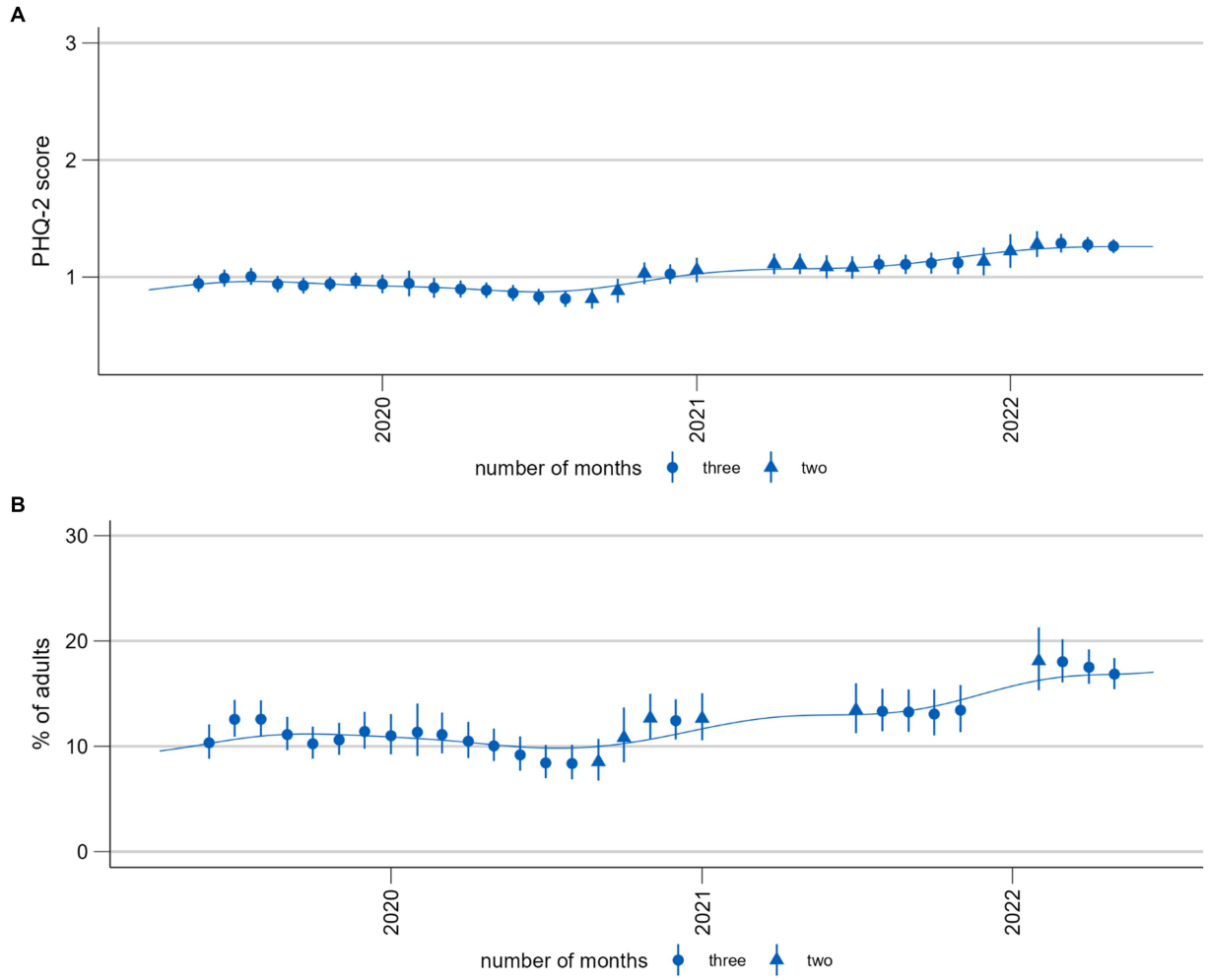


FIGURE 5
Time trends of symptoms of depression (PHQ-2). **(A)** Population mean (range 0–6). **(B)** Proportion of population screening positive for possible depression (PHQ-2 > 2). Please note that these time series are presented here for the purposes of illustrating and discussing a methodological approach. Please see another study for the results of these analyses (56).

clinical significance (57). Although the technique of a moving average results in some smoothing, further aids in the visual differentiation between signal and noise would be beneficial, particularly with regard to stratified results (see Figure 6).

This illustrates the need for a technique which provides more smoothing without overfitting. The addition of smoothing splines facilitates the differentiation between signal and noise to identify trends. An additional benefit is that all available temporal information is used to estimate the curve, providing information at a higher temporal resolution. However, with shorter time series such as the self-rated mental health time series [Figures 7C,D, measured using a single item (58)], this additional temporal information smooths the time series less effectively than the moving three-month averaged predictions: the smoothing curves reflect fluctuations between monthly estimates, which the moving averages, by definition, are unable to show at the same temporal resolution. For shorter time series with low cell counts such as the time series for the screening instrument Generalized Anxiety Disorder-2 [GAD-2, (59)] (Figures 7A,B), the general additive model fails to provide interpretable results for proportions; however, continued data collection may resolve this problem. Otherwise, the model specifications may need to be revised by reducing the number of interactions.

While smoothing curves can ease interpretation for sufficiently long time series, the method is not intuitively understood by those not trained in the field of statistics. Furthermore, there is no straightforward way to estimate confidence intervals for the predictions made with the GAM model. The confidence intervals would need to account for uncertainty arising from the estimation of the smoothing parameter and for survey design. There are existing approaches to capturing uncertainty in the estimation of the smoothing parameter. These include the utilization of Bayesian intervals (60, 61) and simultaneous calculation of confidence intervals (62). However, an approach also incorporating uncertainty from the survey design does not exist to the authors' knowledge. As the motivation for calculating smoothing curves was to support a better interpretation of the moving averages, we did not aim to resolve this issue. Instead, point-wise confidence intervals are provided for each of the three-month predictions.

The interpretation of time trends should be derived from both the three-month moving estimates and the smoothed curve using their respective strengths. For example, in Figure 5, the moving averages

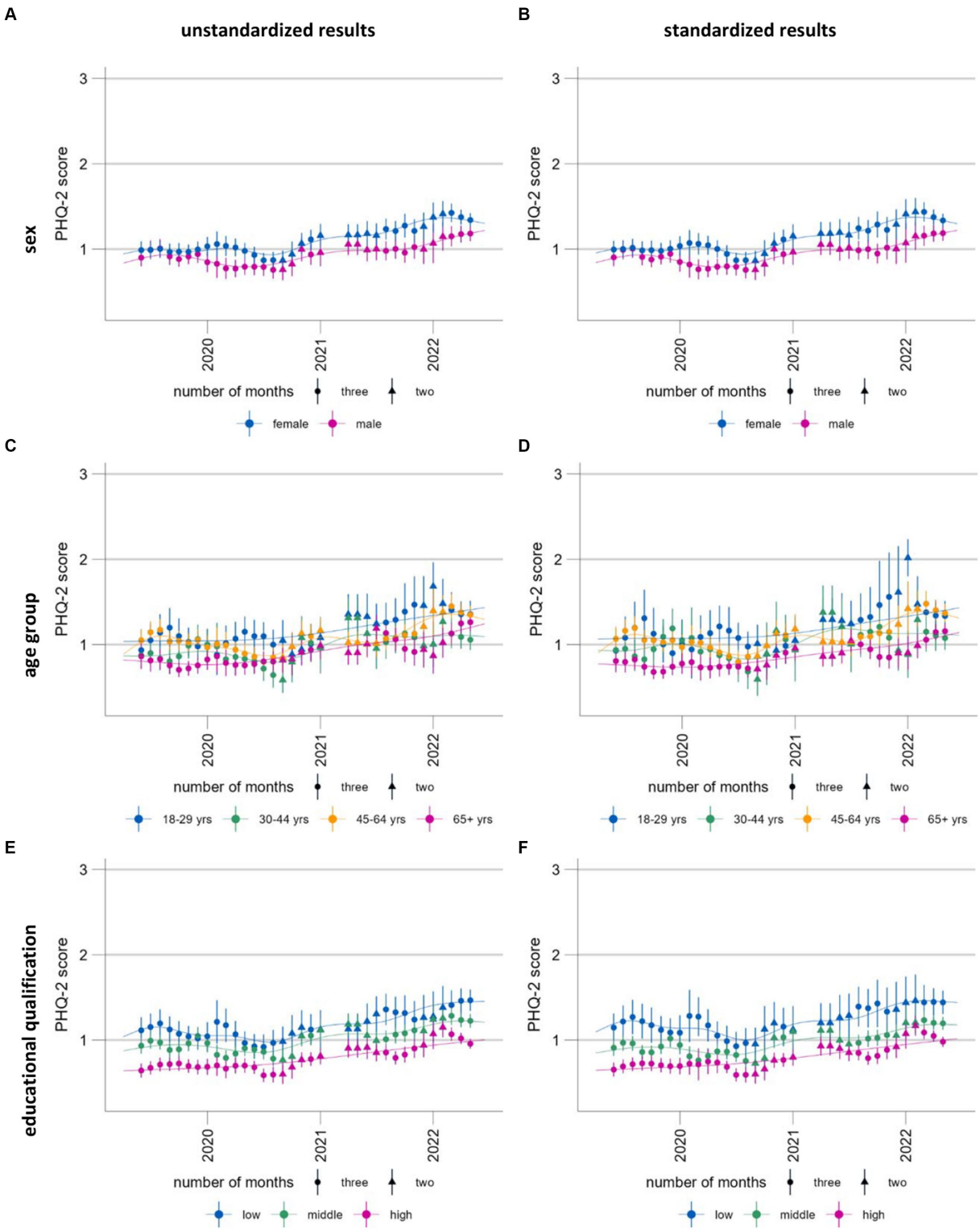


FIGURE 6
Time trends of symptoms of depression (population mean PHQ-2, range 0–6) stratified and standardized or unstandardized by sex **(A, B)**, age group **(C, D)** and educational qualification **(E, F)**, standardized **(A, C, E)** and unstandardized results **(B, D, F)**. Please note that these time series are presented here for the purposes of illustrating and discussing a methodological approach. Please see another study for the results of these analyses (56).

allow for a better visual detection of change points: While the curve shows a steady increase between July/August 2022 and end of 2022, the moving averages show that the development was actually more consistent until the end of the year and only increased then. The strength of the smoothing splines is the visual identification of trends when fluctuation is high (Figure 6).

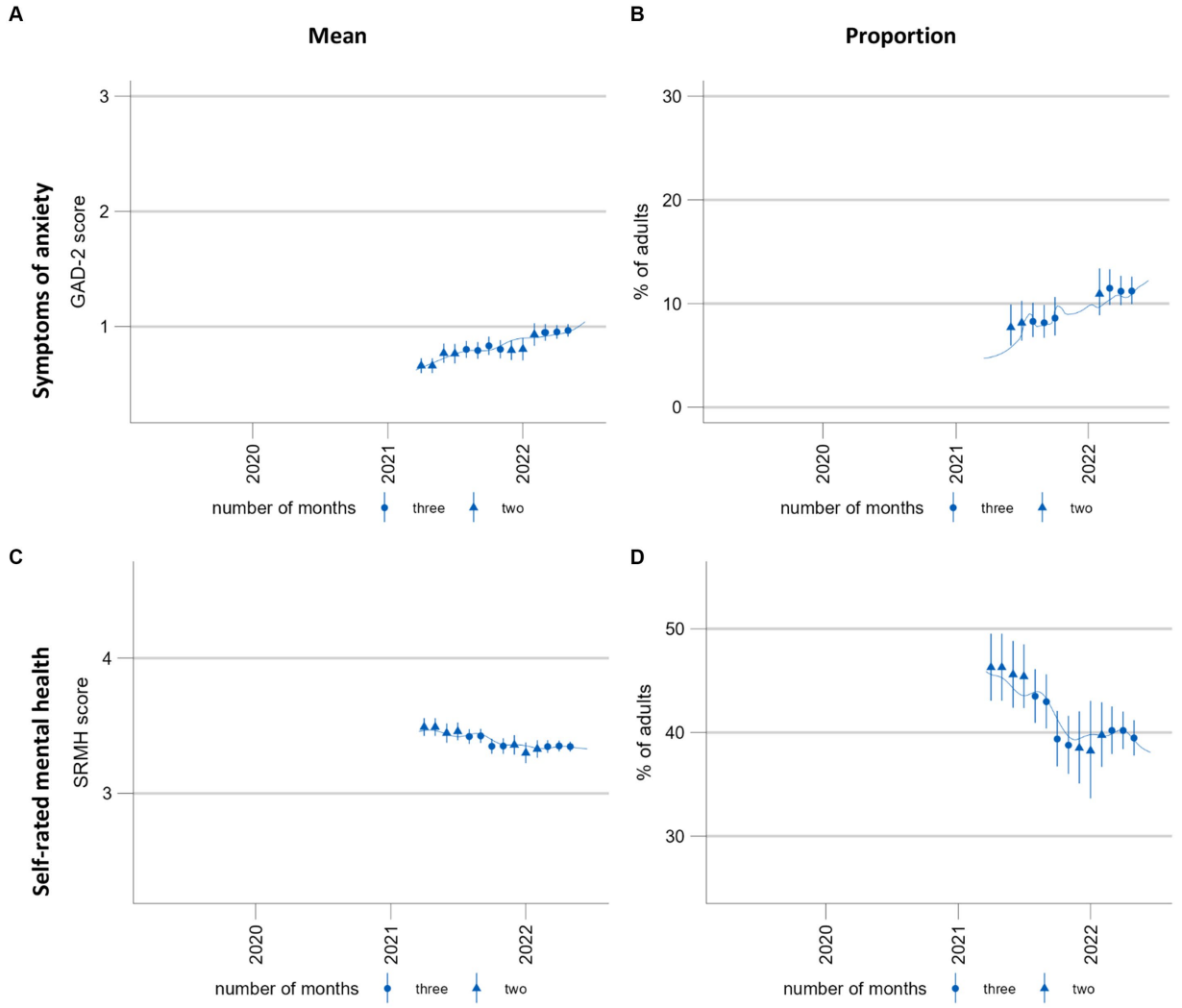


FIGURE 7
Time trends of symptoms of anxiety and self-rated mental health. **(A,C)** population mean GAD-2 scores (range 0–6) and mean SRMH scores (range 1–5), respectively. **(B,D)** show the proportion of the population screening positive for possible anxiety disorder at a GAD-2 score of >2 and those rating their own mental health "very good" or "excellent," respectively. These time series are presented here for the purposes of illustrating and discussing a methodological approach. Please see another study for the results of these analyses (56).

The predictions with a standard population ensure that the estimates can be directly standardized between the subgroups but also between the different time periods. Figure 6 shows the standardized and unstandardized stratified results. With our data, the differences are minimal; however, this might change with different data sources. While the unstandardized time series can be used to examine the development in real population subgroups, the standardized results can be used to better identify vulnerable groups. Both outputs provide important information for the planning of interventions for mental health promotion and prevention.

4. Discussion

The COVID-19 pandemic brought about a need for high-frequency monitoring of developments in the mental health of populations. Against this background, we expanded our range of strategies for a Mental Health Surveillance in Germany to include monthly reporting on a small set of indicators aiming to provide policymakers and practitioners in the health care system with high-frequency updates on developments in population mental health in order to enable swift public health action. We defined six criteria for the prototype presented in this paper and developed an infrastructure which creates new estimates as soon as new data becomes available (criterion 1). At present, data processing has to be initiated manually. However, the checks for new data could easily be automated using a task manager. With the programmed ggplot functions, graphical output can also be created automatically. The estimates are in a format and structure that can easily be fed into further applications such as databases and dashboards (criterion 7). The weighting procedure developed by the EDC allows for representative estimates for the adult population in Germany (criterion 2). As an additional safeguard against deviations between the sample distribution and the population distribution, the estimation procedure includes predictions based on

the latest available estimates of the German population. This technique also allows for standardization between subgroups and over time (criteria 3 and 4). To ease graphical interpretation, the prototype produces two types of output. First, it calculates moving three-month predictions which can be considered as moving averages. Moving averages are intuitively understood and provide some smoothing of the data, but are still sensitive to short-term fluctuations. To facilitate the differentiation between signal and noise and make trends more visible, a smoothing curve is also calculated (criterion 6). The techniques developed also address our problem of few observations per month and temporal gaps in the data while optimizing temporal resolution (criterion 5). Our prototype therefore fulfills the criteria specified and is in use within the MHS (56).

The adaption of this prototype to other surveys is straightforward if the survey design remains the same over time and data has been adequately prepared for further processing. Basic data cleaning is not included in the data pipeline because the prototype was built for data from telephone surveys conducted by the EDC of the Robert Koch Institute, and initial processing of the raw data is handled within this established framework. However, the prototype does include individual scripts to homogenize the different surveys used (GEDA19/20, COVIMO, GEDA 2021, GEDA 2022). Thus, new scripts for other data sources can easily be added within the existing framework.

However, caution is warranted in the application of the prototype to multiple data sources. Minor changes in the main scripts suffice to adapt the analyses to changes in sampling designs (for example, multiple-stage sampling). However, the prototype cannot be as easily modified for other changes in survey design or data collection that might influence sample composition over time. In other words, the potential impacts of changes in data source on results should be carefully considered in applying this prototype.

Because the prototype performs prediction and standardization using a predefined marginal distribution of the German population, it includes a procedure that can correct for biases due to different study participation probabilities in certain population groups. As a consequence it can be used on unweighted data. The marginal distributions of the population used can easily be replaced by the latest or most appropriate available versions of public statistics. However, so far, the models employed for prediction are only adjusted for age group, sex, and level of education. If data is, for example, oversampled for people with a history of migration, the implemented procedure will not correct for this. Furthermore, it should be noted that a modification of the marginal distribution used for prediction and standardization will change results for the entire time series. While this ensures standardization between years, it should be noted that estimates are representative of the population only for the respective microcensus year. To achieve population representative estimates for all years in the time series, the prototype can be modified to standardize separately for each year using the respective microcensus datasets and not for the whole time series.

In the further development of the prototype, greater flexibility for the covariates should be an aim. For example, age or education groups have to be customizable for the expansion of this type of mental health surveillance for children and adolescents. This is also relevant for applications of the prototype to other health topics which might require stratification by different levels or different characteristics. A few adjustments were already made in the application of the prototype to the assessment of developments in child and adolescent mental health using data from the study "Kindergesundheit in Deutschland aktuell" [German Children's Health Update, (63)].

We encountered several difficulties owing to data transformation between SAS, STATA, and CSV throughout the calculation process. The implementation of STATA's margins command, including our specific use case, in R would reduce the variety of different data types to be processed This translation would need to cover the following three steps: first, the integration of probability weights for model estimation and for prediction; second, the calculation of confidence intervals for the means of the predictions; and third, the calculation the logit transformed confidence interval. A promising solution could be the R package marginal effects (64), which could potentially be integrated in the future.

As a smoothing technique to facilitate visual interpretation of the time series, we decided to use a general additive model with a smoothing thin plate spline. It produces curves that rapidly adapt to new trends emerging from new data, which also means that predictions for time periods further in the past do not change abruptly. Furthermore, the smoothing parameter of the spline can be estimated, resulting in a curve which neither over-nor underfits the data, whereas the cubic regression spline seems to excessively smooth and thus underfits. However, neither type of spline offers an advantage over the three-month predictions for short time series: they tend to be too sensitive to short-term changes in shorter time series to provide a sufficiently smoothed fit. We aim to further monitor the development of smoothing curves in these time series and define criteria for the length of time series at which the weekly smoothed predictions can be reported alongside the moving three-months average predictions.

A caveat in combining two representations of time series – a thin plate smoothing spline and three-month average estimates – is that there is more and potentially conflicting information to take into consideration in the process of visual interpretation. These two representations can come apart because the smoothing spline is estimated independently of average predictions for the three-month windows and estimated on weekly data in order to use all available temporal information and to achieve a curve without edges. This serves as a robustness check against overinterpretation of (random) changes in the three-month estimates. While the spline is sometimes inferior to the three-month moving averages when the goal is to visually detect change points, it is superior in separating signal from noise when there are large fluctuations in the estimated moving averages.

5. Conclusion

The high-frequency surveillance of health indicators using survey data can help enable rapid and flexible responses to ongoing changes in population health, particularly in times of crises. However, using survey data to assess health developments at frequent intervals poses unique data processing and analysis challenges. The prototype presented here was designed to overcome these challenges and to provide automatic monthly updates on multiple indicators on the basis of relatively small monthly samples. It will continue to serve as a basis for high-frequency surveillance of mental health within the MHS at the Robert Koch Institute (see 8) and may potentially be applied to high-frequency surveillance in other areas of health in the future. The prototype's output is highly suitable for publication and regular updates on a dashboard, which is the next aim within the MHS. The precondition, however, is ongoing continuous data

collection. While there are numerous possibilities for the further development of the prototype, some of which have been addressed above, the described approach as it stands may be of use to other researchers in public health implementing a similar type of surveillance.

Data availability statement

The datasets presented in this article are not readily available because the population-based data from the German health monitoring program that were used for the development of the prototype presented here are available from the Robert Koch Institute (RKI) but restrictions apply to the availability of these data. The data sets cannot be made publicly available because informed consent from study participants did not cover public deposition of data. However, a minimal data set is archived in the Health Monitoring Research Data Centre at the RKI and can be accessed by all interested researchers. On-site access to the data set is possible at the Secure Data Centre of the RKI's Health Monitoring Research Data Centre. Requests to access the datasets should be directed to fdz@rki.de.

Ethics statement

The studies involving human participants were reviewed and approved by GEDA and COVIMO are subject to strict compliance with the data protection provisions set out in the EU General Data Protection Regulation (GDPR) and the Federal Data Protection Act (BDSG). Participation in the study was voluntary. The participants were informed about the aims and contents of the study and about data protection. Informed consent was obtained verbally. In the case of GEDA 2019/2020, the Ethics Committee of the Charité-Universitätsmedizin Berlin assessed the ethics of the study and approved the implementation of the study (application number EA2/070/19). Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

SD and SJ developed the analysis methods in the paper. SJ mainly scripted the automatic pipeline while SD was in charge of the weighting procedure described in the paper. SD drafted the sections 3.2.1 and 3.2.2. SJ wrote the sections 2, 3.1, 3.2, 3.2.3, 3.2.4 and the Introduction. SD and SJ wrote section 3.2.5 together. Sections 1, 4 and 5 were written by LW, SD, and SJ. LW also edited and commented on all sections extensively. EM also commented on all sections and was in charge of the project. All authors contributed to the article and approved the submitted version.

Funding

The "MHS – Set-up of a National Mental Health Surveillance at Robert Koch Institute" project has been funded by the Federal Ministry of Health (Grant Number: Chapter 1504 Title 54401). The studies GEDA 2019/20, GEDA 2021, COVIMO an GEDA 2022 were funded by the Robert Koch Institute and the German Federal Health Ministry.

Acknowledgments

We would like to thank all colleagues of the Epidemiological Data Center (EDC) who provide us with quality-assured data on a monthly basis especially Jennifer Allen, Sabine Born and Ronny Kuhnert. Further we want to thank our colleagues from the statistics working group at our department of the Robert Koch Institute. Last but not least we thank Silke Beyhl for the design of Figure 2.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. United Nations. *Policy brief: COVID-19 and the need for action on mental health*. New York: United Nations (2020) Available at: https://unsdg.un.org/resources/policy-brief-covid-19-and-need-action-mental-health.

2. Holmes EA, O'Connor RC, Perry VH, Tracey I, Wessely S, Arseneault L, et al. Multidisciplinary research priorities for the COVID-19 pandemic: a call for action for mental health science. *Lancet Psychiatry*. (2020) 7:547–60. doi: 10.1016/S2215-0366(20)30168-1

3. Choi KR, Heilemann MV, Fauer A, Mead M. A second pandemic: mental health spillover from the novel coronavirus (COVID-19). *J Am Psychiatr Nurses Assoc*. (2020) 26:340–3. doi: 10.1177/1078390320919803

4. Schilling J, Buda S, Tolksdorf K. Zweite Aktualisierung der "Retrospektiven Phaseneinteilung der COVID-19-Pandemie in Deutschland". *Epidemiologisches Bulletin*. (2022) 10:3–5.

5. Jia H, Guerin RJ, Barile JP, Okun AH, McKnight-Eily L, Blumberg SJ, et al. National and state trends in anxiety and depression severity scores among adults during the COVID-19 pandemic-United States, 2020-2021. *MMWR Morb Mortal Wkly Rep*. (2021) 70:1427–32. doi: 10.15585/mmwr.mm7040e3

6. Santé publique France. *Covi Prev: une enquête pour suivre l'évolution des comportements et de la santé mentale pendant l'épidémie de COVID-19* (2022) Available at: https://www.santepubliquefrance.fr/etudes-et-enquetes/coviprev-une-enquete-pour-suivre-l-evolution-des-comportements-et-de-la-sante-mentale-pendant-l-epidemie-de-covid-19

7. Office for Health Improvement and Disparities. Wider impacts of COVID-19 on health (WICH) monitoring tool In: *Mental Health and Wellbeing: office for Health Improvement and Disparities* (2022) Available at: https://analytics.phe.gov.uk/apps/covid-19-indirect-effects/#

8. Thom J, Mauz E, Peitz D, Kersjes C, Aichberger M, Baumeister H, et al. Establishing a mental health surveillance in Germany: development of a framework concept and indicator set. *J Health Monit*. (2021) 6:34–63. doi: 10.25646/8861

9. Choi BC. The past, present, and future of public health surveillance. *Scientifica (Cairo)*. (2012) 2012:875253:1–26. doi: 10.6064/2012/875253

10. Allen J, Born S, Damerow S, Kuhnert R, Lemcke J, Müller A, et al. German health update (GEDA 2019/2020-EHIS) – Background and methodology (2021) 6:66–79. doi: 10.25646/8559

11. Damerow S, Rommel A, Prütz F, Beyer A-K, Hapke U, Schienkiewitz A, et al. Developments in the health situation in Germany during the initial stage of the COVID-19 pandemic for selected indicators of GEDA 2019/2020-EHIS. *J Health Monit*. (2020) 5:3–20. doi: 10.25646/7172.2

12. Damerow S, Rommel A, Beyer A-K, Hapke U, Schienkiewitz A, Starker A, et al. Health situation in Germany during the COVID-19 pandemic. Developments over time for selected indicators of GEDA 2019/2020 – an update. *J Health Monit*. (2022) 3, 7:2–19. doi: 10.25646/9883

13. Robert Koch-Institut & Usuma Markt-und Sozialforschung. COVIMO-COVID-19 Impfquoten-Monitoring in Deutschland In: *Bundesweite Bevölkerungsbefragung im Rahmen der Durchführung von telefonischen Ad-hoc-Befragungen für das Robert Koch-Institut*: Methodenbericht (2022) Available at: https://www.rki.de/DE/Content/InfAZ/N/Neuartiges_Coronavirus/Projekte_RKI/COVIMO_Reports/covimo_methodenbericht.pdf?__blob=publicationFile

14. Robert Koch-Institut. *Gesundheit in Deutschland Aktuell (GEDA)* (2022). Available at: https://www.rki.de/DE/Content/Gesundheitsmonitoring/Studien/Geda/Geda_node.html

15. Hastie T, Tibshirani R. Generalized additive models. *Stat Sci*. (1986) 1, 14:297–310.

16. Kurth B-M, Lange C, Kamtsiuris P, Hölling H. *Gesundheitsmonitoring am Robert Koch-Institut*. Robert Koch-Institut; (2009) *52*, 557–570.

17. Lange C, Jentsch F, Allen J, Hoebel J, Kratz AL, von der Lippe E, et al. Data resource profile: German health update (GEDA)—the health interview survey for adults in Germany. *Int J Epidemiol*. (2015) 44:442–50. doi: 10.1093/ije/dyv067

18. Robert Koch-Institut. *COVIMO–COVID-19 vaccination rate monitoring in* Germany: Robert Koch-Institut (2022). Available at: https://www.rki.de/EN/Content/infections/epidemiology/outbreaks/COVID-19/projects/covimo.html.

19. R Core Team. *R: a language and environment for statistical computing*. Vienna, Austria: R Foundation for Statistical Computing (2021).

20. RStudio Team. *RStudio: integrated development environment for R*. Boston, MA: RStudio, PBC (2022).

21. Wickham H, François R, Henry L, Müller K. *Dplyr: a grammar of data manipulation. R package version 1.0.7 ed* (2021).

22. Henry L, Wickham H. *Rlang: Functions for base types and Core R and 'Tidyverse' features. R package version 0.4.12 ed* (2021).

23. Marvin GJ, Jeworutzki S. *readstata13: Import 'Stata' data files. R package version 0.10.0 ed* (2021).

24. Block U. *ISOweek: week of the year and weekday according to ISO 8601. R package version 0.6–2 ed* (2011).

25. Wickham H. *Stringr: simple, consistent wrappers for common string operations. R package version 1.4.0 ed* (2019).

26. Braglia L. *RStata: a bit of glue between R and Stata. R package version 1.1.1. ed* (2016).

27. Allaire J, Xie Y, McPherson J, Luraschi J, Ushey K, Atkins A, et al. *Rmarkdown: dynamic documents for R. R package version 2.11 ed* (2021).

28. Xie Y, Allaire J, Grolemund G. *R markdown: the definitive guide*. Chapman and Hall/CRC (2018).

29. Xie Y, Dervieux C, Riederer E. *R markdown cookbook*. Chapman and Hall/CRC (2020).

30. Wickham H. *ggplot2: elegant graphics for data analysis. 2nd* ed. New York: Springer-Verlag (2016).

31. Stata Corp. *Stata statistical software: release 17*. College Station, TX: Stata Corp LLC (2021).

32. International Organization for Standardization. ISO 8601:2004 (en) Genf (2004) Available at: https://www.iso.org/obp/ui/#iso:std:iso:8601:en

33. Wood SN. *Generalized additive models: an introduction with R. 2nd* ed. Boca Raton, Florida: Chapman and Hall/CRC (2017).

34. Muller CJ, MacLehose RF. Estimating predicted probabilities from logistic regression: different methods correspond to different target populations. *Int J Epidemiol*. (2014) 43:962–70. doi: 10.1093/ije/dyu029

35. Lane PW, Nelder JA. Analysis of covariance and standardization as instances of prediction. *Biometrics*. (1982) 38:613–21. doi: 10.2307/2530043

36. Häder S, Sand M. Telefonstichproben In: S Häder, M Häder and P Schmich, editors. *Telefonumfragen in Deutschland*. Wiesbaden: Springer Fachmedien Wiesbaden (2019). 113–51.

37. Schwarz N. The German microcensus. *Schmollers Jahr*. (2001) 121:649–54. doi: 10.3790/schm.121.4.649

38. Lumley T. *Complex surveys: A guide to analysis using R*. Hoboken, New Jersey: John Wiley & Sons (2011).

39. Hyndman RJ. Moving Averages In: M Lovric, editor. *International encyclopedia of statistical science*. Berlin, Heidelberg: Springer (2011). 866–9.

40. Dey B. *Open data science [internet]* (2018). [cited 17.06.2022].

41. Perperoglou A, Sauerbrei W, Abrahamowicz M, Schmid M. A review of spline function procedures in R. *BMC Med Res Methodol*. (2019) 19:46. doi: 10.1186/s12874-019-0666-3

42. Wood SN. Thin plate regression splines. *J R Stat Soc Series B*. (2003) 65:95–114. doi: 10.1111/1467-9868.00374

43. Stone CJ. [generalized additive models]: comment. *Stat Sci*. (1986) 1:312–4. doi: 10.1214/ss/1177013607

44. Harrell FE. *Regression modeling strategies: With applications to linear models, logistic regression, and survival analysis*. New York: Springer (2001).

45. Breiman L, Peters S. Comparing automatic smoothers (a public service Enterprise). *Int Stat Rev*. (1992) 60:271–90. doi: 10.2307/1403679

46. Wood SN. Fast stable restricted maximum likelihood and marginal likelihood estimation of semiparametric generalized linear models. *J R Stat Soc Ser B*. (2011) 73:3–36. doi: 10.1111/j.1467-9868.2010.00749.x

47. Reiss PT, Ogden RT. Smoothing parameter selection for a class of semiparametric linear models. *J R Stat Soc Ser B*. (2009) 71:505–23. doi: 10.1111/j.1467-9868.2008.00695.x

48. Berry LN, Helwig NE. Cross-validation, information theory, or maximum likelihood? A comparison of tuning methods for penalized splines. *Stats*. (2021) 4:701–24. doi: 10.3390/stats4030042

49. Löwe B, Kroenke K, Gräfe K. Detecting and monitoring depression with a two-item questionnaire (PHQ-2). *J Psychosom Res*. (2005) 58:163–71. doi: 10.1016/j.jpsychores.2004.09.006

50. Coull BA, Ruppert D, Wand MP. Simple incorporation of interactions into additive models. *Biometrics*. (2001) 57:539–45. doi: 10.1111/j.0006-341X.2001.00539.x

51. Hastie T, Tibshirani R. Varying-coefficient models. *J R Stat Soc Ser B*. (1993) 55:757–79. doi: 10.1111/j.2517-6161.1993.tb01939.x

52. RDC of the Federal Statistical Office and Statistical Offices of the Federal States. doi: 10.21242/12211.2018.00.00.3.1.1

53. Graubard BI, Korn EL. Predictive margins with survey data. *Biometrics*. (1999) 55:652–9. doi: 10.1111/j.0006-341X.1999.00652.x

54. Stata Corp. margins. *Stata 17 base reference manual*. College Stattion, TX: Stata Press (2021).

55. Stata Corp. *Svy: Tabulate twoway: Two-way tables for survey data. Stata 17 survey data reference manual*. College Station, TX: Stata Press; (2021). p. 150–170.

56. Mauz E, Walther L, Junker S, Kersjes C, Damerow S, Eicher S, et al. Time trends in mental health indicators in Germany's adult population before and during the COVID-19 pandemic. *Front Public Health*. (2023) 11:11. doi: 10.3389/fpubh.2023.1065938

57. Kroenke K, Spitzer RL, Williams JBW. The patient health Questionnaire-2: validity of a two-item depression screener. *Med Care*. (2003) 41:1284–92. doi: 10.1097/01.MLR.0000093487.78664.3C

58. Ahmad F, Jhajj AK, Stewart DE, Burghardt M, Bierman AS. Single item measures of self-rated mental health: a scoping review. *BMC Health Serv Res*. (2014) 14:398. doi: 10.1186/1472-6963-14-398

59. Kroenke K, Spitzer RL, Williams JBW, Monahan PO, Löwe B. Anxiety disorders in primary care: prevalence, impairment, comorbidity, and detection. *Ann Intern Med*. (2007) 146:317–25. doi: 10.7326/0003-4819-146-5-200703060-00004

60. Nychka D. Bayesian confidence intervals for smoothing splines. *J Am Stat Assoc*. (1988) 83:1134–43. doi: 10.1080/01621459.1988.10478711

61. Marra G, Wood SN. Coverage properties of confidence intervals for generalized additive model components. *Scand J Stat*. (2012) 39:53–74. doi: 10.1111/j.1467-9469.2011.00760.x

62. Simpson GL. Modelling Palaeoecological time series using generalised additive models. *Front Ecol Evol*. (2018) 6:6. doi: 10.3389/fevo.2018.00149

63. Robert Koch-Institut *Kindergesundheit in Deutschland aktuell: Robert Koch-Institut*; (2023). Available at: https://www.rki.de/DE/Content/Gesundheitsmonitoring/Studien/Kida/kida_node.html

64. Arel-Bundock V. *Marginaleffects: marginal effects, marginal means, predictions, and contrasts. 0.7.0 ed* (2022).

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 19 July 2023
DOI 10.3389/fpubh.2023.1198928

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Si Ying Tan,
National University of Singapore, Singapore
Adeel Nasir,
Lahore College for Women University, Pakistan

*CORRESPONDENCE
Zangyi Liao
✉ cu192043@cupl.edu.cn

RECEIVED 02 April 2023
ACCEPTED 05 July 2023
PUBLISHED 19 July 2023

CITATION
Gao Q, Hu Y, Liao Z and Yao L (2023) Cyber-infrastructure and epidemic precautionary policy: evidence from China.
Front. Public Health 11:1198928.
doi: 10.3389/fpubh.2023.1198928

Cyber-infrastructure and epidemic precautionary policy: evidence from China

Qiuming Gao[1], Youlong Hu[1], Zangyi Liao[2]* and Lu Yao[1]

[1]Business School, China University of Political Science and Law, Beijing, China, [2]School of Political Science and Public Administration, China University of Political Science and Law, Beijing, China

Introduction: The application of technology supported by cyber infrastructure has emerged as a critical factor influencing city management. This study aims to investigate whether the development of cyber infrastructure can enhance cities' confidence in responding to potential epidemic threats in the context of COVID-19.

Methods: China serves as a good example for both COVID-19 management and smart city construction. We take advantage of a special time point, the 2022 Chinese New Year, to observe cities' precautionary epidemic policies. We utilize choice models and data from 188 Chinese cities to examine the impact of internet coverage on the degree of policy relaxation.

Results: We found that cities with higher internet coverage tend to adopt looser policies. In the benchmark regression, for every 1 percentage point increase in internet coverage, the likelihood of implementing loose measures increases by 0.9 percentage points. This result remains robust across different classifications of policies. We also addressed potential endogeneity issues by using the instrumental variables method.

Discussion: Our study indicates that effective management of epidemics in the modern era requires not only the utilization of traditional medical resources but also the incorporation of new city features, such as information technology infrastructure.

KEYWORDS

precautionary policies, cyber infrastructure, epidemic, COVID-19, China

1. Introduction

Public health events caused by epidemics have been plaguing and accompanying global social development (1). Since the enactment of the International Health Regulations in 2007, the World Health Organization has declared seven Public Health Emergencies of International Concern, including the COVID-19 pandemic. As a result, precautionary policy-making has become a significant topic in the field of public health. With the improvement of targeted vaccines and drugs, research attention has gradually shifted from focusing on the COVID-19 virus to understanding how we can learn from the experiences of epidemic management in order to effectively address future threats. Large-scale public health events are characterized by the rapid spread and strong pathogenicity of the viruses, whose impact extends beyond the health system. Consequently, responding to such events can hardly rely on medical measures alone, but necessitates the implementation of non-medical interventions and the synergy of the

various economic and social resources behind them. In this context, how the development of city infrastructure may affect the decisions on precautionary policies, has become a matter of concern.

Each outbreak of a pandemic urges lessons to be learned. Existing literature has predominantly focused on intervention policies (2–4). For the precautionary or preventive measures, attention has been given to the institutional mechanism. For instance, based on the observation of SARS outbreak, Smith noted that non-medical interventions can affect public risk perception which leads to severe economic consequences, and thus management mechanisms on risk perception need to be established in advance (5). In the context of the H1N1 pandemic, Baekkeskov compared vaccination approaches between the Netherlands and Denmark. He found that since decisions about public health events are usually faced with urgent decision-making under uncertainty, it was crucial to pre-establish relevant public health management norms (6). The Ebola outbreak in West Africa emphasized the urgent need for establishing emergency mechanisms in both the local healthcare system and international aid efforts (7, 8). These studies address the importance of preset management mechanisms, but the factors and local endowments that determine the eventual adoption of such mechanisms have not been fully explored.

An important factor influencing city development in recent years has been the application of information and intelligence technology supported by internet infrastructure (9). Just as it has had a profound impact on the industrial sector, information and intelligence technology has also played a significant role in urban governance. This impact can be seen not only in enhancing the quantity and efficiency of public service delivery, reducing administrative procedures and time costs, but more importantly, in helping governments collect and analyze large amounts of data for more accurate and scientific policy-making (10–12). Data-driven policy making is increasingly valued by governments and has been proved to play a role in a wide range of areas (13). Furthermore, the connection on the internet has also led to changes in the way social resources are coordinated. The establishment of digital platforms enables information sharing between government agencies and citizens as well as external stakeholders, providing diverse and interactive channels of communication and integration between parties (14, 15).

So does the improvement of cyber infrastructure also help to increase the confidence of cities in dealing with potential epidemic outbreaks? China serves as a good example to observe this issue. China adopted a strict management policy aiming at achieving zero cases during the COVID-19 epidemic, which allowed the country to maintain a very low number of infections during the prevalence of the Delta variant (Figure 1). During this period, the primary concern for most city governments was not how to implement medical or non-medical interventions, but rather how to take precautions against potentially possible outbreaks. The preventive measures adopted by each city reflected their local adaptation based on city characteristics. At the same time, cities in China are also actively engaged in smart city construction (16). Internet coverage, a major indicator of cyber infrastructure, has experienced rapid growth in recent years (Figure 2). Information and intelligence technology applications have permeated various aspects of municipal management (17).In the management of COVID-19 confirmed cases and risk-exposed populations, new technologies merge as a powerful addition to the epidemic management toolbox and are used to provide broad social

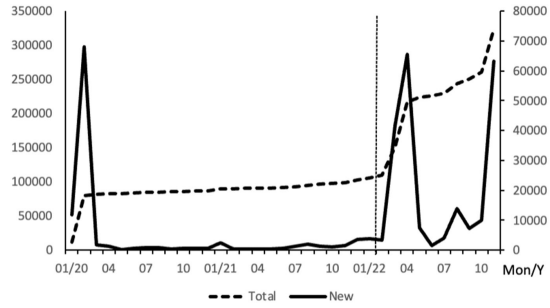


FIGURE 1
New COVID-19 cases in China monthly from Jan 2020 to Nov 2022. National Health Commission of China. data summed from 31 provinces and province-level municipalities.

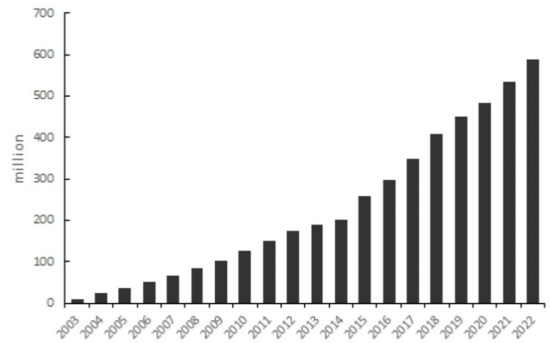


FIGURE 2
Growth in Internet users in China since 2003. Statistical Bulletin of National Economic and Social Development, Statistical Bulletin of China's Communication Industry Development.

coordination support, which differs from the situation during the SARS period in 2003 (18).In this context, it presents an opportunity for us to empirically test the relationship between cyber infrastructure and the cities' precautionary policy choices.

This paper examines the impact of internet infrastructure on COVID-19 preventive policy choices based on data from 188 cities in China. We take advantage of a special time point, the 2022 Chinese New Year (vertical line in Figure 1), when large-scale population movement was anticipated. We identify policy differences based on the measures implemented prior to the movement. We found that cities with higher internet coverage tend to adopt looser preventive measures. This result is robust across different classifications of management measures. To address possible endogeneity problems, we employ the instrumental variables method and include additional control variables, and the conclusion remains unchanged. Our study shows that the epidemic management in the new era relies not only on traditional medical resources but also on new city features such as information technology conditions. The importance of the latter may even surpass that of certain medical infrastructure, such as hospital beds.

The possible contributions of this paper are as follows: first, it verifies the role of cyber infrastructure in the formulation of precautionary policies in the context of COVID-19, thus adding to the lessons learnt from COVID-19 prevention and control. We address

the significance of non-medical technology factor asides from that of the traditional health care facilities. Second, it presents new findings on the influencing factors for epidemic preventive policy-making, which has direct policy implications. Third, our research provides new empirical evidence for the impact of smart city construction in the field of public health, thereby supplementing the existing literature on urban studies.

The rest of this paper is organized as follows: section two provides the background and sorts out the ways in which information and intelligence technology plays a role in epidemic management; Section three describes the research methodology and data; Section four reports the empirical results and includes discussions on robustness and endogeneity. Finally, section five concludes.

2. Background

2.1. China's COVID-19 management measures

Some studies have divided the development stages of the COVID-19 pandemic in China from different time points and perspectives (19, 20). From the perspective of preventive and control measures, China's anti-epidemic policy can be divided into three stages. The period before March 2020 is the Emergency phase. In the face of the sudden outbreak of the epidemic, this stage aimed to swiftly exterminate the virus in its early stages. Rigorous and comprehensive control measures were implemented such as the lockdown of key cities and the nationwide shutdown of work and production. These measures aimed to sever all possible routes of human-to-human and human-to-object transmission by temporarily suspending economic and social activities (21). Due to the limited knowledge of the new virus's transmission in the initial stage, the control measures during this stage were of a very high standard and highly coordinated nationwide. However, these measures came at the cost of substantial loss of economic and social activities and were therefore taken as short-term interim approaches to explore the effective way of managing a new virus (19). The second stage is the Regular management stage from April 2020 to December 2022.With an improved control system and increased vaccine coverage, the objective of this phase was to establish a mechanism for epidemic prevention and control that could minimize disruptions to economic and social development. The focus shifted from rapid eradication to prevention. This stage emphasizes a science-based approach and targeted measures. On the one hand, when cases occurred, the regions and populations that required control measures were gradually refined and narrowed down, making them more precise. On the other hand, monitoring and prevention methods, mainly based on nucleic acid testing, were promoted to replace the control measures implemented after cases arose, helping to balance between economic and social development and epidemic management. Our analysis of epidemic prevention policies is mainly based on this stage. After December 2022, since the dominant epidemic strain transitioned from the previous Delta variant to the new Omicron variant, which is characterized by strong infectivity but weak pathogenicity, control measures and large-scale monitoring measures previously set were replaced in this third stage.

In the formulation of COVID-19 prevention and control system in China, the central authority and local authorities perform respective duties. The *Joint Prevention and Control Mechanism of the State Council* (JPCM), established by the State Council on January 20, 2020, led by the National Health Commission and composed of 32 ministries and commissions, is at the core to coordinate the national epidemic prevention and control efforts. It issues national guidelines for epidemic management measures. The decisions are made based on the *Protocol on Prevention and Control of COVID-19* issued by the National Health Commission. This medical technical guidebook has been updated ten versions by the end of 2022 and provides definitions, treatment methods, and management criteria for infected and high risk-exposed populations. According to the medical protocol and combined with the experience found in practice, JPCM provides guidance at the nation level on the management of key population groups, locations and organizations. It also establishes binding rules that must be followed by all local regions, such as specifying the exact quarantine measures and duration for close contacts with the virus. Local authorities at the provincial, municipal and county levels are responsible for their local epidemic prevention and control respectively, setting localized measures under the requirements of the central authorities and bearing the responsibility for any local epidemic outbreak (22). During the Emergency stage, almost all local authorities adopted rigorous control measures out of prudence, resulting in a relatively uniform approach nationwide, while in the Regular stage, their measures showed greater variation. The JPCM also encourages policy localization with local characteristics. It identified the best practices initiated by individual local communities and promoted them as common standards nationwide. For instance, the health QR code, which was widely used across China during the epidemic, was first introduced by Hangzhou city in Zhejiang province.

A key aspect of epidemic control is to sever the transmission routes. In addition to hospitalizing infected individuals in designated treatment centers, differentiated management measures are imposed on different at-risk groups. These measures mainly include the following: *Centralized quarantine*, which refers to staying in a designated quarantine facility with on-site medical staff assisting in daily health and psychological monitoring as well as conducting regular nucleic acid tests. *Home quarantine*, which involves isolation in a separate house or room within the individual's residence. It requires regular health monitoring and door-to-door nucleic acid testing or antigen self-testing, the results of which need to be reported to the specialized management team of the community through the internet. People under home quarantine are not allowed to leave their residences or receive visits from outsiders. *Home health monitoring* is also conducted within the individual's residence, but with more relaxed requirements for contact with co-inhabitants. It does not mandate isolation in a single room. Individuals under home monitoring are permitted to go out when necessary. Table 1 provides a summary of these measures. Vulnerable people are categorized into close contacts, close contacts of close contacts, and personnel exposed to epidemic-related premises. Each group is subject to differentiated measures. For instance, close contacts are required to undergo centralized quarantine, while close contacts of close contacts only receive home quarantine. The specific measure for each group is not constant but is modified according to updates in the medical technical protocol, resulting in variations during different time periods. For

TABLE 1 Measures for risk populations.

Measure	Contents
Centralized quarantine	Stay in a designated place determined by local authorities, where on-site medical staff are available. Undergo daily morning and evening health monitoring, psychological monitoring, and regular nucleic acid testing in accordance with epidemic prevention regulations. During this period, leaving the premises is prohibited, and all visits are denied.
Home quarantine	Quarantine at a personal residence, in a separate house or separate room. Undergo health monitoring, door-to-door nucleic acid tests or antigen self-testing in accordance with regulations. A specialized team from the community conducts online information collection and provides on-site management assistance. Going out is prohibited and all visits are denied.
Home health monitoring	Quarantine at a personal residence, preferably in a separate house or room. Undergo health monitoring, door-to-door nucleic acid tests or antigen self-testing in accordance with regulations. A specialized team from the community conducts online information collection and provides on-site management assistance. Going out is allowed when necessary.

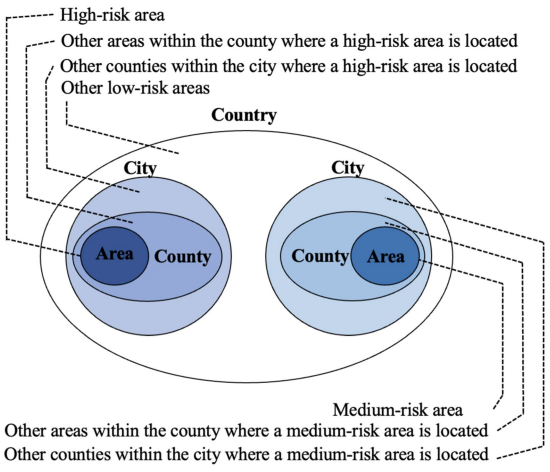


FIGURE 3
Risk Categories.

example, close contacts were initially required to undergo 14 days of centralized quarantine, which was subsequently reduced to 7 days in June 2022.

In addition to controlling the populations at risk within a specific region, it is equally important to cut off potential cross-regional transmission routes as part of the management policy. According to the JPCM, regions are classified into three risk levels based on a comprehensive evaluation of factors such as local population and the number of infected cases within a given period. These risk levels include high-risk, medium-risk and low-risk areas. Correspondingly, regions at each level adopt differentiated control measures. The region (area) was initially defined as the county level or above during the emergency stage, but gradually contracted to towns, blocks, and later building units in the regular management stage (In November 2022, the medium-risk category was abolished). For the cross-regional travel, strict restrictions are imposed by JPCM for the outflow from high- and medium-risk areas. Accordingly, local authorities at the destination usually impose control measures on these people. For people coming from low-risk areas, further distinctions are made considering the proximity to medium- or high-risk regions, as there is still a possibility of exposure to the epidemic. For instance, JPCM in its *Work Plan for the Prevention and Control of COVID-19 during the New Year and Chinese New Year in 2022*, singles out two types of low-risk areas, namely "other areas within the county where a medium- or high-risk area is located" and "other counties within the city where a medium- or high-risk area is located "(Figure 3 illustrates the classification of risk categories). For the former, in practice the management measures for people living in these areas are typically the same as those in the corresponding medium- or high-risk area, and thus require "strict restrictions on travel (across provinces)" as specified by the *Work Plan*, while for the latter, "no (cross-province) travel unless necessary" is required. Both areas are subject to measures distinct from those applied to general low-risk areas. Local authorities also follow these guidelines to further classify the population and arrange control measures. Table 2 summarizes these cross-regional mobility control requirements. It is important to note that there are no uniform regulations for the management of individuals coming from areas close to high- or medium-risk areas. Instead, the approach depends on the discretion of local governments. This perspective allows us to identify differences in the design of prevention and control policies among different cities.

2.2. The role of internet and information technology in China's epidemic control

As new tools for urban governance, the internet and information technologies have played a broad role in epidemic control during COVID-19. It can be summarized into the following four aspects.

Epidemiological investigation. The tracing of cases and identification of contacts have transitioned from the traditional manual approach to locating them with cell phone signals. The holders of mobile phones that presented at the time and geographical range of risk exposure can be quickly reached by CDC personnel and their risk level can be categoried automatically. This greatly improves the efficiency of epidemiological investigations. Based on the traceability of mobile phones, China has employed QR code in epidemic management with authorization from the public. Each person is assigned a *Health QR Code* displayed through a mobile phone program. The code's color (green, yellow, or red) corresponds to the individual's risk level, which is calculated based on their public visits. The code is used to access public venues. The form and functions of the codes vary across cities, determined by the municipal authorities. Some are integrated with additional features such as displaying virus test results and vaccination status, as well as binding with electronic transportation cards for automatic identification on public transport. In addition to the health QR codes for intra-city use, for cross-city travel, the China Academy of Information and Communication Technology in collaboration with China's three major mobile communication operators, has established *Digital Travel Records*. These records identify and track the mobile phone users' paths

TABLE 2 Measures for cross-regional mobility of people (issued in December 2021).

Risk category of the source region		*Control guidelines of JPCM*	*Measures in the destination made by*
High-risk area		Strict restrictions on (inter-provincial) travel	Local authorities
Medium-risk area		Strict restrictions on (inter-provincial) travel	Local authorities
Low-risk area	Other areas within the county where a high-risk area is located	Strict restrictions on (inter-provincial) travel	Local authorities
	Other areas within the county where a medium-risk area is located		
	Other counties within the city where a high-risk area is located	No (across-province) travel unless necessary	Local authorities
	Other counties within the city where a medium-risk area is located		
	Other low-risk areas	None	Local authorities

through base stations, making it easy for people to check whether they have recently passed through risk areas. This system helps filter people at risk and avoids misreporting of travel information. As of June 2022, digital trip records have served 1.6 billion cell phone users in China, processing over 55.6 billion inquiries.

Medical treatment capacity. Internet-based remote diagnosis and treatment has become a powerful complement to on-site hospital services. Firstly, online platforms that support video consultations and surgical assistance break the previous geographical limitations of medical facilities, thereby expanding the emergency mobilization capability to deal with large-scale outbreaks (23). Secondly, quarantine and control measures may consume limited medical resources, reducing medical accessibility for common and chronic diseases (24). However, the demand for medical services tends to rise during epidemics as people become more sensitive to their health conditions due to the presence of cases around them. In response to these medical needs, online medical services provided by internet healthcare companies and hospital internet programs have developed rapidly during the COVID-19 epidemic in China (25). The availability of higher internet coverage enables these online services to reach a wider population, thereby enhancing primary care capacity during the epidemic.

Information dissemination. Emerging infectious diseases often lack effective means of prevention and treatment, which tends to cause public panic when they break out (26). In China during the COVID-19 outbreak, nearly all city governments launched special epidemic prevention and control sections on their official websites and developed dedicated mobile APP or program modules. This approach serves two purposes. Firstly, it facilitates the transparent dissemination of information regarding the progression of the epidemic, enabling citizens to receive timely alerts about changes in the risk status of each region. Secondly, these platforms efficiently delivers new knowledge about the virus and the corresponding updates on protective measures to the public. These information platforms provide the authoritative interpretations of management policies and the knowledge about disease prevention, thus guiding the public to a scientific understanding of the epidemic, raising public awareness, and preventing public panic.

Urban governance and resource coordination. At the city level, nearly all cities have established electronic coordinating systems for COVID-19 prevention and control. These systems utilize technology support from the internet, internet of things, and big data computing to integrate functions such as contacts tracing, reporting confirmed case, epidemic monitoring and analysis, and emergency command and dispatch. This replaces the traditional manual communication methods with a more timely and efficient approach, promoting information sharing and collaboration across government departments and agencies (27). At the community level, residential communities are organized into "grid" for management. For instance, Longgang District in Shenzhen city divided its population of 4.3 million into 3,823 community-based blocks. Each community block has dedicated staff responsible for monitoring residents' risk conditions and managing those under control measures. Much of their work is conducted through internet or mobile tools such as Wechat, a widely used chatting APP in China, for communication with local residents. For the communities under access control due to the epidemic, technology tools are also employed to provide daily necessities. Household needs are reported through the internet, and digital files are created to track special needs. Some communities even established online platforms to connect with external suppliers, so as to match the residents' demands timely and precisely with available supplies.

3. Methodology

3.1. Empirical strategy

We use the management measures targeting cross-city movement during the Chinese New Year in 2022 to identify differences in cities' precautionary epidemic policies. The Chinese New Year is the most important festival in Chinese culture, during which people return to their hometowns for family reunions, making it the most mobile period of the year. In 2019, the number of passengers (including trains, buses, passenger ships and airplanes) reached 421 million, equivalent to 30% of the national population (21).The massive influx of people poses a potential risk of epidemic spread. In response to this challenge, the JPCM of the State Council issued the *Work Plan for the Prevention and Control of COVID-19 during the New Year and Chinese New Year in 2022*, based on which local authorities also issued their

specific measures. In 2022, the Chinese New Year fell on February 1st (indicated by the vertical line in Figure 1). Prior to this date, the epidemic situation in China was generally stable. On January 29th, among the 188 cities included in our sample, the city with the highest number of current cases was Anyang in Henan Province, with 400 cases, while 165 cities had no existing cases. Only three cities reported new cases on that day, with the largest number being 22 in Hangzhou, Zhejiang Province. This suggests that at that time, cities did not have a heavy burden of controlling the epidemic outbreak, but still faced the potential threat of sporadic cases. Therefore, policy-making at that time reflected precautionary considerations to deal with the potential risk.

Using the Chinese New Year as the focal point of our study also offers several advantages. Firstly, during this time, very few cities are immune to the potential impacts of epidemic risks. The movement of people across the country, as individuals return to their hometowns, is difficult to predict, unlike population movements driven by commercial activities. Secondly, as workers return home, factories typically reduce production intensity or even shut down for approximately 3 weeks during the New Year period. This alleviates concerns on the economic consequences of the epidemic in policy-making, compared to other times of the year. Thirdly, almost all cities update their policies in preparation for the New Year population flow, making it easier for us to make comparison. If we were to choose a random time point, cities may have varying policies due to individual needs, leading to potential biases in our analysis. The specific date we use for policy extraction is January 29, 2022, which was the last working day before the Chinese New Year's day.

Specifically, our regression model can be represented as follows:

$$y_c = \alpha + \beta Cyber_c + X_c\gamma + \varepsilon_c$$

where y_c indicates the strict degree of the precautionary epidemic policy in city c.$Cyber_c$ measures the city's cyber infrastructure. X_c is a set of control variables for city characteristics.

In constructing the dependent variable, we focus on the city's management policy specifically targeting people travelling from "other areas within the county where a medium-risk area is located." This level represents the lowest level that requires control measures according to the JPCM. Areas above this level, i.e., the medium- and high-risk areas, as well as other areas within the county where a high-risk area is located, are associated with a high risk of exposure. Local authorities at the destination typically adopt strict control measures for people arriving from these areas, leading to policy convergence. Conversely, below this level, local authorities tend to impose no control measures, resulting in similar practices. Thus, the diversification at this level helps capture policy differences among cities. The specific measures implemented for people falling within this category include (for cities that impose a combination of more than one measures, only that of the highest degree was taken) 14 days of centralized quarantine, 7 days of centralized quarantine, 3 days of centralized quarantine, 14 days of home quarantine, 7 days of home quarantine, 3 days of home quarantine, 14 days of home monitoring, 3 days of home monitoring, and self-monitoring (i.e., no control measures). Recognizing that centralized quarantine requires individuals to stay in designated places for isolation, which significantly impacts their daily lives, we further classified these measures into a dummy variable indicating centralized or non-centralized management, where $y_1 = 0$ denotes centralized management including centralized quarantine for 14 days, 7 days or 3 days, and $y_1 = 1$ for other cases including all types of home management and no measures. We use larger values to indicate looser measures. This variable serves as the dependent variable in our benchmark regression. In the robustness section, we utilize alternative classifications to validate our results. Additionally, we employ choice models alongside LPM to reflect the features of different dependent variables.

The independent variable, cyber infrastructure, is represented by the city's internet coverage following existing literature (28). It is calculated as: Internet coverage = number of internet broadband access users/year-end population *100.

Control variables include local healthcare resources and other city characteristics. Healthcare resources are represented by the number of hospital beds per thousand population and the number of doctors per thousand, which measure the city's medical infrastructure from the perspectives of hardware and software, respectively. Moreover, as most of the epidemic-controlling activities are led by the local authorities and thus funded through local public finance, we also incorporate the city's fiscal revenue *per capita* as a proxy for the fiscal space for health[1]. Other city characteristics include city size (population), level of socio-economic development (GDP *per capita*, *China Integrated City Index* ranking), and degree of urbanization (proportion of urban population, population density). Considering the possible demonstration effect of provincial capital cities, a dummy variable of provincial capital city is also added. Fiscal revenue *per capita*, population, population density and GDP *per capita* are in logarithmic form in regressions.

3.2. Data

Data on the precautionary policies of cities were collected from a manual search on the official websites of local authorities and from official media reports on the internet. City characteristics were obtained from the *China City Statistical Yearbook*. CICI ranking was sourced from *Yunhe City Research Institute*. In order to mitigate the endogeneity problem, we used data from the year prior to the outbreak of COVID-19, i.e., the year of 2019, as the epidemic itself may influence social and economic performance.

The original dataset contains all cities in the Yearbook. We exclude those of special status to form our regression sample. Cities excluded are: cities from ethnic autonomous regions, as well as Qinghai, Yunnan, and Guizhou provinces, which are classified as ethnic regions by the Ministry of Finance for public finance funding purposes; cities from provinces that are adjacent to other countries; province-level municipalities directly under the Central Government; and Hebei province, which was preparing to host the Winter Olympics. Additionally, eight cities that could not obtain the specific policies were also excluded, as well as six cities with missing variables in the Yearbook. Our final sample contains 188 cities.

Table 3 provides descriptive statistics. It can be seen that there is a significant difference in internet coverage between the two city

1 We thank the reviewer for pointing this out.

TABLE 3 Summary statistics.

	Full ($N = 188$)		$y_1 = 0$ ($N = 117$)		$y_1 = 1$ ($N = 71$)	
	Mean	*sd*	Mean	*sd*	Mean	*sd*
Internet coverage (%)	34.443	*16.747*	30.380	*12.70*	41.138	*20.212*
Number of hospital beds (/1,000)	4.895	*1.611*	4.910	*1.385*	4.871	*1.937*
Number of doctors (/1,000)	2.673	*1.067*	2.484	*0.781*	2.984	*1.369*
Fiscal revenue *per capita* (yuan)	5610.82	*6670.87*	4093.42	*3176.35*	8111.31	*9590.12*
Population (10,000)	477.777	*264.612*	472.667	*280.637*	486.197	*237.540*
GDP *per capita* (yuan)	66610.4	*36855.1*	56918.4	*27642.8*	82581.8	*44120.2*
CICI ranking	142.931	*84.629*	161.595	*76.487*	112.437	*88.877*
Proportion of urban population (%)	37.604	*22.500*	35.550	*20.367*	40.990	*25.424*
Population density(10,000/km^2)	0.052	*0.037*	0.045	*0.026*	0.064	*0.049*
Provincial capital	0.080	*0.272*	0.068	*0.253*	0.099	*0.300*

groups, with a difference of more than 10 percentage points. Cities with loose policies also tend to exhibit a higher number of doctors per thousand population, higher fiscal revenue *per capita*, higher GDP *per capita*, a larger proportion of urban population and a higher CICI ranking.

4. Empirical results

4.1. Basic results

Table 4 shows the regression results. Column 1 includes only internet coverage as a right-hand variable. It can be seen that the coefficient of internet coverage is significantly positive, indicating that cities with better internet infrastructure tend to adopt looser precautionary policies. Column 2 introduces the number of hospital beds and the number of doctors as controls, which represent local medical resources. The coefficient of internet coverage is still significantly positive, with the scale nearly unchanged. Internet facilities function independently of the traditional medical infrastructure. Column 3 further introduces city characteristics, and the coefficient of internet coverage remains stable, suggesting that cyber infrastructure does have a positive effect on cities' confidence in responding to potential epidemic risks. In column 3, for every 1 percentage point increase in internet coverage, the probability of a city adopting loose measures increases by 0.8 percentage points.

Since the dependent variable is in discrete form, we also change the LPM setting and use binary choice models for regression. Columns 4 and 5 of Table 4 show the results of Logit regression and Probit regression, respectively. As can be seen, the marginal effects of internet coverage are consistent with that in LPM, showing that the positive effect of network infrastructure is not affected by the model setup.

Among the control variables, it is noteworthy that the number of hospital beds and the number of doctors act in a different way. Although the number of doctors has significantly positive effect on cities' choosing loose policies, the effect of hospital beds is negative. This suggests that increase in physical facilities alone does not directly lead to a boost in confidence in epidemic prevention and control; even in the case of medical resources, the confidence depends on the corresponding capability building. This supports the idea that software improvements on cities' epidemic responding capability may play an important role in precautionary decision making.

4.2. Robustness

4.2.1. Alternative classifications of precautionary policies

In our benchmark regression, cities' management measures are grouped into centralized management and non-centralized management to construct the dependent variable y_1. In this section we use other alternative classification methods to check the robustness of our findings. These classifications are shown in Table 5. On the basis of y_1, y_2 categorizes the measures into three groups, with $y_2 = 1$ for centralized management defined the same as in y_1, $y_2 = 2$ for home management including home quarantine and home monitoring, and $y_2 = 3$ for no measures. On the basis of y_2, y_3 further subdivides centralized management into centralized management for 14 days ($y_3 = 1$) and centralized management for 7 days and below ($y_3 = 2$), thus forming a variable containing four categories. We use y_2 and y_3 to replace y_1 as dependent variable, respectively, and repeat regression. Considering dependent variables take values with the ordinal feature, Ordered Probit models are used. The regression results are shown in columns 1 and 2 of Table 6. For each additional 1% increase in internet coverage, in column 1 the probability of choosing centralized management, home management and no control measures will increase by −0.6, 0.1, and 0.5%, respectively, while in the setting of column 2, the probability of choosing 14-day centralized management, 7-day centralized management or below, home management, and no control measures will increase by −0.4%, nearly 0, 0.1, and 0.3%, respectively. These results indicate that higher internet coverage is associated with looser management measure, which is consistent with our benchmark finding.

Policy-making in cities can be influenced by the opinions of their provinces. Some provinces have even unified the policies over their cities, which makes the policy choice of these cities unable to reflect their own characteristics. We then control for provinces and categorize the policy leniency of cities by comparison within provinces. We exclude those provinces with completely uniform policies and take only those provinces with differed policies within its boundary, and

TABLE 4 Basic results.

	(1)	(2)	(3)	(4)	(5)
	LPM	LPM	LPM	Logit	Probit
Dependent var.	y_1	y_1	y_1	y_1	y_1
Internet coverage	0.009***	0.009**	0.008**	0.008*	0.008**
	(0.002)	(0.004)	(0.004)	(0.004)	(0.003)
Hospital beds		−0.185***	−0.189***	−0.205***	−0.208***
		(0.030)	(0.034)	(0.036)	(0.035)
Doctors		0.163**	0.173**	0.205***	0.211***
		(0.074)	(0.076)	(0.078)	(0.076)
Fiscal revenue *per capita* (ln)		0.109	0.034	0.048	0.054
		(0.074)	(0.099)	(0.100)	(0.099)
Population (ln)			−0.041	−0.038	−0.036
			(0.083)	(0.074)	(0.076)
GDP *per capita* (ln)			0.107	0.079	0.080
			(0.139)	(0.134)	(0.137)
CICI ranking			−0.000	−0.000	0.000
			(0.001)	(0.001)	(0.001)
Urban proportion			−0.002	−0.002	−0.002
			(0.003)	(0.002)	(0.002)
Population density (ln)			0.016	0.023	0.020
			(0.058)	(0.058)	(0.057)
Provincial capital			0.130	0.136	0.129
			(0.166)	(0.172)	(0.166)
Constant	0.065	−0.353	−0.480		
	(0.077)	(0.497)	(1.481)		
N	188	188	188	188	188
R-sq	0.098	0.237	0.251		

[1] ***, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively. [2] Robust standard errors are reported in the parentheses. [3] Columns 4 and 5 report marginal effects.

TABLE 5 Classifications of management measures.

y	Definitions
y_1	$y_1 = 0$ for centralized management, $y_1 = 1$ for non-centralized management
y_2	$y_2 = 1$ for centralized management, $y_2 = 2$ for home management, $y_2 = 3$ for no control measures
y_3	$y_3 = 1$ for 14-day centralized management, $y_3 = 2$ for 7-day centralized management or below, $y_3 = 3$ for home management, $y_3 = 4$ for no control measures
y_4	$y_4 = 0$ for strict measure group, $y_4 = 1$ for loose measure group

divide the cities into strict group and loose group based on comparison with other cities within the province. The grouping method follows the rationale of the previous classifications. Specifically, if within the province cities take either centralized or non-centralized management measures for our targeted people flow, those cities with centralized management are grouped as being strict while those with non-centralized management being loose; if all the cities within the province take non-centralized measures, those with home management are sent to the strict group, while those with no measures to the loose group; if all the cities within the province take centralized measures, those with centralized management for 14 days are considered being strict, and those for 7 days and below are considered being loose. If the measures for our targeted people flow (i.e., travelling from "other areas within the county where a medium-risk area is located") are completely unified within the province, the policies for "other counties within the city where a county with medium-risk areas is located" is taken and used to divide cities following the above method. In this way we obtain binary variable y_4, which we use to replace the dependent variable in the benchmark model, while controlling for province fixed effects (as the cities' CICI rankings lead

TABLE 6 Robust checks.

		(1)	(2)	(3)	(4)
		Oprobit	Oprobit	Probit	Probit
Dependent var.		y_2	y_3	y_4	y_1
Internet coverage				0.016*	
				(0.010)	
	$y = 1$	−0.006**	−0.004*		
		(0.003)	(0.002)		
	$y = 2$	0.001*	−0.000		
		(0.001)	(0.000)		
	$y = 3$	0.005**	0.001*		
		(0.002)	(0.001)		
	$y = 4$		0.003*		
			(0.002)		
Mobile phone coverage					0.008***
					(0.002)
Province FE		No	No	Yes	No
N		188	188	80	188

[1] ***, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively. [2] Other control variables include population (ln), GDP per capita (ln), proportion of urban population, population density (ln), CICI ranking (not in column 3), hospital beds per thousand population, doctors per thousand population, fiscal revenue per capita (ln) and provincial capital city dummy. [3] Robust standard errors are reported in the parentheses. [4] All columns report marginal effects.

to multicollinearity concern with province fixed effect, we exclude CICI ranking from this regression). The results are shown in column 3 of Table 6. It can be seen that the coefficient of internet coverage remains positive and significant, and our results remain robust to this classification.

4.2.2. Mobile phone coverage

The support of cyber infrastructure for epidemic prevention and control is not solely generated by broadband internet; mobile network also makes its contribution. Therefore, we also use mobile phone coverage as an alternative measure of cyber infrastructure, and put it into the regression. The mobile phone coverage of the city is calculated as: mobile phone coverage = number of mobile phone subscribers at year-end /total population at year-end *100. Data is from the China City Statistical Yearbook. Column 4 of Table 6 provides the results of the repeated regression. It can be seen that the coefficient of mobile phone coverage is positive and significant, which echoes our benchmark finding.

4.3. Endogeneity

Decisions on precautionary policies may not be entirely based on objective conditions, but also involve subjective factors of the authorities such as cautious or bold city governance styles (22), which may also affect the development of information infrastructure. Omitting these variables can lead to endogeneity issues. To alleviate this concern, we use two methods to verify our findings.

First, we use the instrumental variable method. The geographic distance from each city to Hangzhou was used as an instrument. Hangzhou is among the most developed cities in China in terms of digital economy. The health QR code widely used during COVID-19 period in China was originally invented by Hangzhou, and then promoted to its local province and the whole country. In Chinese literature, the geographic distance to Hangzhou is commonly used as an instrument to represent the level of digital economy development of the city (29). We use IV-Probit regression based on this instrumental variable, and the results are shown in columns 1 to 2 of Table 7. Column 1 shows the results of the first-stage regression with internet coverage as the dependent variable. It can be seen that the coefficient of distance is negative and significant, indicating that greater distance to Hangzhou is associated with lower internet coverage of the city, which suggests that distance is a good instrument. Column 2 shows the second-stage results. The coefficient of internet coverage is still positive and significant, which corroborates the findings of the benchmark regression. This suggests that the effect of internet coverage is independent of the effect of subjective factors.

Second, we add on control variables that may contribute to the formation of subjective styles of cities. In the context of epidemic management, we use two variables indicating the city's COVID-19 experience, namely the severity of the city's current outbreak and the severity of its past outbreaks. The former is measured by a dummy variable which takes a value of 1 if the number of current existing cases is above zero and 0 otherwise. The latter is measured by a dummy indicating "whether the city's cumulative number of cases is high ", which takes a value of 1 if the city's cumulative number of cases exceeds the median and 0 otherwise. Case data are obtained from the Baidu website epidemic statistics column as of January 28, 2022. Columns 3 and 4 of Table 7 show the regression results with the current outbreak variable and its cross-term with internet coverage added in controls. It can be seen that the coefficients of both the variable and its cross-term are not significant, and their

TABLE 7 Endogeneity analysis.

	(1)	(2)	(3)	(4)	(5)	(6)
	IV-Probit		Probit	Probit	Probit	Probit
Dependent var.	Internet coverage	*y*1	*y*1	*y*1	*y*1	*y*1
Internet coverage		0.099***	0.008**	0.008**	0.006	0.002
		(0.008)	(0.003)	(0.003)	(0.004)	(0.004)
Distance to Hangzhou (ln)	−2.632*					
	(1.579)					
Current outbreak			0.114	−0.068		
			(0.105)	(0.237)		
				0.005		
Internet coverage * Current outbreak				(0.006)		
Past outbreaks					−0.297***	−0.568***
					(0.070)	(0.137)
						0.009**
Internet coverage * Past outbreaks						(0.004)
N	187	187	188	188	176	176

[1] ***, **, and * represent statistical significance at the 1, 5, and 10% levels, respectively. [2] Other control variables include population (ln), GDP per capita (ln), proportion of urban population, population density (ln), CICI ranking (not in column 3), hospital beds per thousand population, doctors per thousand population, fiscal revenue per capita (ln) and provincial capital city dummy. [3] Robust standard errors are reported in the parentheses. [4] Probit regressions report marginal effects. [5] Cities in Hubei Province are excluded from regressions in Column 5 and 6 as outliers.

inclusion has little effect on the coefficient of internet coverage. This suggests that the ongoing outbreak does not affect precautionary policy making of cities. Columns 5 and 6 of Table 7 show the regression results after adding the past outbreak variable and its cross-term. Cities in Hubei Province are excluded from this regression as outliers considering their extraordinarily large case numbers compared with other Chinese cities since the epidemic initially broke out in that province. It can be seen from column 5 of Table 7, that although past outbreaks are supposed to increase a city's experience in managing epidemics, they actually decrease the probability of a city taking loose precautionary policy, indicating that these cities become more cautious. The coefficient of internet coverage tends to remain positive but insignificant. A closer look in column 6 including the cross-term shows that the coefficient of the cross-term is positive and significant. Thus internet infrastructure is able to moderate the cautiousness of experiencing past outbreaks, thereby helping to offset its effect. These results confirm our findings that information infrastructure does contribute to the relaxation of precautionary epidemic policies.

5. Conclusion

We examined the precautionary epidemic policies of 188 cities in China in the face of COVID-19 and found that cities with higher levels of internet coverage tended to develop looser policies when faced with unknown risk exposures. This result remains robust across different policy classifications. Our study shows that cyber infrastructure gives confidence in cities' public health management, a role that may exceed that of the traditional medical infrastructure such as hospital beds. Therefore, to prepare for future pandemics, cities need to look beyond the healthcare system and prioritize the application of technology to establish comprehensive capabilities for epidemic response.

Our study confirms that cyber infrastructure, as a new foundation for development, also plays a role in the health sector. As described in the background section, the internet-enabled techniques applied to epidemiological investigation, treatment capability expansion and dissemination of epidemic knowledge, feature in ultra-high analytical speed and efficiency, which enable them to achieve effective epidemic control at the early stage of an outbreak. This greatly transforms the epidemic management practices from the traditional manual approach. The effectiveness of this new model gives cities the confidence to respond to epidemics, which further translates into the confidence to adopt loose precautionary policies that entails less interference to social activities in the face of an epidemic threat. This correlation is underpinned by the fact that a larger network coverage corresponds to a greater abundance of technological management tools and a superior new management model. Consequently, the adoption of looser precautionary policies is not a subjective decision, but rather a consequence of objective, superior cyber-infrastructure conditions.

Our paper also suggests that the smart city development can help empower cities to respond to public health emergencies. A limitation of our study is that we only focus on China. Different countries may have distinct social mores and cultures that can influence policy decisions, suggesting that the factors influencing policy-making may vary. Nevertheless, the management of epidemics in all countries should be grounded in certain objective conditions. Therefore, the findings of this paper hold instructive value even for countries with different socio-economic backgrounds. Specifically, we have focused on the role of networks as city infrastructure rather than the specific applications. Future research could further investigate the role of cyber-infrastructure in different countries and against different public health events.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

QG led the overall study. She designed the study, led the data collection and analysis, and wrote the manuscript. YH contributed to the data analysis and literature review, as well as assist in manuscript writing. ZL contributed to the study design, reviewed the manuscript and put inputs in the writing of the first manuscript. LY contributed to the data interpretation and manuscript edits. All authors contributed to the article and approved the submitted version.

Funding

This paper was funded by Program for Young Innovative Research Team in China University of Political Science and Law.

Acknowledgments

The authors acknowledge the valuable contribution of Huadong Li in shaping the research idea. The authors also appreciate the contributions of Yuchen Zhou in data collection and analysis.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Cohen ML. Changing patterns of infectious disease. *Nature*. (2000) 406:762–7. doi: 10.1038/35021206

2. Bloom DE, Kuhn M, Prettner K. Modern infectious diseases: macroeconomic impacts and policy responses. *J Econ Lit*. (2022) 60:85–131. doi: 10.1257/jel.20201642

3. Bruine de Bruin W, Saw H-W, Goldman DP. Political polarization in US residents' COVID-19 risk perceptions, policy preferences, and protective behaviors. *J Risk Uncertain*. (2020) 61:177–94. doi: 10.1007/s11166-020-09336-3

4. Chen C, Frey CB, Presidente G. Culture and contagion: individualism and compliance with COVID-19 policy. *J Econ Behav Organ*. (2021) 190:191–200. doi: 10.1016/j.jebo.2021.07.026

5. Smith RD. Responding to global infectious disease outbreaks: lessons from SARS on the role of risk perception, communication and management. *Soc Sci Med*. (2006) 63:3113–23. doi: 10.1016/j.socscimed.2006.08.004

6. Baekkeskov E. Same threat, different responses: experts steering politicians and stakeholders in 2009 H1N1 vaccination policy-making. *Public Adm*. (2016) 94:299–315. doi: 10.1111/padm.12244

7. Buseh AG, Stevens PE, Bromberg M, Kelber ST. The Ebola epidemic in West Africa: challenges, opportunities, and policy priority areas. *Nurs Outlook*. (2015) 63:30–40. doi: 10.1016/j.outlook.2014.12.013

8. Quaglio G, Goerens C, Putoto G, Rübig P, Lafaye P, Karapiperis T, et al. Ebola: lessons learned and future challenges for Europe. *Lancet Infect Dis*. (2016) 16:259–63. doi: 10.1016/S1473-3099(15)00361-8

9. Camero A, Alba E. Smart City and information technology: a review. *Cities*. (2019) 93:84–94. doi: 10.1016/j.cities.2019.04.014

10. Athey S. Beyond prediction: using big data for policy problems. *Science*. (2017) 355:483–5. doi: 10.1126/science.aal4321

11. Kandt J, Batty M. Smart cities, big data and urban policy: towards urban analytics for the long run. *Cities*. (2021) 109:102992. doi: 10.1016/j.cities.2020.102992

12. Veenstra AFvan, Kotterink B, editors. Data-driven policy making: the policy lab approach. *Electronic participation: 9th IFIP WG 85 international conference; 2017 September 4–7*; St Petersburg, Russia. Heidelberg: Springer; (2017). 100–111p.

13. Stübinger J, Schneider L. Understanding smart city—a data-driven literature review. *Sustainability*. (2020) 12:8460. doi: 10.3390/su12208460

14. Abella A, Ortiz-de-Urbina-Criado M, De-Pablos-Heredero C. A model for the analysis of data-driven innovation and value generation in smart cities' ecosystems. *Cities*. (2017) 64:47–53. doi: 10.1016/j.cities.2017.01.011

15. Yahia NB, Eljaoued W, Saoud NBB, Colomo-Palacios R. Towards sustainable collaborative networks for smart cities co-governance. *Int J Inf Manag*. (2021) 56:102037. doi: 10.1016/j.ijinfomgt.2019.11.005

16. Guo M, Liu Y, Yu H, Hu B, Sang Z. An overview of smart city in China. *China Commun*. (2016) 13:203–11. doi: 10.1109/CC.2016.7489987

17. Shen L, Huang Z, Wong SW, Liao S, Lou Y. A holistic evaluation of smart city performance in the context of China. *J Clean Prod*. (2018) 200:667–79. doi: 10.1016/j.jclepro.2018.07.281

18. Luo M, Liu Q, Wang J, Gong Z. From SARS to the omicron variant of COVID-19: China's policy adjustments and changes to prevent and control infectious diseases. *Biosci Trends*. (2021) 15:418–23. doi: 10.5582/bst.2021.01535

19. Jin H, Li B, Jakovljevic M. How China controls the Covid-19 epidemic through public health expenditure and policy? *J Med Econ*. (2022) 25:437–49. doi: 10.1080/13696998.2022.2054202

20. Wu J, Wang K, He C, Huang X, Dong K. Characterizing the patterns of China's policies against COVID-19: a bibliometric study. *Inf Process Manag*. (2021) 58:102562. doi: 10.1016/j.ipm.2021.102562

21. Lin R, Lin S, Yan N, Huang J. Do prevention and control measures work? Evidence from the outbreak of COVID-19 in China. *Cities*. (2021) 118:103347. doi: 10.1016/j.cities.2021.103347

22. Zhou K, Xin G. Who are the front-runners? Unravelling local government responses to containing the COVID-19 pandemic in China. *China Rev*. (2021) 21:37–54.

23. Dou K, He X, Li J, Wen S. Research on promotion of the information technologies on economic and social high-quality development in the context of the COVID-19 epidemic. *Scientific Manag Res*. (2021) 39:2–8. doi: 10.19445/j.cnki.15-1103/g3.2021.02.001

24. Huang F, Liu H. The impact of the COVID-19 pandemic and related policy responses on non-COVID-19 healthcare utilization in China. *Health Econ*. (2023) 32:620–38. doi: 10.1002/hec.4636

25. Liu L, Gu J, Shao F, Liang X, Yue L, Cheng Q, et al. Application and preliminary outcomes of remote diagnosis and treatment during the COVID-19 outbreak: retrospective cohort study. *JMIR Mhealth Uhealth*. (2020) 8:e19417. doi: 10.2196/19417

26. Depoux A, Martin S, Karafillakis E, Preet R, Wilder-Smith A, Larson H. The pandemic of social media panic travels faster than the COVID-19 outbreak. *J Travel Med*. (2020) 27:taaa031. doi: 10.1093/jtm/taaa031

27. Yang S, Chong Z. Smart city projects against COVID-19: quantitative evidence from China. *Sustain Cities Soc*. (2021) 70:102897. doi: 10.1016/j.scs.2021.102897

28. Czernich N, Falck O, Kretschmer T, Woessmann L. Broadband infrastructure and economic growth. *Econ J*. (2011) 121:505–32. doi: 10.1111/j.1468-0297.2011.02420.x

29. Fu Q, Huang Y. Digital Finance's heterogeneous effects on rural financial demand: evidence from China household finance survey and inclusive digital finance index. *J Financ Res*. (2018) 461:68–84.

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 08 August 2023
DOI 10.3389/fpubh.2023.1222125

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Juliana Parise Baldauf,
Federal University of Rio Grande do Sul, Brazil
Mihaela Simionescu,
University of Bucharest, Romania

*CORRESPONDENCE
Beata Gavurova
✉ beata.gavurova@lf1.cuni.cz

RECEIVED 13 May 2023
ACCEPTED 05 July 2023
PUBLISHED 08 August 2023

CITATION
Gavurova B, Kelemen M, Polishchuk V, Mudarri T and Smolanka V (2023) A fuzzy decision support model for the evaluation and selection of healthcare projects in the framework of competition.
Front. Public Health 11:1222125.
doi: 10.3389/fpubh.2023.1222125

A fuzzy decision support model for the evaluation and selection of healthcare projects in the framework of competition

Beata Gavurova[1]*, Miroslav Kelemen[2], Volodymyr Polishchuk[3], Tawfik Mudarri[4] and Volodymyr Smolanka[5]

[1]Department of Addictology, First Faculty of Medicine, Charles University and General Teaching Hospital in Prague, Prague, Czechia, [2]Department of Flight Training, Faculty of Aeronautics, Technical University of Košice, Košice, Slovakia, [3]Department of Software Systems, Faculty of Information Technology, Uzhhorod National University, Uzhhorod, Ukraine, [4]Technical University of Košice, Faculty of Mining, Ecology, Process Control and Geotechnologies, Košice, Slovakia, [5]Department of Neurology, Neurosurgery and Psychiatry, Faculty of Medicine, Uzhhorod National University, Uzhhorod, Ukraine

Our research aims to support decision-making regarding the financing of healthcare projects by structural funds with policies targeting reduction of the development gap among different regions and countries of the European Union as well as the achievement of economic and social cohesion. A fuzzy decision support model for the evaluation and selection of healthcare projects should rank the project applications for the selected region, accounting for the investor's wishes in the form of a regional coefficient in order to reduce the development gap between regions. On the one hand, our proposed model evaluates project applications based on selected criteria, which may be structured, weakly structured, or unstructured. On the other hand, it also incorporates information on the level of healthcare development in the region. The obtained ranking increases the degree of validity of the decision regarding the selection of projects for financing by investors, considering the level of development of the region where the project will be implemented. At the expense of European Union (EU) structural funds, a village, city, region, or state can receive funds for modernization and development of the healthcare sector and all related processes. To minimize risks, it is necessary to implement adequate support systems for decision-making in the assessment of project applications, as well as regional policy in the region where the project will be implemented. The primary goal of this study was to develop a complex fuzzy decision support model for the evaluation and selection of projects in the field of healthcare with the aim of reducing the development gap between regions. Based on the above description, we formed the following scientific hypothesis for this research: if the project selected for financing can successfully achieve its stated goals and increase the level of development of its region, it should be evaluated positively. This evaluation can be obtained using a complex fuzzy model constructed to account for the region's level of development in terms of the availability and quality of healthcare services in the region where the project will be implemented.

KEYWORDS

healthy cities, projects, expert evaluation, fuzzy sets, European Green Deal, industry 5.0, decision-making

1. Introduction

Although many statistics and numerous reports have declared an improvement in the average health level in the member countries of the European Union (EU) over the last several decades, health differences among segments of the population continue to persist in various parts of the EU, as well as differences between the most and the least advantaged regions (1, 2). In some cases, these differences are even more pronounced. Major health differences among various regions and between rural and urban areas have been confirmed to be present. Across the EU member countries, we observe a relationship between socioeconomic status and health of the population: that is, people with lower levels of education, lower-status job titles, or lower incomes tend to die younger and to have more health problems (3, 4). Gender also plays a significant role: although women live longer than men, they live more years in poorer health (5, 6). Everyday living conditions significantly affect health equality, as do the factors of technological development and spatial planning of the urban environment. In order to achieve health equity, it is fundamentally important to provide communities in urban and local areas with access to fundamental goods and to support the physical and mental health of the population while protecting the environment (7).

Schemes that focus on eliminating health inequalities can take several forms, and can be aimed either at disadvantaged sectors of the population or at reducing health differences across the entire population (8). Local public policies aiming to eliminate health inequalities can support the improvement of the physical and socioeconomic environment in disadvantaged areas in several ways: for instance, improving access to nutritious food, or enhancing housing quality, employment, physical activity, and so on Salmi et al. (9). Interventions aimed at improving the overall health status of the population may not affect the entire population. Therefore, the universal approaches applied in regional health policies must be supplemented with specific approaches that take regional specificities into consideration (10). It is important to constantly analyze the best practices in the implementation of effective interventions aimed at eliminating health inequalities, to look for new challenges for local interventions, and to share experiences with city and local government administrators (11, 12). These measures will aid in difficult decision-making processes and in effective national and regional policy implementation (13).

A recent study by The Lancet Public Health[1] reports the contributions by critical factors that play a role in generating health inequalities as follows: a 35% share of the contributions can be attributed to income security and social protections; 29% to living conditions; 19% to a lack of education and low self-confidence; 10% to access to healthcare; and 7% to employment and working conditions. The heterogeneity of these factors clearly indicates the need to create policies that can influence each of these factors in order to support the elimination of health inequalities at various regional levels. Policies aiming to reduce health inequalities between countries will not be successful if they lead to the persistence of health disparities within countries, or to such disparities becoming even more pronounced.

Several financial mechanisms providing resources for the creation and implementation of effective tools to eliminate health inequalities have been created to solve these problems. Financial mechanisms for the distribution of EU resources are among these, and policymakers and public health administrators must therefore tackle difficult decision-making problems in the selection of appropriate health projects. Considering the multi-sector importance of the issue and its systemic and procedural interconnectedness, the decision-making processes aiming to select the most effective projects are highly demanding (14, 15). Many factors that have come to prominence may also vary based on demographic effects, population structure, economic development of the relevant region, the health profile of the relevant region, and so on. Therefore, it is necessary to develop and seek out the appropriate tools to support decision-making mechanisms that will help policymakers in healthcare and other domains to improve the corresponding decision-making processes (16, 17). These consistently relevant issues formed the motivation behind our research.

During the development of intelligent systems, subject knowledge is neither complete nor reliable. In addition, our research uses knowledge obtained from experts, which is subjective and vague in nature. However, the use of precise statistical methods does not account for verbal inaccuracies and subjective factors arising from the incorporation of expert-derived information. This problem, in turn, leads to inadequate representation of the knowledge base according to which further decisions are made. In the domain of artificial intelligence, problems dealing with fuzziness are solved using descriptions of fuzzy concepts by linguistic variables and corresponding membership functions. This enables data mining and decision-making based on knowledge gained from experts. The problem of multi-criteria evaluation of objects falls within the domain of selection problems, which are an integral subset of the problems involved in decision support systems. Thus, the formulation of a multi-criteria evaluation problem based on the theory of fuzzy sets is necessary to develop a decision support system.

Our research aims to support decision-making regarding the financing of healthcare projects by structural funds with policy goals involving reduction of the development gap among different regions and countries of the EU and the achievement of economic and social cohesion. A fuzzy decision support model for the evaluation and selection of healthcare projects should rank the project applications made by the selected region, accounting for the investor's wishes regarding the regional coefficient, in order to reduce the development gaps between regions. On the one hand, such a model should evaluate project applications based on specified criteria, which may be structured, weakly structured, or unstructured. On the other hand, it should also incorporate information on the level of healthcare development in the corresponding region. The obtained ranking would increase the validity of decisions regarding the selection of projects for financing by investors, taking into consideration the level of development of the region where the project will be implemented.

At the expense of the EU structural funds, a village, city, region, or state can receive funds for modernization and for development of the healthcare sector and all related processes. However, the financing of the implementation of such projects is a risky business. To minimize risks, it is necessary to put in place

1 Global Burden of Disease 2019. https://www.thelancet.com/gbd.

adequate support systems for decision-making in the assessment of project applications, as well as accounting for regional policy where the project will be implemented. Experience indicates that, based on the quality of project applications, applications from more developed regions or from capitals are more likely to receive funding. There are situations in which a project application from a less developed region may receive fewer points, even though it could have been successfully implemented within the available financial constraints. Under such circumstances, a less developed region can be prevented from reducing the development gap relative to more developed regions.

The primary goal of this study was to develop a complex fuzzy decision support model for the evaluation and selection of projects in the field of healthcare in order to reduce the development gap between regions.

Based on the above outline, we can form a scientific hypothesis for this research as follows. If the project selected for financing can successfully achieve its stated goals and increase the level of development of its region, a positive project evaluation can be claimed. This evaluation can be obtained using a complex fuzzy model that is constructed to account for the level of development of the region where the project is to be implemented, in terms of the availability and quality of healthcare services in that region.

2. Literature review

In recent years, many studies have tackled the issue of health inequalities and sought optimal solutions for the elimination of such inequalities. Mackenbach and Kunst (18) point out three main problems with these studies: first, the small number of countries included, which reduces the possibility of obtaining a global understanding of the problems from the perspective of particular country; second, the un-harmonized nature of the data collected from participating countries; and third, the fragmentation associated with the unavailability of intermediate data or evidence (19–22). Knowledge-sharing among countries has proven to be a necessary component in the process of the development of the EU member countries (23–25). Therefore, studies investigating this issue can be considered highly valuable, in that they highlight the status of significant societal problems and possibilities for solving them (26–28).

The outcomes of these studies, presented in the subsection "Importance of regional policies for eliminating health inequalities in various regions," point to the importance of examining factors that affect decision-making mechanisms at the regional level and the importance of interdepartmental collaboration in the process of the creation and implementation of active policies. In the subsection "Fuzzy approaches as an optimal tool in project evaluation processes," an overview is provided of studies that have examined the effects of applying fuzzy approaches in decision-making mechanisms for the selection of optimal projects. These approaches enable the solution of regional development problems, such as the elimination of health inequalities between regions or countries. Although these studies are quite heterogeneous in their content, they made it possible to clarify the state of the problem at the international level, thereby emphasizing the strong significance of the research topic discussed.

2.1. Importance of regional policies for the elimination of health inequalities between regions

Mackenbach and Kunst (29) have pointed out the extent of health inequalities related to the socioeconomic environment. They propose improving educational opportunities, income distribution, health literacy, and access to health care as the main tools to solve these inequalities. According to Helgesen et al. (4), examining the prerequisites and capacities of municipalities for the implementation of appropriate policies and measures is very important for reducing inequalities in health care. The importance of examining socioeconomic factors to support public health within municipalities has also been justified by Hagen et al. (30). The authors observed great potential for the reduction of health disparities between the regions through intermunicipal collaboration related to local health promotion, as well as through the creation of intersectoral working groups.

The importance of intersectoral collaboration in the elimination of health inequalities between regions has also been evaluated by Storm et al. (7). This kind of collaboration between the public health sector and social and physical policy sectors is essential for reducing regional health inequalities, but implementing it in local practice is relatively difficult. When the effects of health strategies implemented at the national and regional levels were examined, some countries, such as France, Portugal, Poland, and Germany, obtained highly positive results. However, the effects varied greatly in countries such as Spain, Italy, and Belgium (8), which also confirms the weakness of the governance system in a majority of the countries regarding the impact of mechanisms for reducing health inequalities and the problematic integration of health strategies between the national and regional levels.

Morrison et al. (10) have confirmed that socioeconomic inequalities in the domain of health in urban areas are large. According to the authors, local governments have several possibilities for the creation of adequate policies to reduce them. The perceptions of public policymakers and their beliefs about the implementation of urban public policies are important.

Guldbrandsson and Bremberg (11) have also described the problems with intersectoral collaboration in public health and with reducing health disparities in their study. The authors considered these intersectoral collaborations to be insufficient and recommended the coordination of these activities between the Ministry of Health and other ministries. Borrell and Vaughan (31) investigated the need for a combination of political will, technical capacities, and efforts by citizens in order to achieve success in policies aimed at reducing social disparities in health. Health inequalities can be addressed by appropriate health and social policies involving various community groups and the government.

Szymborski and Zatoński (32) have highlighted the need to investigate the universal and selective approach adopted by interventions aiming to eliminate health inequalities. According to the authors, health literacy also plays an important role in this process (33–35).

Finally, Diez et al. (13) reported in their study on the effects of regional interventions on health inequalities within

European cities and observed that few local-level interventions address the socioeconomic determinants of health inequalities. The dominant determinants included in the interventions are healthcare, employment, and education. When examining the effectiveness of interventions, it is important to focus on the evidence base, participation, and intersectorality. Administrators reported perceiving the lack of funds and the sustainability of projects as the main obstacles. The authors appeal for strengthening of the capacities of administrators and for political leadership in the field of health management.

2.2. Fuzzy approaches as an optimal tool in the project evaluation processes

Mardani et al. (14) systematically investigated conventional and fuzzy decision-making techniques that are applied in solving health and medical problems. The authors found that the most frequently implemented decision-making techniques in healthcare were analytic hierarchy process (AHP) techniques and hybrid approaches. These techniques were primarily used to assess the quality of services in healthcare and the medical industry (36). Shaygan and Testik (37) employed fuzzy approaches to select projects aimed at eliminating the causes of underperformance. They considered the fuzzy analytical hierarchy process (FAHP) for decision-making, which is integrated with cause and effect diagrams, to be the optimal method.

Chatterjee et al. (38) drew attention to the risks involved in the construction of strategies based on project assortment and prioritization. Selection of the optimal project portfolio is a risky activity due to the lack of funds and due to nominal technology with the non-legal judgment of experts. The authors considered the use of an analytical hierarchy process in a fuzzy environment to be optimal for selection of the best projects, as it takes into account the multiple levels of project risk and a set of criteria and subcriteria.

Furthermore, Fouladgar et al. (39) used the FAHP and VIKOR techniques as optimal methods to calculate importance weights for evaluation criteria, and thus to rank a set of feasible projects. Bolat et al. (40) drew attention to the fact that the combination of FAHP and fuzzy multi-objective linear programming (FMOLP) is a suitable tool for supporting project selection. The complex model proposed by the authors takes into account the conflicting ideas of decision-makers about quantitative and qualitative criteria and evaluates projects in an integrated way. Rębiasz et al. (41) prefer a two-step evaluation model that combines fuzzy AHP and fuzzy TOPSIS for project evaluation. The authors established the advantage of this model through a case study.

Enea and Piazza (42) identified several limitations of the fuzzy AHP approach. Knowledge of these limitations when creating models will enable achievement of the best possible results in terms of certainty and reliability. Tulasi and Rao (43) positively evaluated several aspects of fuzzy AHP, primarily the fact that fuzzy AHP effectively examines data fuzziness. Mahmoodzadeh et al. (44) have proposed a new method for solving project selection problems through fuzzy AHP and implementation of the TOPSIS algorithm. Fuzzy AHP techniques significantly eliminate uncertainty in project evaluation, unlike the traditional AHP method.

Additionally, Mohammed et al. (45), based on the results of analyses, confirmed that the application of fuzzy AHP approaches will make it possible to obtain more accurate, scientific, and objective results in the evaluation of projects and will support the improvement of the quality level of project management. The authors also acknowledged the advantages of fuzzy AHP.

Tüysüz and Kahraman (46) evaluated information technology projects and stated that project risks are multidimensional, so they must be assessed through multi-attribute decision-making methods. Mohagheghi and Mousavi (47) state that fuzzy models are an optimal tool even in the evaluation of high-tech projects that are associated with a high level of risks and technological knowledge. The authors present a new decision-making model that operates under Pythagorean fuzzy set (PFS) uncertainty, applying their method to a real case study. This model employs last aggregation and avoids defuzzification until the final step of the process.

Oh et al. (48) propose a decision-making framework based on a fuzzy expert system that uses three tools: a strategic bucket for strategic resource allocation, scoring models for evaluating projects, and portfolio matrices for identifying the optimal set of projects in a portfolio. The final selection of projects was carried out by an expert system.

Jafarzadeh et al. (49) state that many methods have trouble accounting for three important criteria: selection criteria preference, decision uncertainty, and interdependencies. The authors propose a project evaluation method based on a combination of quality function development (QFD), fuzzy logic, and data envelopment analysis (DEA) to account for prioritization, uncertainty, and interdependence.

The selection of projects in the field of research and development is also a highly complex decision-making problem, as pointed out in a study by Mohanty et al. (50). The authors evaluated the importance of the opportunity environment, the impact of stakeholders on the evaluation, and the capacity of the candidate projects. In this area, important barriers also include bureaucratic factors, the different perceptions of the institution's goals by the pluralistic set of interested parties, and the functional specialization of organization members. These factors are significant obstacles to the achievement of coordination and consensus. The authors recommended applying fuzzy ANP (analytic network process) along with fuzzy cost analysis in the selection of research and development projects.

Bellahcene et al. (51) tackled with the selection of information systems projects, proposing an integrated AHP and a weighted-additive fuzzy goal programming (WAFGP) method as the optimal tools for their evaluation and selection. Similarly, Riddell and Wallace (52) tackled the problem of selecting a portfolio of research and development projects. The authors proposed a new tool to facilitate decision-making processes, which integrates fuzzy logic and expert judgment into the individual decision-making criteria for the decision-making process on projects in the research and development field. These authors also presented a real case study for illustration.

Mohagheghi et al. (53) evaluated studies focused on project portfolio selection and optimization, with an emphasis on evaluation criteria, applied approaches, uncertainty modeling, and application processes. The authors criticized the insufficient

attention that has been paid to the issue of the development of decision-making methods in the area of projects in previous periods and the insufficient critical evaluation of available studies. According to the authors, expert systems, artificial intelligence, and big data science have not been given sufficient consideration or sufficiently widely applied in project selection processes.

Wu et al. (54) propose a project selection method based on stochastic dominance and fuzzy theory. The authors attempted to eliminate the subjective influences in risk assessment when estimating the expected value of the project portfolio.

The outcomes of these research studies clearly indicate the strong benefits of applying fuzzy methods or fuzzy techniques in the process of evaluating projects in various social areas. The multidisciplinary nature and strong systemic interconnectedness of health inequalities also create various dimensions of uncertainty, indeterminacy, and risks. Fuzzy approaches play a crucial role in addressing these challenges and supporting the achievement of optimal results in the decision-making processes of policymakers, strategic planning, and development plans. Review of these studies also revealed a clear research gap. Specifically, there is a significant lack of studies reporting on the use of fuzzy approaches in decision-making processes in the evaluation and selection of projects aiming to improve health across the regions and eliminate health inequalities at regional and national levels.

3. Materials and methods

3.1. Formal formulation of the evaluation problem

Let us define the following: $P = \{P_1; P_2; \ldots; P_n\}$, a set of projects in the healthcare field of a certain region for evaluation and selection for financing by investors; C_P, an information model of the criteria for evaluating projects or scientific developments in the healthcare field; C_R, an information model of evaluation criteria for the regions where projects will be implemented; and M_P, a complex fuzzy mathematical model for evaluating projects in the healthcare field, considering the region of project implementation.

With these definitions, the system-theoretical-multiple model of the problem of evaluating and selecting projects in the healthcare field that will contribute to reducing the gap in development between regions, is presented as follows:

$$\left\{P, C_P, C_R, M_P | Y(f)\right\}. \quad (1)$$

As a result, we obtain output estimates of $Y\left(f\right)$, on the basis of which decisions are made on the financing of projects in the healthcare field, considering the level of development of the region. $Y\left(f\right) = \{\mu\left(P\right), \left(R\right), KR\}$, where $\mu(P)$ is the score of the project application in the healthcare field; (R) is the level of development of the region where the project will be implemented; and KR is the "desire for a regional coefficient" on the part of investors, which allows for the support of projects in less developed regions, thereby reducing the gap in development among regions.

The following administrative agents are introduced for the given task: experts are individuals who analyze and evaluate the project applications; a project analyst is a person who configures and manages the evaluation process according to investors' needs, forms a set of evaluation criteria for relevant types of project in the healthcare field, and builds an information model of the evaluation criteria for project implementation regions; and investors are the managers of the corresponding structural or investment funds, who make decisions on the selection and financing of the evaluated projects and introduce additional parameters for selection.

The structural scheme of the complex fuzzy model for evaluating projects in the healthcare field, accounting for the region of project implementation, is shown in Figure 1.

Figure 1 illustrates the structural scheme for the evaluation of projects in the healthcare field. After the evaluation and output of a ranking of projects, a decision is made regarding the selection. If the decision does not satisfy the investors, there is an opportunity to incorporate additional indicators and data for evaluation. At the output step, in order to increase the degree of reasonableness of decision-making regarding the investor's choice of projects for financing, a ranking of projects is provided, as well as their output evaluations, accounting for the region of project implementation and the policy of structured funds to reduce the development gap among regions.

3.2. Information models of project evaluation criteria and regions of project implementation

Information models based on which the submitted project applications will be evaluated are given below. Information models form the basis of the complex fuzzy model constructed to evaluate projects in the healthcare field, considering the region of project implementation.

C_P–Information model of criteria for evaluating projects or scientific developments in the healthcare field.

This information model consists of four groups of criteria: $G = \{G_1; G_2; G_3; G_4\}$. Each group consists of its own set of criteria, and applications are scored on each criterion.

G_1–*The idea and quality of the future project in the healthcare field.*

This group of criteria includes an assessment of the justification for the project, its focus on solving an actual problem in the social or scientific sphere of health care, the clarity of the formulation of the goal and tasks, and their compliance with the current level of innovative achievements.

K_{11}–Relevance of the project to the development policies of the healthcare industry.

The relevance of the project, in terms of its correspondence to one or more cross-cutting priorities of the development of the healthcare sector, both at the state level and at the EU level, is substantiated.

K_{12}–Relevance of the purpose, results, and target audiences.

The specified project description and its subsequent implementation will lead to expected products or services in the healthcare field, which will reflect its key priorities and attract expected target audiences.

K_{13}–Motivation and validity of the project concept in the healthcare field.

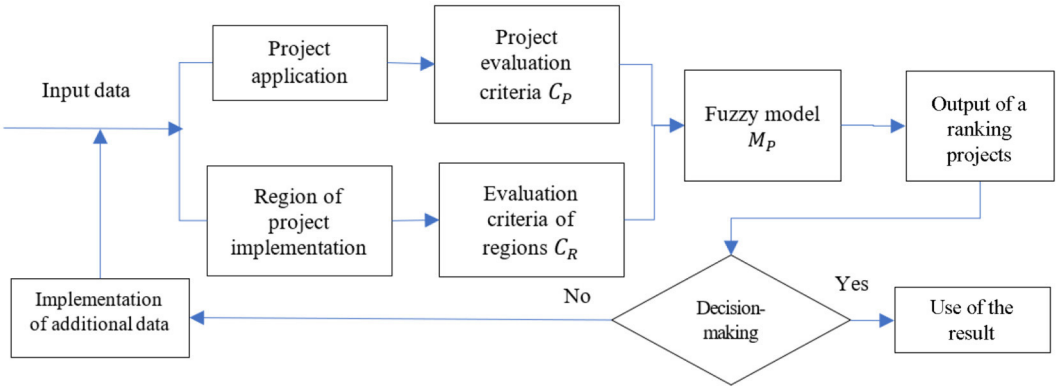


FIGURE 1
Structural scheme of the complex fuzzy model.

The main focus is on whether the current state of research and the problems that need to be solved are described adequately and with appropriate references.

K_{14}–Innovativeness of ideas (including from an interdisciplinary perspective).

K_{15}–Adequacy of the proposed approaches and methods for project implementation and their compliance with the purpose and tasks of the project.

G_2–Significance of the project in the healthcare field for further development of the territorial community or society.

Under this group of criteria, the rationale for the prospect of further application of the results obtained during the implementation of the project, or the possibility of commercialization of the project assets, is assessed.

K_{21}–The potential importance of the expected results and the acquisition of new knowledge, the development of new approaches and technologies, and/or their importance for solving real, practical scientific/technical/social problems.

K_{22}–The effectiveness and appropriateness of planned ways of publicizing/using project results.

G_3–The quality and realism of the proposed project implementation plan.

Here, the reasonableness of the work plan and the clarity of the intermediate goals, as well as their logical sequence, are evaluated. This includes evaluation of the clarity of the description of the planned tasks with the indication of specific results that can be verified; consistency of the complexity of the tasks with their time frames; compliance of the equipment and materials specified as necessary for implementing the project, the realization of its purpose and tasks; and the clarity of the description of equipment and materials and the adequacy of their price in the budget.

K_{31}–The validity of the work plan, the compliance of the time frame with the complexity of the formulated stages and tasks, the clarity of intermediate goals, and their logical sequence.

K_{32}–Correspondence of the material and technical base and equipment (available and planned) to the assigned tasks.

K_{33}–Balance and reasonableness of the overall project budget.

K_{34}–Availability and reasonableness of an assessment of possible risks and prediction of ways to prevent or resolve them.

G_4–Subjects involved in project implementation in the healthcare field.

Here, the validity of the qualitative composition of the subjects involved in project implementation and their partners, and their degree of preparedness to successfully make decisions regarding the declared goals of the project, is evaluated.

K_{41}–The presence of a project partner or the intention to involve one.

Involved and/or potential partners representing an industry other than healthcare.

K_{42}–Project team.

The composition of the project team is balanced between implementation of project tasks and project management; it includes all key performers responsible for the implementation of project tasks.

K_{43}–Experience in project activities.

The project applicant's previous experience and activities meet the requirements and match the declared areas of activity.

The groups of criteria listed and their sets of sub-criteria are open and non-exhaustive, and the developed model does not depend on their number. This means that the project analyst can always add other important indicators, depending on the specifics of the projects or the subject of the competition.

Next, C_R is considered; this is an information model of evaluation criteria for project implementation regions.

This information model must be developed in consideration of the regions where the projects will be implemented. An example of the criteria for evaluation of the development of regions is given for regions of Ukraine. The information is taken from open data provided by the Ministry of Development of Communities and Territories of Ukraine (1). The indicators for "Availability and quality of services in the field of health care" are as follows:

RC_1–Total mortality rate per 1,000 people of the existing population (per mille).

RC_2–Average life expectancy at birth (years).

RC_3–Number of live births per 1,000 people of the existing population (per mille).

RC_4–Planned capacity of outpatient polyclinic facilities per 10,000 people (visits per shift).

RC_5–Number of patients diagnosed with active tuberculosis for the first time in their lives per 100,000 population (persons).

Assessments according to the above criteria are quantitative and are not normalized. Validation of the research is carried out using real data obtained from open reports by the Ministry of Development of Communities and Territories of Ukraine.

The information model presented here is not a benchmark for assessment of the level of healthcare in the region. Instead, it demonstrates the possibility of formulating estimates for particular regions based on real data and is also used to verify and demonstrate a fuzzy model. The developed mathematical model does not depend on the number of evaluation criteria.

3.3. A complex fuzzy model for evaluating projects in the healthcare field, accounting for the region of project implementation

The mathematical model of project evaluation in the healthcare field, accounting for the region of project implementation, is presented in three stages: fuzzy evaluation of the project applications in the healthcare field; derivation of the level of development of the project implementation region; and derivation of output estimates of projects in the healthcare field, considering the level of development of the region and decision-making by investors regarding financing.

First stage: fuzzy evaluation of the project application in the healthcare field

According to the given information model consisting of the C_P criteria, an expert assigns the appropriate score for each criterion, for example, from the interval (1, 10). Such a score can be determined by the expert through analysis of the project application, using their own experience and practical knowledge. A convolution of evaluations can be determined, for example, as the sum of the scores for of the answers of the grading scale separately for each group of criteria; this can be denoted as $g_i,\ i = \underline{1,k}$.

Thus, a set of numerical variables $g = \{g_1; g_2; \ldots; g_k\}$ can be obtained for the group of evaluation criteria $G = \{G_1; G_2; \ldots; G_k\}$, taking values within a certain numerical interval. Each of these numerical variables is considered to be a carrier set of the linguistic variable U, consisting of the following terms:

- U_{i1}–the evaluation of the group of criteria G_i is significantly lower than "investors' wishes";
- U_{i2}–the evaluation of the group of criteria G_i is lower than "investors' wishes";
- U_{i3}–the evaluation of the group of criteria G_i is close to "investors' wishes";
- U_{i4}–the evaluation of the group of criteria G_i is a little better than "investors' wishes";
- U_{i5}–the evaluation of the group of criteria G_i is much better than "investors' wishes."

"Investors' wishes" is a conditional convolution of scores of a group of criteria that satisfies the investors when considering, evaluating, and choosing a project for financing.

Since the input data are obtained by expert means and are subjective by nature, it is necessary reveal uncertainty in the input data for the groups of criteria. This operation is referred to as fuzzification of input data. Next, we project the set of "investors' wishes" onto the carrier set of linguistic variables U.

Since the obtained numerical variables $\{g_1; g_2; \ldots; g_k\}$ take different numerical values, it is necessary to calculate normalized values for comparison. To perform fuzzification of the input data, we construct a membership function of the type "Value x is greater". For example, an s-shaped membership function will have the following form:

$$\mu(g_{ij}) = \{0,\ g_{ij} \le min;\ 2\left(\frac{g_{ij} - min}{max - min}\right)^2,\ min < g_{ij} \le \frac{min + max}{2};\ 1 - 2\left(\frac{max - g_{ij}}{max - min}\right)^2,\ \frac{min + max}{2} < g_{ij} < max;\ 1,\ g_{ij} \ge max. \quad (2)$$

Here, min is the convolution of the sum of the minimum points (grades) and max is the convolution of the sum of the maximum points (grades) according to the criteria. In the group G_i, g_{ij} is the convolution of the sum of the points (grades) for the *j-th* project under consideration($i = \underline{1,k}; j = \underline{1,n}$). In this way, the received input data can be normalized and rendered comparable.

Let $\gamma_{ij} = \mu(g_{ij})$ be the value of the function of membership of the corresponding project applications by groups of criteria G_i,$(\ i = \underline{1,k})$.

Let the investor have a set of considerations for each group of criteria, which should be regarded as the "investors' wishes"; that is, the sum of the points for each group of criteria. We denote these by the vector $T = (t_1, t_2, ..., t_k)$ by groups of criteria G_i,$(\ i = \underline{1,k})$. Similarly, for each value, the membership function can be calculated according to formula (2). Consequently, the vector of the membership function "investors' wishes" can be obtained as $\alpha = (\alpha_1, \alpha_2, ..., \alpha_k)$, where $\alpha_i = \mu(t_i), (\ i = \underline{1,k})$. The obtained values are given in Table 1.

Next, relative to the "investors' wishes" and the results obtained for each group of criteria G_i, the values of the membership function are projected onto the set of carriers of the linguistic variable U, which allows us to reveal the essence of the considered project application in relation to the "investors' wishes". Therefore, for each term U, the construction of triangular membership functions can be proposed, as follows:

$$\mu_{U1}\left(\gamma; \alpha - \frac{\alpha}{2}; \alpha - \frac{\alpha}{4}\right) = \{1,\ \gamma \le \alpha - \frac{\alpha}{2};\ \frac{3\alpha - 4\gamma}{\alpha},\ \alpha - \frac{\alpha}{2} < \gamma \le \alpha - \frac{\alpha}{4}. \quad (3)$$

$$\mu_{U2}\left(\gamma; \alpha - \frac{\alpha}{2}; \alpha - \frac{\alpha}{4}; \alpha\right) = \{\frac{4\gamma - 2\alpha}{\alpha},\ \alpha - \frac{\alpha}{2} < \gamma \le \alpha - \frac{\alpha}{4};\ \frac{4\alpha - 4\gamma}{\alpha},\ \alpha - \frac{\alpha}{4} < \gamma \le \alpha. \quad (4)$$

$$\mu_{U3}\left(\gamma; \alpha - \frac{\alpha}{4}; \alpha; \alpha + \frac{\alpha}{4}\right) = \{\frac{4\gamma - 3\alpha}{\alpha},\ \alpha - \frac{\alpha}{4} < \gamma \le \alpha;\ \frac{5\alpha - 4\gamma}{\alpha},\ \alpha < \gamma \le \alpha + \frac{\alpha}{4}. \quad (5)$$

TABLE 1 Fuzzification of input data.

Groups of criteria	"Investors' wishes"	P_1	P_2	...	P_n
G_1	$(t_1; \alpha_1)$	$(g_{11};\ \gamma_{11})$	$(g_{12};\ \gamma_{12})$	…	$(g_{1n};\ \gamma_{1n})$
G_2	$(t_2; \alpha_2)$	$(g_{21};\ \gamma_{21})$	$(g_{22};\ \gamma_{22})$	…	$(g_{2n};\ \gamma_{2n})$
…	…	…	…	…	…
G_k	$(t_k; \alpha_k)$	$(g_{k1};\ \gamma_{k1})$	$(g_{k2};\ \gamma_{k2})$	…	$(g_{kn};\ \gamma_{kn})$

$$\mu_{U4}\left(\gamma; \alpha; \alpha+\frac{\alpha}{4}; \alpha+\frac{\alpha}{2}\right) = \{\frac{4\gamma-4\alpha}{\alpha},\ \alpha<\gamma\le\alpha+\frac{\alpha}{4};\ \frac{6\alpha-4\gamma}{\alpha},\ \alpha+\frac{\alpha}{4}<\gamma\le\alpha+\frac{\alpha}{2}. \quad (6)$$

$$\mu_{U5}\left(\gamma; \alpha+\frac{\alpha}{4}; \alpha+\frac{\alpha}{2}\right) = \{\frac{4\gamma-5\alpha}{\alpha},\ \alpha+\frac{\alpha}{4}<\gamma\le\alpha+\frac{\alpha}{2};\ 1,\ \gamma\ge\alpha+\frac{\alpha}{2}. \quad (7)$$

Depending on which interval γ falls into for each group of criteria G_i, the appropriate membership function μ_U is selected relative to the "investors' wishes" of α. As a result, for each group of criteria G_i for all projects P_j, we obtain a linguistic value and its confidence assessment. The confidence assessment means that the assessment of the group of criteria belongs to one term or another. This allows the model to reveal the subjectivity of opinions regarding the assignment of points by experts and to construct a formal representation of the quality of the project application.

Since the constructed membership functions (3)–(7) have intersections, either one or two terms are obtained for each group of criteria and, accordingly, the same number of reliability estimates are obtained for them. In this regard, we offer the following aggregation function:

$$\mu(O_{ij}) = \{\mu_{Uijf}\cdot\sigma_{ijf},\ if\ one\ term,\ \mu_{Uijf}\cdot\sigma_{ijf} + \mu_{Uij(f\pm1)}\cdot\sigma_{ij(f\pm1)},\ if\ two\ terms, \quad (8)$$

where $i = \underline{1,k}; j = \underline{1,n}; f = \underline{1,5}$; and σ_{ijf} is determined by the characteristic function on the interval [1; 100]: for example,

$$\sigma_{ijf} = \{50\ if\ U_{ijf} = U_{ij1};\ 75\ if\ U_{ijf} = U_{ij2};\ 100\ if\ U_{ijf} = U_{ij3};\ 75\ if\ U_{ijf} = U_{ij4};\ 50\ if\ U_{ijf} = U_{ij5}. \quad (9)$$

Without reducing generality, the project analyst can choose a different possible interval, as well as an alternative approach for the transition from linguistic to quantitative evaluation. The construction of such a characteristic function stems from the authors' own experience, as well as from the consideration that, as a rule, the final evaluation of project applications is provide on a 100-point scale. The output of the characteristic function decreases when the evaluation of the groups of criteria is further away from the "investors' wishes."

The obtained membership function $\mu(O_{ij})$ shows to what extent the project application under consideration satisfies the wishes of the investors according to each group of criteria.

The investor may need to set the weighting coefficients $\{p_1, p_2, \ldots, p_k\}$ for each group of criteria on the interval (1, 10). If there is no such need, then the weighting coefficients will be considered balanced. Next, normalized weighting factors for each group of criteria are determined:

$$w_i = \frac{p_i}{\sum_{i=1}^{k} p_i},\ i = \underline{1,k};\ w_i \in [0,1] \quad (10)$$

meeting the condition $\sum_{i=1}^{k} w_i = 1$.

A weighted average convolution is proposed to obtain the output estimate for the healthcare project application $\mu(P)$:

$$\mu(P_j) = \sum_{i=1}^{k} w_i\cdot\mu(O_{ij}), i = \underline{1,\ k}; j = \underline{1,\ n}. \quad (11)$$

Thus, for all projects under consideration, we obtain an output estimate for the project application within the interval [0; 100].

Second stage: determination of the level of development of the region where the project will be implemented

As mentioned above, our research is aimed at supporting decision-making regarding the financing of healthcare projects by structural funds whose policy involves reducing the development gap among different regions. Therefore, a feature of the presented model is that it can adequately account for policies aimed at reducing the development gap among regions. To this end, the level of development of the region where the project will be implemented is derived from the mathematical model as (R). This is presented in Table 2, which represents input assessments of regions according to C_R, the information model of the assessment criteria for project implementation regions.

TABLE 2 Table of evaluations of regions by criteria.

	R_1	R_2	...	R_r
RC_1	C_{11}	C_{12}	…	C_{1r}
RC_2	C_{21}	C_{22}	…	C_{2r}
…	…	…	…	…
RC_{rc}	C_{rc1}	C_{rc2}	…	C_{rcr}

Here, C_{rcr} is an estimate of the rc-th criterion for the r-th region, and is quantitative and not normalized. In all cases, $r \le n$, since several projects may be submitted for consideration from the same region. In general, this assessment can be made quantitatively on different assessment scales, or even qualitatively. In this case, it is necessary to standardize the data. To do so, we can use the method of displaying fuzzy knowledge that is described in Petrovic et al. (2). For the normalization of quantitative data, we use the relative

normalization formula:

$$O_{rcr} = \frac{C_{rcr}}{\max_r C_{rcr}} \text{ or } O_{rcr} = \frac{\min_r C_{rcr}}{C_{rcr}}. \quad (12)$$

Let the investor or project analyst set the weighting coefficients for each regional criterion $\{v_1, v_2, \ldots, v_{rc}\}$ on the interval [1, a]. Following this, the normalized weighting coefficients can be determined similarly for each criterion:

$$\varepsilon_g = \frac{v_g}{\sum_{g=1}^{rc} v_g}, g = \underline{1, rc}; \varepsilon_g \in [0, 1], \quad (13)$$

meeting the condition $\sum_{g=1}^{rc} \varepsilon_g = 1$.

To deduce the level of development of the region, the following multiplication is proposed:

$$\Delta_j(R_h) = \sum_{g=1}^{rc} \alpha_g \cdot O_{hg}, h = \underline{1, r}, j = \underline{1, n}. \quad (14)$$

Third stage: derivation of aggregated estimates for projects in the healthcare field, accounting for the level of development of the region and decision-making by investors on their financing

Based on practical experience, more developed regions submit better project applications. This is due to many factors: for example, the region's adherence to modern trends, best practices, the experience of the project implementation team, access to a wide range of partners, experience in implementing similar projects, greater financial opportunities in co-financing, and so on. Therefore, to reduce the gap in the development of regions, it is proposed that investors specify a "desire for a regional coefficient", i.e., $KR \in [0; 1]$. Specifically, if KR approaches 1, then investors are interested in the most developed regions, and vice versa. This will allow for rapid adjustment of the weight placed by investors on the regions where future projects are to be implemented. Regarding the "desire for a regional coefficient", we calculate the following values, which will represent a relative estimate of the proximity of the "desire for a regional coefficient" to the value of the corresponding level of development of the region:

$$\chi(R_h) = 1 - \frac{|KR - \Delta(R_h)|}{\{KR - \min_h \Delta(R_h); \max_h \Delta(R_h) - KR\}}, \quad h = \underline{1, r}, j = \underline{1, n}. \quad (15)$$

To derive the output estimates for projects in the healthcare field, accounting for the level of development of the region and the decision-making by investors on financing, we use the following formula:

$$Y(f_j) = \mu(P_j) \cdot \chi_j(R), j = \underline{1, n}. \quad (16)$$

Based on the output score $Y(f_j) \in [0; 100]$, a ranking of projects P_j is constructed.

The obtained output estimate $Y(f)$ incorporates the content of the project assessment, accounting for the policy of reducing the gap in the development of regions. Based on the output data, investors make decisions on the feasibility of financing healthcare projects, accounting for the level of development of the region where the project is to be implemented. If a situation arises in which the investors are not satisfied with any of the solutions, then we return to re-evaluation with the involvement of additional indicators and data.

The value of the model lies in enabling us to understand the essence of the evaluated project within the space of assessments, accounting for the wishes of the investors at various stages of assessment, including the region where the project will be implemented. The use of fuzzy set theory is another significant advantage, as it allows the subjectivity of expert determinations to be revealed, in order to obtain a quantitative assessment of projects based on fuzzy expert data inputs. Making a reasoned decision is possible only based on quantitative initial data. Another advantage is the ability to easily adjust the parameters of the model depending on the evaluation purpose and to enter the desired regional coefficient, which collectively reduces the subjective influence of project analysts or experts on the evaluation process and the final result of project selection by investors. Without reducing the generality, other researchers can use other methods of multi-criteria alternative selection, such as the hierarchy analysis method, fuzzy TOPSIS, or VIKOR. However, in order to incorporate the desired regional coefficient, special procedures must be introduced, entailing additional calculations. This will make the calculations involved in using the decision support system much more difficult, and in turn, increase the difficulty of implementing it in practice. In addition, with a large number of projects, for example, the hierarchy analysis method will not achieve adequate results. The disadvantages of this approach include the use of different types of membership functions, characteristic functions, and convolutions, which may lead to ambiguity in the final results. However, these disadvantages will not affect the reliability of the results.

4. Results

We verify and test the results of the research on the example of the evaluation of five projects in the field of healthcare, $P = (P_1; P_2; \ldots; P_5)$, which are implemented at the expense of state funds of Ukraine (3, 4):

- P_1–Personalized approaches to the diagnosis, prevention, and treatment of vascular diseases with prognostic modeling of the individual development of atherosclerosis.
- P_2–Study of the course and consequences of COVID-19 in patients with diabetes and the impact of SARS-CoV-2 infection on the rate of biological aging.
- P_3–Study of the circulation of zoonotic influenza A viruses in the natural reservoir and assessment of their epidemic risks and danger to human health in Ukraine.
- P_4–Development of new anesthetic agents.
- P_5–Drosophila melanogaster as a platform for screening new antiviral compounds and studying cellular mechanisms of defense against viruses.

Project P_1 is currently being implemented at the expense of the state budget of Ukraine at the Uzhhorod National University (region: Zakarpattia) (3), and the remaining projects P_2–P_5 are being implemented at the expense of grant support from the National Research Fund of Ukraine (4).

The evaluation calculation is carried out based on the complex fuzzy model developed for evaluation of projects in the healthcare field, accounting for the region of project implementation. For this purpose, the assessment is carried out via the three stages described above. Such an evaluation was carried out by the authors of this article, who are experts in various commissions and competitions for the evaluation of grants, scientific, technical, and startup projects.

As an example, consider in more detail the evaluation of a project application for a project P_1.

First stage: fuzzy evaluation of the project application in the healthcare field.

At the first stage of assessment of project P_1, we receive the input data for each evaluation criterion according to C_P, the information model of evaluation criteria for projects or scientific developments in the healthcare field. G_1 represents the idea and the quality of the project ($K_{11} = 9$; $K_{12} = 10$; $K_{13} = 8$; $K_{14} = 7$; $K_{15} = 10$; $g_{11} = 44$); G_2 represents the significance of the project for further development of society ($K_{21} = 10$; $K_{22} = 8$; $g_{21} = 18$); G_3 represents the quality and realism of the proposed project implementation plan ($K_{31} = 9$; $K_{32} = 10$; $K_{33} = 10$; $K_{34} = 7$; $g_{31} = 36$); and G_4 represents the subjects involved in project implementation ($K_{41} = 8$; $K_{42} = 10$; $K_{43} = 10$; $g_{41} = 28$).

Formula (2) is used for fuzzification of the input data. The following is thereby obtained for G_1: min = 5, max = 50, $\mu\left(g_{11}\right) = 1 - 2\left(\frac{50-44}{50-5}\right)^2 \approx 0.97$. Similarly, $\mu\left(g_{21}\right) = 1 - 2\left(\frac{20-18}{20-2}\right)^2 \approx 0.98$; $\mu\left(g_{31}\right) = 1 - 2\left(\frac{40-36}{40-4}\right)^2 \approx 0.98$; $\mu\left(g_{41}\right) = 1 - 2\left(\frac{30-28}{30-3}\right)^2 \approx 0.99$.

Next, for each group of criteria, investors express their "investors' wishes" according to four groups of criteria: $T = (40; 18; 37; 25)$. Similarly, the membership function is calculated for each value according to formula (2): $\alpha = (0.9; 0.98; 0.99; 0.93)$.

Subsequently, the values of the membership function relative to the "investors' wishes" and the results obtained for each group of criteria are projected onto the set of carriers of the linguistic variable U according to formulas (3)–(7):

G_1: U_{113} with confidence $\mu_{U113} = 0.69$ or U_{114} with confidence $\mu_{U114} = 0.31$.

G_2: U_{212} with confidence $\mu_{U212} = 0$ or U_{213} with confidence $\mu_{U213} = 1$.

G_3: U_{312} with confidence $\mu_{U312} = 0.04$ or U_{313} with confidence $\mu_{U313} = 0.96$.

G_4: U_{413} with confidence $\mu_{U413} = 0.78$ or U_{414} with confidence $\mu_{U414} = 0.22$.

Next, the extent to which the project application under consideration satisfies the wishes of the investor according to each group of criteria is calculated using formula (8):

$\mu(O_{11}) = 0.69 \cdot 100 + 0.31 \cdot 75 = 92.25$; $\mu(O_{21}) = 0 \cdot 75 + 1 \cdot 100 = 100$; $\mu(O_{31}) = 0.04 \cdot 75 + 0.96 \cdot 100 = 99$; $\mu(O_{41}) = 0.78 \cdot 100 + 0.22 \cdot 75 = 94.5$.

Let the investor set the weighting coefficients for each group of criteria {10; 9; 8; 8}. On this basis, the normalized weighting factors calculated by formula (10) are: $w_1 = 0.28$; $w_2 = 0.26$; $w_3 = 0.23$; $w_4 = 0.23$.

Finally, a weighted average convolution according to the formula is used to obtain the output estimate for the project application (11): $\mu(P_1) = 0.28 \cdot 92.25 + 0.26 \cdot 100 + 0.23 \cdot 99 + 0.23 \cdot 94.5 = 96.4$.

Information on the evaluation of the remaining projects P_2—P_5 is provided in the official results of the competition (5): $\mu(P_2) = 96.1$; $\mu(P_3) = 94.4$; $\mu(P_4) = 93.4$; $\mu(P_5) = 92.8$.

Second stage: determination of the level of development of the region where the project will be implemented

The indicators of "availability and quality of services in the field of healthcare" (1) according to the above criteria for the regions corresponding to the projects under consideration are presented in Table 3. Information on indicators for Ukraine is also provided in the table, for purposes of normalization of the quantitative data, as well as the weighting factors for each regional criterion set by the project analyst.

In the next step, the relative normalization formula (12) is used to normalize quantitative data. Normalized weighting factors for each criterion are also determined according to formula (13). The results are shown in Table 4.

To derive the level of development of the region, the membership functions are calculated using formula (14): $\Delta_1(R_1) = 0.861$; $\Delta_2(R_2) = 0.936$; $\Delta_3(R_3) = 0.774$; $\Delta_4(R_2) = 0.936$; $\Delta_5(R_4) = 0.789$.

Third stage: derivation of aggregated estimates for projects in the healthcare field, accounting for the level of development of the region and decision-making by investors on financing

In pursuit of the goal of reducing gaps in development between the regions, the investors specify their "desire for a regional coefficient". For example, let us set this coefficient at the value of $KR = 0.8$. Using formula (15), values are calculated to provide a relative estimate of the proximity of the value of this "desire for a regional coefficient" to the corresponding level of development of the region: $\chi(R_1) = 0.56$; $\chi(R_2) = 0$; $\chi(R_3) = 0.81$; $\chi(R_4) = 0.92$.

The following formula is used to derive output estimates for the projects (16):

$$Y\left(f_1\right) = 96.4 \cdot 0.56 = 53.59;\ Y\left(f_2\right) = 0;\ Y\left(f_3\right) = 76.71;$$
$$Y\left(f_4\right) = 0;\ Y\left(f_5\right) = 84.97.$$

Finally, based on the obtained estimates, we can construct a ranking of projects, accounting for the policy of reducing the gaps in development between the regions: P_5, P_3, P_1, P_2, P_4.

The investor concludes that, with the "desire for a regional coefficient" set to 0.8, the best decision in terms of the selection of a project for financing and implementation will be project P_5.

5. Discussion

In the study, a fuzzy model of support for decision-making in the evaluation and selection of projects in the healthcare field was developed to reduce the development gap between regions. For this purpose, the following components were developed: an information model of criteria for evaluating investment projects or scientific developments in the healthcare field; a model of criteria for evaluating regions where projects are planned to be implemented in terms of the level of development of these regions; and a complex fuzzy mathematical model for evaluating projects

10.3389/fpubh.2023.1222125

TABLE 3 Input data on "availability and quality of services in the field of healthcare".

Criterion label	Weight	Values for Ukraine	P_1	P_2,P_4	P_3	P_5
			R_1	R_2	R_3	R_4
			Zakarpattia	Kyiv	Kharkiv region	Lviv region
RC_1	10	14.8 (min)	14.8	15.3	21	16
RC_2	9	73.5 (max)	70.47	73.5	71.11	72.42
RC_3	9	10.2 (max)	10.1	10	5.9	7.8
RC_4	8	306.8 (max)	250.6	287.9	298.1	201.6
RC_5	7	18.4 (min)	44	24.5	28.2	35.3

TABLE 4 Normalized data on "availability and quality of services in the field of healthcare".

Criterion label	Normalized data	P_1	P_2,P_4	P_3	P_5
		$\mathbf{R_1}$	$\mathbf{R_2}$	$\mathbf{R_3}$	$\mathbf{R_4}$
		Zakarpattia	Kyiv	Kharkiv region	Lviv region
RC_1	0.23	1	0.967	0.705	0.925
RC_2	0.21	0.959	1	0.967	0.985
RC_3	0.21	0.99	0.98	0.578	0.765
RC_4	0.19	0.817	0.938	0.972	0.657
RC_5	0.16	0.418	0.751	0.652	0.521

in the healthcare field, with the region of project implementation taken into consideration. The resulting model was tested on an example evaluation of five projects in the healthcare field.

This research is based on the apparatus of fuzzy sets, which allows for increasing the degree of validity of decisions. The value of the model is that it allows the user to obtain a quantitative assessment of projects based on fuzzy input expert data, accounting for the wishes of the investor at different stages of the assessment, the policy of reducing development gaps among regions, and the wishes of the investor regarding the regional coefficient. The evaluation procedure itself is simple and natural for experts to implement. The input data are processed by a fuzzy model based on information models for evaluating project applications and regions. This reveals the subjectivity of experts' evaluations and establishes the model parameters and regional coefficients in order to reduce the subjective influence of project analysts or experts on the evaluation process and the final selection of projects by investors. The output of the model takes the form of a quantitative assessment and a ranking of the candidate healthcare projects for investors to choose from to pursue the goal of reducing the development gap between regions.

The advantages of a fuzzy decision support model for the evaluation and selection of projects in the healthcare field with the goal of reducing the development gap between regions arise from several features: (1) the mathematical model is based on various information models of input data adapted for the evaluation of projects or scientific developments in the healthcare field; (2) the sets and groups of criteria are open; (3) the model does not depend on their number, and project analysts can always adapt the set of criteria to highly specialized project topics; (4) the model makes it possible to understand the essence of the proposed project within the assessment space; (5) the model can easily be adjusted depending on the purpose of the assessment; (6) this approach reveals the uncertainty in the input data (expert estimates) using the carrier set of the linguistic variable U relative to "investors' wishes"; (7) it considers the wishes of the investor regarding the region where the project will be implemented by specifying a "desire for a regional coefficient"; and (8) it focuses on the unbiased assessment of projects, which increases the security of their financing overall.

It should be noted that the outputs of this fuzzy decision-making support model for the evaluation and selection healthcare projects are dependent on the meaning of the "investors' wishes". This means that the maximum input values for a project do not mean a high output value. In addition, the input data undergo fuzzification, after which the values of the membership function are projected onto the set of carriers of the linguistic variable U. Through this procedure, errors of both external and internal origin can be avoided. Therefore, the decision support system is robust.

A limitation of our study is the use of different types of membership functions, characteristic functions, and convolutions, which may lead to ambiguity in the final results. Nevertheless, this limitation did not affect the reliability of the results obtained. This is supported by the research findings and the justified use of the fuzzy sets apparatus. The rationality of the obtained initial estimate $Y(f)$ for building a ranking series of projects also demonstrates the advantages of the model developed. Furthermore, the results obtained fully conform to the research hypothesis formulated.

The development of tools to support decision-making techniques in the field of health represents a powerful mechanism in the process of reducing of health inequalities between regions (55). However, no tool can replace collaboration networks applying a multidisciplinary approach, alongside collaboration

between sectors (56, 57). Many studies have claimed that urban administrators perceive health inequalities and understand the concepts of intersectorality, participation, and evidence, but considerate has become increasingly important to consider the sustainability of health systems at the regional level (58, 59).

Regional health policies require constant attention and are dependent on collaborative systems, data registries, and collaboration with various regional and national health associations (60–62). Diez et al. (13) recommended strengthening the capacities of administrators and of the regional political leadership in the healthcare field. If city governments want to make progress on policies aiming to reduce health inequalities, they need strong political commitment and support from social movements, including the support of public health experts. As stated by Borrell et al. (31), the policy agenda must include the goals in the area of health inequalities at different regional levels. Bekken et al. (63) drew attention to the insufficient capacity for effective activities aiming toward reducing health inequalities in smaller municipalities within defined regional units. Furthermore, they regarded a weak knowledge base as a critical factor, including the absence of systems for monitoring of social inequalities. New legislation in the domain of health may represent significant opportunities, and many countries are constantly developing such legislation in order to adapt to demographic trends and globalization risks. Morrison et al. (10) recommend supporting academic research on the creation of effective universal policies and evaluating their impact. This could also support the development of regional benchmarking indicators.

To reduce inequalities in the healthcare field, intersectoral collaboration will still be necessary (specifically, collaboration between the public health sector and other sectors), and this is often difficult to implement in practice. High-quality interdepartmental collaboration can also enable decision-making processes in the selection of effective interventions in the healthcare field while simultaneously eliminating resource and preference risks in the decision-making mechanisms. Therefore, it is necessary to investigate the potential for this collaboration, which already exists in the regions, because its absence can represent a significant barrier to the implementation of quality projects targeting the promotion of health. Storm et al. (7) also call for the involvement of these sectors in the network of public health policies, along with the harmonization of goals, the use of policies by relevant sectors, and formalized collaboration.

There is no optimal model for effective collaboration, so the success of health policies depends on the synergy between individual components of regional development systems. Many studies have claimed that space for improvement of this collaboration among sectors at regional and national levels will always be created, but it is necessary to seek out the most effective forms of collaboration in the context of the political goals being supported. This study creates a space for subsequent research in this area.

The fuzzy model for decision-making support developed by us for the evaluation and selection of projects in the healthcare field will help reduce the development gap in regions and ensure their sustainability. If projects are positively evaluated based on this comprehensive fuzzy model (which accounts for several aspects of the health system, including the availability and quality of healthcare provision), this is an indication that their outcomes can successfully fulfill the development goals set by health policy by and national and regional strategies. This will contribute to the reduction of regional and national disparities in population health, which will be reflected in macroeconomic indicators (64). From a macroeconomic perspective, the appropriate selection and successful implementation of ambitious projects in the healthcare field, which follow the resources and processes of the health sector, will help with the achievement of economic and social stability within and among countries. The developed model will be a useful tool for administrators and project analysts in such decision-making processes; it can be used to avoid ineffective financing of projects and to obtain resources from EU funds. From a long-term perspective, the need to develop tools that can be used to compare and evaluate the effectiveness of decision-making processes in various sectors when using resources drawing on EU funds has been highlighted, leading to the development of benchmarking indicators (65, 66). Their absence in the healthcare system to date is the result of not only the methodological complexity and strong heterogeneity of the healthcare systems, but also a lack of effort on the part of research teams to search for optimal decision-making mechanisms and indicators for their evaluation (67). Thus, the development of benchmarking indicators to enable the evaluation of the effects of implemented projects is an additional topic of research. Finally, these issues will also be related to an examination of their relationships with sustainable development goals (SDGs-17), which have not been sufficiently explored in existing studies. Inadequate fulfillment of the SDG-17 goals within individual countries has often been the subject of criticism among experts and in research. Financial schemes backed by EU funds can also help to solve these problems.

6. Conclusions

Sustaining good health and enhancing the quality of life of the population is the primary objective not only of the EU, but of all institutions that are intensively working toward improving public health and preventing diseases through their activities and policies. EU health strategy focuses on strengthening collaboration and coordination between the member countries, analyzing the factors affecting public health, and strengthening prevention processes, cross-border healthcare, and many other strategic areas. The availability of various financial mechanisms in the healthcare field should support access to healthcare provision, as well as increasing its availability, safety, quality, and efficiency. Health policy managers at regional and national levels are increasingly exposed to demanding decision-making processes, which prompts the construction of effective decision-making tools. Fuzzy approaches have been effectively applied in decision-making mechanisms in various sectors and can even solve difficult decision-making tasks. This study focused on constructing a tool based on a fuzzy approach, enabling effective decision-making support for the process of selection of projects in the healthcare field; this may involve many criteria regarding causal factors in health and its determinants, as well as the specifics of regional health systems.

The primary objective of our research was to develop a fuzzy decision-making support model for the evaluation and selection of

healthcare projects in order to reduce the development gap between regions. The following results were obtained:

- An information model of criteria for evaluating investment projects or scientific developments in the healthcare field was developed for the first time. The set of criteria is open, and the model is not dependent on the use of a specific number of criteria. Project analysts can always add their own metrics when customizing the evaluation model for specific projects.
- A model for assessment and derivation of the level of development of regions was presented for the first time, using the example information indicator "availability and quality of services in the field of health care". Investors are offered the opportunity to specify a "desire for a regional coefficient", which allows them to quickly adapt the weight placed in decision-making on the regions where future projects are to be implemented.
- For the first time, a complex fuzzy decision-making support model for the evaluation and selection of healthcare projects was developed to reduce the development gap between regions. The model is based on the opinions of experts in point-based assessments. The output of the model takes the form of a ranking of projects, as well as their output evaluations, which takes into account the region of project implementation and the policy of structured funds to reduce the development gap between regions.
- The results of the study were tested in an evaluation of five real projects in the healthcare field that have been implemented at the expense of state funds in Ukraine. Furthermore, the adequacy of the complex fuzzy model developed in this study and the information models of the criteria laid down on its basis was experimentally confirmed.

The obtained results demonstrated the applied value of the model and supported the scientific hypothesis of this study.

In future studies, software could be constructed in the form of a web platform, based on a complex fuzzy model, providing an innovative tool for selecting healthcare projects for support from structural funds, considering their policies in relation to reduction of the development gaps between different regions and countries in order to achieve economic and social cohesion.

The significance of developing and implementing these tools to support decision-making processes in healthcare systems will grow in the future. Based on the demographic aging processes occurring on a global scale, it is necessary to assume that the sustainability of health and social systems in individual countries will take on increasing importance. As the population continues to age, a larger proportion of individuals will live to an older age, leading to an increase in patients with numerous comorbidities and a growing demand for health and social care services. This issue is also strongly related to limited resources. This will create pressure to optimize health systems and systematically search for opportunities to ensure the availability and provision of adequate healthcare services. Resources from EU funds will represent a strong tool for support of individual countries in meeting these increasingly demanding health goals. The use of suitable decision-making processes in the selection of optimal projects will support the effective use of resources provided by EU funds and the fulfillment of global goals in the healthcare field, thereby reducing inequalities among various countries.

The findings of this study will be highly beneficial to health policymakers; they will also aid in the formulation of strategies in the healthcare field and regional development plans, thereby supporting interdepartmental collaboration, which is necessary for effective decision-making mechanisms. The study and its results strongly advocate for the construction of national and international data platforms to develop benchmarking indicators. These indicators will play a decisive role in evaluation processes and in quantifying the effects arising from the support of activities funded by the EU.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

BG, MK, and VP: conceptualization and writing—original draft preparation. VP and VS: methodology and formal analysis. VP and BG: software, visualization, and project administration. TM and MK: validation. BG, MK, and TM: investigation. MK and BG: data curation. BG, MK, VP, and VS: writing—review and editing. BG: supervision. TM: funding acquisition. All authors contributed to the article and approved the submitted version.

Funding

This research was supported by the Program Cooperatio—Health Sciences (Charles University in Prague).

Acknowledgments

The authors of the article thank the Office of the Government of the Slovak Republic for a grant to support researchers from Ukraine, project code: 09I03-03-V01-00059.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Clark J, Horton R. A coming of age for gender in global health. *Lancet.* (2019) 393:2367–9. doi: 10.1016/S0140-6736(19)30986-9

2. Petrovic D, de Mestral C, Bochud M, Bartley M, Kivimäki M, Vineis P, et al. The contribution of health behaviors to socioeconomic inequalities in health: a systematic review. *Prev Med.* (2018) 113:15–31. doi: 10.1016/j.ypmed.2018.05.003

3. Mackenbach JP, Stirbu I, Roskam AJR, Schaap MM, Menvielle G, Leinsalu M, et al. Socioeconomic inequalities in health in 22 European countries. *N Engl J Med.* (2008) 358:2468–81. doi: 10.1056/NEJMsa0707519

4. Helgesen MK, Fosse E, Hagen S. Capacity to reduce inequities in health in Norwegian municipalities. *Scand J Public Health.* (2017) 45(18_suppl.):77–82. doi: 10.1177/1403494817709412

5. Luy M, Minagawa Y. Gender gaps-Life expectancy and proportion of life in poor health. *Health reports.* (2014) 25:12. doi: 10.1093/eurpub/cku211

6. Williams DR. The health of men: structured inequalities and opportunities. *Am J Public Health.* (2008) 98(Suppl._1):S150–7. doi: 10.2105/AJPH.98.Supplement_1.S150

7. Storm I, den Hertog F, Van Oers H, Schuit AJ. How to improve collaboration between the public health sector and other policy sectors to reduce health inequalities?–A study in sixteen municipalities in the Netherlands. *Int J Equity Health.* (2016) 15:1–14. doi: 10.1186/s12939-016-0384-y

8. Barsanti S, Salmi LR, Bourgueil Y, Daponte A, Pinzal E, Ménival S. Strategies and governance to reduce health inequalities: evidences from a cross-European survey. *Global Health Res Policy.* (2017) 2:1–11. doi: 10.1186/s41256-017-0038-7

9. Salmi LR, Barsanti S, Bourgueil Y, Daponte A, Piznal E, Ménival S, et al. Interventions addressing health inequalities in European regions: the AIR project. *Health Promot Int.* (2017) 32:430–41. doi: 10.1093/heapro/dav101

10. Morrison J, Pons-Vigués M, Díez E, Pasarin MI, Salas-Nicás S, Borrell C. Perceptions and beliefs of public policymakers in a Southern European city. *Int J Equity Health.* (2015) 14:1–10. doi: 10.1186/s12939-015-0143-5

11. Guldbrandsson K, Bremberg S. Cross-sectoral cooperation at the ministerial level in three Nordic countries-With a focus on health inequalities. *Soc Sci Med.* (2020) 256:112999. doi: 10.1016/j.socscimed.2020.112999

12. Pons-Vigués M, Diez È, Morrison J, Salas-Nicás S, Hoffmann R, Burstrom B, et al. Social and health policies or interventions to tackle health inequalities in European cities: a scoping review. *BMC Public Health.* (2014) 14:1–12. doi: 10.1186/1471-2458-14-198

13. Diez E, Morrison J, Pons-Vigués M, Borrell C, Corman D, Burström B, et al. Municipal interventions against inequalities in health: The view of their managers. *Scand J Public Health.* (2014) 42:476–87. doi: 10.1177/1403494814529850

14. Mardani A, Hooker RE, Ozkul S, Yifan S, Nilashi M, Sabzi HZ, et al. Application of decision making and fuzzy sets theory to evaluate the healthcare and medical problems: a review of three decades of research with recent developments. *Expert Syst Appl.* (2019) 137:202–31. doi: 10.1016/j.eswa.2019.07.002

15. Gavurova B, Kelemen M, Polishchuk V. Expert model of risk assessment for the selected components of smart city concept: From safe time to pandemics as COVID-19. *Socioecon Plann Sci.* (2022) 82:101253. doi: 10.1016/j.seps.2022.101253

16. Stefko R, Gavurova B, Korony S. Efficiency measurement in healthcare work management using Malmquist indices. *Polish J Manag Stud.* (2016) 13:168–80. doi: 10.17512/pjms.2016.13.1.16

17. Bhatti MA, Alyahya M. Role of leadership style in enhancing health workers job performance. *Polish J Manag Stud.* (2021) 24:55–66. doi: 10.17512/pjms.2021.24.2.04

18. Mackenbach JP, Kunst AE. Measuring the magnitude of socio-economic inequalities in health: an overview of available measures illustrated with two examples from Europe. *Soc Sci Med.* (1997) 44:757–71. doi: 10.1016/S0277-9536(96)00073-1

19. Shpak N, Sorochak O, Gvozd M, Horbal N, Mykhalyuno Y, Sroka W. Mechanism of competitiveness management in the public healthcare: a practical aspect. *Administr Manag Public.* (2022) 39:40–62. doi: 10.24818/amp/2022.39-03

20. Kočvarová L, Barták M. Analysis of the media image and presentation of direct and hidden advertising of alcohol in selected Czech mass communication media. *Study Protoc. Adiktol.* (2022) 22:264–71. doi: 10.35198/01-2022-004-0006

21. Papadaki Š. The amount of excise tax and its effect on the consumption of alcohol and cigarettes in European countries. *Adiktologie.* (2022) 22:234–43. doi: 10.35198/01-2022-004-0005

22. Muneer A, Abdemaqsoud SH, Foad W, Zidan M. Epidemiological study of suicidal ideation and suicidal behaviour among patients with substance use disorders in a rehabilitation and treatment centre for addiction in Dubai. *Adiktologie.* (2022) 22:172–83. doi: 10.35198/01-2022-003-0002

23. Cerešník M, Cerešníková M. Risk behaviour of adolescents aged 10–15 in Slovakia. Relation to sex, age, and body mass index. *Adiktologie.* (2022) 22:162–70. doi: 10.35198/01-2022-003-0001

24. Štrangfeldová J, Mališová D. Application of actuarial modeling to determine the rate of health insurance in solidary health care systems: a case of Slovakia. *Administr Manag Public.* (2021) 37:90–102. doi: 10.24818/amp/2021.37-06

25. Pisár P, Priščáková S, Špaček D, Nemec J. Digitization as a tool of e-government in selected public services of the state: international comparison of Slovakia and the Czech Republic. *Administr Manag Public.* (2022) 39:111–32. doi: 10.24818/amp/2022.39-07

26. Stefko R, Gavurova B, Rigelsky M, Ivankova V. Evaluation of selected indicators of patient satisfaction and economic indices in OECD country. *Econ Sociol.* (2019) 12:149–65. doi: 10.14254/2071-789X.2019/12-4/9

27. Liu H, Li Y, Tisdell CA, Wang F. How does childcare by grandparents affect the health of children in China? *Econ Sociol.* (2021) 14:11–30. doi: 10.14254/2071-789X.2021/14-4/1

28. Riklikiene O, Didenko O, Ciutiene R, Daunoriene A, Ciarniene R. Balancing nurses' workload: a case study with nurse anaesthetists and intensive care nurses. *Econ Sociol.* (2020) 13:11–25. doi: 10.14254/2071-789X.2020/13-2/1

29. Mackenbach JP. Can we reduce health inequalities? An analysis of the English strategy (1997–2010). *J Epidemiol Commun Health.* (2011) 65:568–75. doi: 10.1136/jech.2010.128280

30. Hagen S, Torp S, Helgesen M, Fosse E. Promoting health by addressing living conditions in Norwegian municipalities. *Health Promot Int.* (2017) 32:977–87. doi: 10.1093/heapro/daw052

31. Borrell LN, Vaughan R. An AJPH supplement toward a unified research approach for minority health and health disparities. *Am J Public Health.* (2019) 109:S6–7. doi: 10.2105/AJPH.2019.304963

32. Szymborski J, Zatoński W. The activities of the Government Population Council aimed at limiting health care inequalities. *J Health Inequal.* (2017) 3:30–40. doi: 10.5114/jhi.2017.69163

33. Javakhishvili JD, Kirtadze I, Otiashvili D. 'Ten years later' – Developing institutional mechanisms for drug demand reduction and addictology education in Georgia – A case study. *Adiktologie.* (2022) 22:35–46. doi: 10.35198/01-2022-001-0005

34. Orte C, Amer J, Gomila AM, Pascual B. Combining the European Prevention Curriculum (EUPC) and Universal Treatment Curriculum (UTC) in a Master's Degree in Addictions. *Adiktologie.* (2022) 22:7–12. doi: 10.35198/01-2022-001-0006

35. Rolová G. Health literacy in residential addiction treatment programs: study protocol of a cross-sectional study in people with substance use disorders. *Adiktologie.* (2020) 20:145–50. doi: 10.35198/01-2020-002-0009

36. Gul M. A review of occupational health and safety risk assessment approaches based on multi-criteria decision-making methods and their fuzzy versions. *Human Ecol Risk Assess.* (2018) 24:1723–60. doi: 10.1080/10807039.2018.1424531

37. Shaygan A, Testik ÖM. A fuzzy AHP-based methodology for project prioritization and selection. *Soft Comput.* (2019) 23:1309–19. doi: 10.1007/s00500-017-2851-9

38. Chatterjee K, Hossain SA. Kar S. Prioritization of project proposals in portfolio management using fuzzy AHP. *OPSEARCH.* (2018) 55:478–501. doi: 10.1007/s12597-018-0331-3

39. Fouladgar MM, Yazdani-Chamzini A, Zavadskas EK, Yakhchali SH, Ghasempourabadi MH. Project portfolio selection using fuzzy AHP and VIKOR techniques. *Transf Bus Econ.* (2012) 11.

40. Bolat B, Çebi F, Tekin Temur G, Otay I. A fuzzy integrated approach for project selection. *J Enterpr Inf Manag.* (2014) 27:247–60. doi: 10.1108/JEIM-12-2013-0091

41. Rębiasz B, Gaweł B, Skalna I. Fuzzy multi-attribute evaluation of investments. *Adv ICT Bus Ind Public Sector.* (2015) 141–56. doi: 10.1007/978-3-319-11328-9_9

42. Enea M, Piazza T. Project selection by constrained fuzzy AHP. *Fuzzy Optimiz Decis Making.* (2004) 3:39–62. doi: 10.1023/B:FODM.0000013071.63614.3d

43. Tulasi CL, Rao AR. Resource allocation in project scheduling application of fuzzy AHP. In: *Proc. Int. Conf. Technol. Business Manage.* (2015). p. 512–21.

44. Mahmoodzadeh S, Shahrabi J, Pariazar M, Zaeri MS. Project selection by using fuzzy AHP and TOPSIS technique. *Int J Ind Manuf Eng.* (2007) 1:270–5.

45. Mohammed HJ, Al-Jubori IAM, Kasim MM. Evaluating project management criteria using fuzzy analytic hierarchy Process. In: *AIP Conference Proceedings.* AIP Publishing LLC (2019). 040018 p.

46. Tüysüz F, Kahraman C. Project risk evaluation using a fuzzy analytic hierarchy process: an application to information technology projects. *Int J Intell Syst.* (2006) 21:559–84. doi: 10.1002/int.20148

47. Mohagheghi V, Mousavi SM. A new framework for high-technology project evaluation and project portfolio selection based on Pythagorean fuzzy WASPAS, MOORA and mathematical modeling. *Iran J Fuzzy Syst.* (2019) 16:89–106. doi: 10.22111/IJFS.2019.5022

48. Oh J, Yang J, Lee S. Managing uncertainty to improve decision-making in NPD portfolio management with a fuzzy expert system. *Exp Syst Appl.* (2012) 39:9868–85. doi: 10.1016/j.eswa.2012.02.164

49. Jafarzadeh H, Akbari P, Abedin B. A methodology for project portfolio selection under criteria prioritisation, uncertainty and projects interdependency–combination of fuzzy QFD and DEA. *Expert Syst Appl.* (2018) 110:237–49. doi: 10.1016/j.eswa.2018.05.028

50. Mohanty RP, Agarwal R, Choudhury AK, Tiwari MK. A fuzzy ANP-based approach to R&D project selection: a case study. *Int J Prod Res.* (2005) 43:5199–216. doi: 10.1080/00207540500219031

51. Bellahcene M, Benamar FZ, Mekidiche M. Ahp and wafgp hybrid model for information system project selection. *Int J Anal Hierar Process.* (2020) 12:228–253. doi: 10.13033/ijahp.v12i2.761

52. Riddell S, Wallace WA. The use of fuzzy logic and expert judgment in the R&D project portfolio selection process. *Int J Technol Manag.* (2011) 53:238–56. doi: 10.1504/IJTM.2011.038592

53. Mohagheghi V, Mousavi SM, Antuchevičiene J, Mojtahed M. Project portfolio selection problems: a review of models, uncertainty approaches, solution techniques, and case studies. *Technol Econ Dev Econ.* (2019) 25:1380–412. doi: 10.3846/tede.2019.11410

54. Wu LH, Wu L, Shi J, Chou Y-T. Project portfolio selection considering uncertainty: stochastic dominance-based fuzzy ranking. *Int J Fuzzy Syst.* (2021) 23:2048–66. doi: 10.1007/s40815-021-01069-y

55. Mardani A, Jusoh A, Zavadskas EK. Fuzzy multiple criteria decision-making techniques and applications–Two decades review from 1994 to 2014. *Expert Syst Appl.* (2015) 42:4126–48. doi: 10.1016/j.eswa.2015.01.003

56. Mardani A, Saraji MK, Mishra AR, Rani P. A novel extended approach under hesitant fuzzy sets to design a framework for assessing the key challenges of digital health interventions adoption during the COVID-19 outbreak. *Appl Soft Comput.* (2020) 96:106613. doi: 10.1016/j.asoc.2020.106613

57. Zare H, Tavana M, Mardani A, Masoudian S, Kamali Saraji M. A hybrid data envelopment analysis and game theory model for performance measurement in healthcare. *Health Care Manag Sci.* (2019) 22:475–88. doi: 10.1007/s10729-018-9456-4

58. Grondys K, Slusarczyk O, Androniceanu A. Risk assessment of the sme sector operations during the COVID-19 pandemic. *Int J Environ Res Public Health.* (2021) 18:4183. doi: 10.3390/ijerph18084183

59. Androniceanu A, Sabie OM, Pegulescu A. An integrated approach of the human resources motivation and the quality of health services. *Theor Empir Res Urban Manag.* (2020) 15:42–53.

60. Gavurova B, Kubák M. The importance of evaluating inpatients' satisfaction with emphasis on the aspect of confidence. *Oecon Copern.* (2021) 12:821–48. doi: 10.24136/oc.2021.027

61. Jakubowska D, Radzymińska M. Health and environmental attitudes and values in food choices: a comparative study for Poland and Czech Republic. *Oecon Copern.* (2019) 10:433–52. doi: 10.24136/oc.2019.021

62. Liu N, Xu Z, Skare M. The research on COVID-19 and economy from 2019 to 2020: Analysis from the perspective of bibliometrics. *Oecon Copern.* (2021) 12:217–68. doi: 10.24136/oc.2021.009

63. Bekken W, Dahl E, Van Der Wel K. Tackling health inequality at the local level: Some critical reflections on the future of Norwegian policies. *Scand J Public Health.* (2027) 45(18_suppl):56–61. doi: 10.1177/14034948177 01012

64. Kelemen M, Gavurova B, Polishchuk V. A complex hybrid model for evaluating projects to improve the sustainability and health of regions and cities. *Int J Environ Res Public Health.* (2022) 19:8217. doi: 10.3390/ijerph191 38217

65. Simionescu M, Strielkowski W, Gavurova B. Could quality of governance influence pollution? Evidence from the revised Environmental Kuznets Curve in Central and Eastern European countries. *Energy Rep.* (2022) 8:809–19. doi: 10.1016/j.egyr.2021.12.031

66. Androniceanu A. The social sustainability of smart cities: urban technological innovation, big data management, and the cognitive internet of things. *Geopolit Hist Int Relat.* (2019) 11:110–5. doi: 10.22381/GHIR112201910

67. Saja P, Wozny A, Bednarova L. Risk management in the context of COVID-19 pandemic in an enterprise–Ishikawa cause-and-effect diagram. *Syst Safety.* (2021) 3:253–9. doi: 10.2478/czoto-2021-0026

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 24 August 2023
DOI 10.3389/fpubh.2023.1202980

OPEN ACCESS

EDITED BY
Colm Antoine O. Morain,
Trinity College Dublin, Ireland

REVIEWED BY
Paula Berstad,
Cancer Registry of Norway, Norway
Francesk Mulita,
General University Hospital of Patras, Greece
Mohamedraed Elshami,
University Hospitals Cleveland Medical Center, United States

*CORRESPONDENCE
Fang Wang
✉ wangfangahmu@163.com

†These authors have contributed equally to this work and share first authorship

RECEIVED 10 April 2023
ACCEPTED 08 August 2023
PUBLISHED 24 August 2023

CITATION
Wang F, Hu D, Sun H, Yan Z, Wang Y, Wang L, Zhang T, Meng N, Zhai C, Zong Q, Hu W, Yu G and Zou Y (2023) Global, regional, and national burden of digestive diseases: findings from the global burden of disease study 2019. *Front. Public Health* 11:1202980. doi: 10.3389/fpubh.2023.1202980

Global, regional, and national burden of digestive diseases: findings from the global burden of disease study 2019

Fang Wang[1*†], Dingtao Hu[1,2†], Hongyu Sun[3†], Ziye Yan[3], Yuhua Wang[3], Linlin Wang[3], Tingyu Zhang[3], Nana Meng[4], Chunxia Zhai[3], Qiqun Zong[3], Wanqin Hu[3], Guanghui Yu[3] and Yanfeng Zou[3]

[1]Department of Oncology, The First Affiliated Hospital of Anhui Medical University, Hefei, Anhui, China, [2]Clinical Cancer Institute, Center for Translational Medicine, Second Military Medical University, Shanghai, China, [3]Department of Epidemiology and Biostatistics, School of Public Health, Anhui Medical University, Hefei, Anhui, China, [4]Department of Quality Management Office, The Second Affiliated Hospital of Anhui Medical University, Hefei, Anhui, China

Background: The global burden of digestive diseases has been rising in the last 30 years. The rates and trends of incidence, deaths, and disability-adjusted life-years (DALYs) for digestive diseases need to be investigated.

Methods: We extracted the data on overall digestive diseases and by cause between 1990–2019 from the Global Burden of Diseases 2019 website, including the absolute number and the corresponding age-standardized rates of incidence (ASIR), deaths (ASDR), and DALYs (ASDALYs).

Results: Globally, the incident cases, deaths, and DALYs of digestive diseases in 2019 increased by 74.44, 37.85, and 23.46%, respectively, compared with that in 1990, with an increasing ASIR of 0.09%, as well as decreasing ASDR and ASDALYs of 1.38 and 1.32% annually. The sociodemographic index (SDI) of overall digestive diseases showed a slight increase in ASIR from low to middle-low regions. The downtrend in ASDR and ASDALYs was found in all SDI regions. The burden of incidence was higher in females, while the burden of deaths and DALYs was higher in males for the overall digestive diseases and most causes. The estimated annual percentage changes were significantly associated with the baseline ASIR, ASDR, and ASDALYs for the overall digestive diseases, and the negative correlations between ASDR, ASDALYs, and human development index both in 1990 ($R = -0.68$, $R = -0.69$) and 2019 ($R = -0.71$, $R = -0.73$) were noticed.

Conclusion: The findings indicate that digestive diseases remain a significant public health burden, with substantial variation across countries, sexes, and age groups. Therefore, implementing age, gender, and country-specific policies for early screening and targeted interventions could significantly reduce the global burden of digestive diseases.

KEYWORDS

digestive diseases, global burden of disease, incidence, deaths, DALYs

Introduction

The global burden of disease has shifted from perinatal, maternal, nutritional, and communicable diseases to non-communicable diseases, including digestive diseases, due to changes in global demographics and socio-economic factors such as improvements in health care, sanitation, and nutrition, an aging population, changes in dietary habits, and increasing urbanization (1). As an important part of non-communicable diseases, the global burden of digestive diseases has been on the rise in the last few decades (2). Based on available data, the incidence of digestive diseases in 2017 was over 4.6 billion worldwide, with the percentage of change of years lived with disability increased by 31.1% from 1990 to 2007 and 20.5% from 2007 to 2017 (3). Meanwhile, the counts of all-age disability-adjusted life-years (DALYs) also increased by 4.1% from 2006–2016 (3). Although the epidemiological characteristics of the global and regional level of several specific digestive diseases, such as cirrhosis (4), inflammatory bowel disease (5), and pancreatitis (6) have been reported, the studies that focus on the characterization of the burden and distribution of all digestive diseases in diverse countries and territories are still lacking. Therefore, a systematic analysis of the comparable epidemiological statistics of digestive diseases would help to evaluate the global burden of these diseases in diverse countries at different economic development levels and facilitate the formation of standard healthcare policy, which could decrease the burden of digestive diseases over time.

Based on the Global Burden of Disease (GBD) study (7), all digestive diseases were classified into ten categories, including appendicitis, pancreatitis, cirrhosis and other chronic liver diseases, inflammatory bowel disease, upper digestive system diseases, paralytic ileus and intestinal obstruction, inguinal femoral and abdominal hernia, vascular intestinal disorders, gallbladder and biliary diseases, and other digestive diseases. In the current research, we retrieved data on digestive diseases from the GBD 2019 study, ranging from 1990–2019, to analyze the burden of digestive diseases caused by nine major causes at the national, regional, and global levels. The association of these comparable statistics with the human development index (HDI) of different countries and the baseline age-standardized incidence rate (ASIR), death rate (ASDR), and DALYs rate (ASDALYs) was also explored. Since the GBD study did not provide any specific data on other digestive diseases in 2019 globally, we did not include this category in the study.

Materials and methods

Overview

Data about the burden of digestive diseases were downloaded from the GBD 2019 study, which provides estimations comprehensively on the burden of 369 diseases among 204 countries and territories based on all available information, such as the clinical and hospital data, survey data, surveillance data, and published literature (7). To assess and correct the potential bias of different data sources for the assessment of model performance and standardized statistical evaluation, the DisMod-MR V.2.1 meta-regression tool was used. The detailed information about the methodology for processing and estimating disease burden levels and trends in the GBD 2019 studies has been reported extensively (8).

Data sources

Comparable statistics of digestive diseases from 1990 to 2019, including the numbers and age-standardized rates, which were sorted by cause, location, gender, and age, were obtained from the GBD 2019 study (7). 204 countries and regions were zoned as five SDI quintiles based on a combination of regional *per capita* income, average educational attainment, and fertility rankings. Meanwhile, these countries and territories were also separated into 21 regions on the basis of geographical contiguity. The list of five SDI quintiles, 21 regions, and all 204 countries and territories are presented in Table 1 and Supplementary Table S10. HDI Data of 193 countries and territories in 1990 and 2019, which was available from the Human Development Report 2019[1] and can be matched with the data from the GBD 2019 study, was obtained for further study. Eleven countries and territories, including the United States Virgin Islands, Cook Islands, Tokelau, American Samoa, Taiwan (China), Northern Mariana Islands, Guam, Puerto Rico, Niue, Greenland, and Bermuda, were excluded.

Statistical analysis

Consistent with the previous studies, the burden levels and trends of digestive diseases were estimated by the ASRs (including ASIR, ASDR, and ASDALYs) and estimated annual percentage change (EAPC) (8). To compare the populations across various locations over time, the potential confounding of age structure needed to be adjusted, and the data was thus standardized. Considered a_i as the age-specific rate for the ith age class, wi denotes the numbers (or weights) for the same age class i of the selected reference standard population, the truncated ASR could be calculated as the following formula:

$$\mathrm{ASR} = \frac{\sum_{i=1}^{A} aiwi}{\Sigma_{\mathrm{i}=1}^{A} w\mathrm{i}} \times 100{,}000$$

In addition, the trends of ASRs over a specified time interval were summarized and evaluated quantitatively by EAPC, which was counted by a regression model fitted to the natural logarithm of ASRs, and the details for calculating EAPC have been described in detail elsewhere (8).

An optimistic EAPC estimation indicates an increasing trend of ASR while being minus means a decreasing trend. Moreover, we also performed a correlation analysis between the EAPC and ASRs in 1990 and between ASRs and HDI in 1990 and 2019 for overall digestive diseases and causes. According to the EAPC and values of 95%CI, we also classified the 204 countries and territories by hierarchical cluster analysis. Depicting with maps, we presented the global

1 http://hdr.undp.org/en/composite/trends

incidence, death, and DALYs of overall, appendicitis, pancreatitis, cirrhosis and other chronic liver diseases, inflammatory bowel disease, upper digestive system diseases, paralytic ileus and intestinal obstruction, inguinal femoral and abdominal hernia, vascular intestinal disorders, and gallbladder and biliary diseases by locations for all ages, both sexes combined, including the numbers in 2019, ASRs in 2019, and EAPCs of ASRs in 1990–2019. The R-index and value of *p* of the relationship between the variables were probed using Pearson correlation analysis with the R version 3.5.3 of the utilization. Statistical meaningfulness is deemed when the *value of p* is less than 0.05.

Results

Number of incidences, deaths, and DALYs of digestive diseases

Table 1 and Supplementary Tables S1–S9 showed the absolute number, ASRs, and the EAPC of the incidences, deaths, and DALYs of the overall digestive diseases and by causes in 1990 and 2019. Globally, the incident cases, deaths, and DALYs of digestive diseases in 2019 were 443.53 million, 2.56 million, and 88.99 million, increased by 74.44, 37.85, and 23.46%, respectively, compared with that in 1990 (Table 1). Of notice, we found India had the prominent incidences, deaths, and DALYs in 2019, with the corresponding present change in absolute numbers as 109.11, 47.48, and 34.42%, respectively. The country-specific contribution of the incidence, deaths, and DALYs presented in Supplementary Table S10. The incidence, deaths, and DALYs of digestive diseases increased particularly in the 25–59-year class, 45–79-year class, and 39–69-year class, respectively, with the peak shifting from 25–29 years in 1990 to 30–34 years in 2019 for incidence, from 60–64 years in 1990 to 65–69 years in 2019 for deaths, and peak for DALYs was occurred both in 55–59 years in 1990 and 2019 (Figures 1A–C). Of interest, we observed relatively higher deaths and DALYs in 1–4 years than that in 5–19 years, both in 1990 and 2019.

Compared with female groups (236.26 million for incidence, 1.03 million for deaths, and 34.49 million for DALYs), males had relatively lower incident cases (207.26 million), and higher deaths (1.52 million) and DALYs (54.50 million) in 2019 (Figures 1D–F; Table 1). In general, we observed an increasing trend in the incidences, deaths, and DALYs of digestive diseases across all regions from 1990 to 2019, especially for locations with lower SDI (Table 1; Figure 2A; Supplementary Figures S1A, S2A). Among 21 GBD regions, the highest increase in the incidences, deaths, and DALYs was in Central Sub-Saharan Africa (CSS, 162.59%), Central Asia (CA, 102.92%), and CA (88.37%), respectively (Table 1; Figure 2B; Supplementary Figures S1B, S2B). While a prominent number of incidences, deaths, and DALYs were observed in South Asia (SA) both in 1990 and 2019.

The ASIR, ASDR, and ASDALYs of digestive diseases

Globally, the ASIR, ASDR, and ASDALYs of digestive diseases were 5454.63, 32.07, and 1096.99 per 100,000 in 2019, with the variation of 2.82-fold, 17.2-fold, and 8.28-fold across countries. The highest rates in 2019 were in Mexico (8468.46 per 100,000) for ASIR, Egypt (138.60 per 100,000) for ASDR, and Cambodia (2937.01 per 100,000) for ASDALYs. While the lowest rates were in Papua New Guinea (3001.97 per 100,000) for ASIR, Singapore (8.06 per 100,000) for ASDR, and Iceland (354.88 per 100,000) for ASDALYs (Table 1; Supplementary Table S10). Although the ASIR increased by an average of 0.09% (95% CI, 0.05–0.12%) between 1990–2019, the ASDR and ASDALYs decreased instead, with the average of 1.38% (95% CI, −1.44% to −1.31%) and 1.32% (95% CI, −1.36% to −1.27%), respectively (Table 1). The countries-specific distribution of EAPC for ASIR, ASDR, and ASDALYs were presented in Figures 3A–C. Notable, The EAPC (95% CI) of ASIR, ASDR, and ASDALYs were 0.12 (0.09 to 0.15), −1.38 (−1.44 to −1.31), and − 1.31 (−1.35 to −1.27) for females, and 0.05(0.02 to 0.09), −1.40(−1.45 to −1.34), and − 1.33(−1.38 to −1.28) for males (Table 1).

As for the five SDI regions, the ASIR of digestive diseases was on the rise in the regions with low to moderate SDI, while it was on the decline in the regions with high-moderate and high SDI (Figure 4A; Table 1). Meanwhile, we observed highly decreasing trends of ASDR and ASDALYs in all SDI regions (Figures 4B,C; Table 1). Moreover, stable and slight changes in ASIR were observed among 21 GBD regions over time, with the highest decreasing trend occurring in High-income North America (−0.53, −0.64 to −0.41) and the highest increasing trend appeared in High-income Asia Pacific (0.27, 0.18 to 0.36) (Figure 4A; Table 1). Of interest, the overall trends of ASDR and ASIR in various GBD regions were also decreasing, except in Central Asia (ASDR: 0.79, 0.43 to 1.16; ASDALYs: 0.50, 0.14 to 0.85) and Eastern Europe (ASDR: 1.77, 1.24 to 2.31; ASDALYs: 1.76, 1.19 to 2.33), which presented with increasing trends (Figures 4B,C; Table 1). In addition, the 204 countries and territories were also zoned as five classes by the hierarchical cluster analysis according to the EAPC and its 95%CI, and the detailed information was shown in Supplementary Figure S3.

Incidence, deaths, and DALYs of digestive diseases by cause

Globally, the incident ranking of the nine causes of digestive diseases in 2019 was the same as in 1990, upper digestive system diseases was the leading incident cause of digestive diseases, followed by gallbladder and biliary diseases, appendicitis, inguinal femoral and abdominal hernia, paralytic ileus and intestinal obstruction, pancreatitis, cirrhosis and other chronic liver diseases, vascular intestinal disorders, and inflammatory bowel disease, accounting for 77.55, 11.73, 3.99, 2.94, 2.28, 0.63, 0.46, 0.33, and 0.09%, respectively (Figures 5A,B). As for deaths and DALYs, the top five leading causes were cirrhosis and other chronic liver diseases (accounts for 60.00 and 53.40%, respectively), upper digestive system diseases (accounts for 11.15 and 17.20%, respectively), paralytic ileus and intestinal obstruction (accounts for 9.73, and 8.19%, respectively), gallbladder and biliary diseases (accounts for 5.09, and 7.35%, respectively), and pancreatitis (accounts for 4.69, and 4.21%, respectively) in 2019, and appendicitis ranks the last cause of deaths (1.36%) and DALYs (1.74%) in 2019 (Figures 5C–F). The incidences for nine causes increased between 1990–2019, ranging from 37.80% for

TABLE 1 The incidence, death, and DALYs of digestive diseases in 1990 and 2019.

Characteristics	1990		2019		1990–2019	1990		2019		1990–2019	1990		2019		1990–2019
	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	EAPC No (95% CI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)
Global	254.25 (231.57–277.83)	5.32 (4.87–5.80)	443.53 (405.58–484.42)	5.45 (4.99–5.94)	0.09 (0.05 to 0.12)	185.54 (175.45–193.02)	46.67 (44.06–48.76)	255.77 (238.99–271.63)	32.07 (29.87–34.05)	−1.38 (−1.44 to −1.31)	72.08 (66.88–77.58)	1.57 (1.47–1.68)	88.99 (81.41–97.58)	1.10 (1.00–1.20)	−1.32 (−1.36 to −1.27)
Sex															
Female	134.15 (122.24–146.45)	5.56 (5.09–6.06)	236.26 (216.39–258.15)	5.73 (5.24–6.25)	0.12 (0.09 to 0.15)	73.82 (68.15–79.00)	34.92 (32.24–37.24)	103.35 (94.05–111.43)	24.01 (21.88–25.90)	−1.38 (−1.44 to −1.31)	28.11 (25.31–31.16)	1.19 (1.07–1.31)	34.49 (30.95–38.79)	0.83 (0.74–0.94)	−1.31 (−1.35 to −1.27)
Male	120.10 (109.18–131.50)	5.08 (4.65–5.56)	207.26 (188.91–227.15)	5.17 (4.73–5.65)	0.05 (0.02 to 0.09)	111.72 (104.19–117.46)	59.80 (55.66–63.05)	152.42 (141.71–163.67)	40.80 (38.02–43.82)	−1.40 (−1.45 to −1.34)	43.97 (40.72–46.85)	1.97 (1.84–2.09)	54.50 (49.90–59.47)	1.37 (1.25–1.50)	−1.33 (−1.38 to −1.28)
SDI															
Low SDI	21.22 (19.04–23.58)	5.78 (5.21–6.40)	46.76 (41.94–51.84)	5.63 (5.10–6.21)	0.08 (0.03 to 0.14)	21.61 (18.99–24.06)	82.86 (73.27–91.85)	32.62 (28.76–36.75)	58.46 (52.22–65.25)	−1.30 (−1.40 to −1.19)	9.22 (7.86–10.50)	2.58 (2.29–2.85)	13.69 (11.92–15.66)	1.81 (1.60–2.04)	−1.30 (−1.39 to −1.21)
Low-middle SDI	52.57 (47.48–57.94)	5.98 (5.44–6.55)	102.49 (92.94–112.41)	6.14 (5.61–6.71)	0.12 (0.10 to 0.14)	45.36 (41.78–48.27)	70.53 (64.24–76.42)	63.12 (57.99–69.01)	46.21 (42.50–50.41)	−1.56 (−1.64 to −1.48)	19.30 (17.72–20.93)	2.32 (2.13–2.48)	24.13 (21.78–26.58)	1.54 (1.39–1.69)	−1.49 (−1.55 to −1.44)
Middle SDI	69.46 (63.17–76.02)	4.74 (4.35–5.16)	127.75 (116.71–139.78)	4.94 (4.51–5.37)	0.30 (0.24 to 0.36)	52.40 (49.05–55.26)	51.75 (48.07–55.14)	72.66 (66.69–79.45)	31.42 (28.66–34.35)	−1.77 (−1.81 to −1.73)	21.21 (19.69–22.74)	1.62 (1.50–1.73)	25.15 (22.83–27.8)	0.99 (0.90–1.09)	−1.75 (−1.78 to −1.72)
High-middle SDI	60.66 (55.48–66.24)	5.27 (4.84–5.74)	90.82 (83.58–99.50)	5.20 (4.77–5.66)	−0.07 (−0.11 to −0.03)	36.16 (34.60–37.59)	35.47 (33.79–36.93)	46.58 (43.28–49.48)	23.92 (22.20–25.42)	−1.45 (−1.61 to −1.28)	13.22 (12.24–14.41)	1.19 (1.11–1.30)	15.45 (14.17–17.13)	0.83 (0.76–0.93)	−1.36 (−1.52 to −1.20)
High SDI	50.20 (46.10–54.80)	5.41 (4.96–5.90)	68.28 (62.79–74.60)	5.24 (4.81–5.74)	−0.11 (−0.15 to −0.06)	29.91 (28.50–30.66)	29.58 (28.16–30.33)	40.63 (36.67–42.90)	21.02 (19.33–22.03)	−1.26 (−1.30 to −1.22)	9.09 (8.43–9.88)	0.94 (0.87–1.03)	10.52 (9.60–11.53)	0.69 (0.63–0.76)	−1.17 (−1.22 to −1.13)
Region															
Andean Latin America	2.73 (2.50–2.97)	8.42 (7.75–9.11)	5.10 (4.67–5.54)	8.11 (7.45–8.80)	0.07 (0.07 to 0.08)	1.77 (1.58–1.96)	69.43 (62.58–76.57)	2.44 (1.97–2.99)	43.84 (35.54–53.62)	−1.59 (−1.70 to −1.47)	0.92 (0.81–1.03)	2.67 (2.39–2.96)	0.80 (0.66–0.97)	1.35 (1.12–1.64)	−2.45 (−2.66 to −2.23)

(Continued)

10.3389/fpubh.2023.1202980

TABLE 1 (Continued)

Characteristics	1990		2019		1990–2019	1990		2019		1990–2019	1990		2019		1990–2019
	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	EAPC No (95% CI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)
Australasia	1.12 (1.02–1.24)	5.07 (4.61–5.59)	1.82 (1.67–2.00)	5.14 (4.68–5.65)	−0.21 (−0.27 to −0.16)	0.47 (0.44–0.49)	21.15 (19.72–22.02)	0.77 (0.68–0.83)	14.75 (13.18–15.82)	−1.12 (−1.28 to −0.95)	0.14 (0.12–0.15)	0.61 (0.55–0.68)	0.20 (0.17–0.22)	0.47 (0.41–0.54)	−0.79 (−0.93 to −0.66)
Caribbean	2.35 (2.12–2.58)	7.36 (6.70–8.05)	3.75 (3.42–4.09)	7.53 (6.86–8.22)	0.05 (−0.02 to 0.11)	1.19 (1.05–1.31)	44.10 (39.40–47.51)	1.72 (1.42–2.01)	33.59 (27.75–39.45)	−1.08 (−1.29 to −0.86)	0.50 (0.41–0.59)	1.62 (1.37–1.87)	0.62 (0.50–0.74)	1.25 (1.00–1.49)	−0.98 (−1.19 to −0.76)
Central Asia	3.16 (2.84–3.49)	5.35 (4.85–5.92)	5.01 (4.51–5.57)	5.45 (4.95–6.02)	0.07 (0.06 to 0.09)	2.06 (2.00–2.11)	41.22 (39.93–42.31)	4.18 (3.77–4.64)	54.18 (48.90–59.76)	0.79 (0.43 to 1.16)	0.86 (0.81–0.92)	1.50 (1.42–1.60)	1.62 (1.46–1.80)	1.83 (1.66–2.02)	0.50 (0.14 to 0.85)
Central Europe	8.64 (7.93–9.48)	6.38 (5.86–7.00)	9.61 (8.83–10.48)	6.41 (5.89–7.02)	0.02 (−0.01 to 0.05)	5.76 (5.60–5.87)	41.01 (39.73–41.87)	6.16 (5.46–6.91)	30.99 (27.34–34.82)	−1.22 (−1.35 to −1.08)	2.03 (1.90–2.19)	1.45 (1.36–1.57)	1.90 (1.67–2.13)	1.10 (0.97–1.24)	−1.25 (−1.38 to −1.12)
Central Latin America	10.73 (9.73–11.73)	8.16 (7.49–8.84)	21.07 (19.29–22.90)	8.27 (7.59–8.97)	0.09 (0.07 to 0.11)	5.78 (5.61–5.90)	63.78 (61.16–65.32)	11.28 (9.81–12.81)	47.97 (41.86–54.41)	−1.17 (−1.28 to −1.05)	2.50 (2.35–2.70)	2.15 (2.03–2.30)	3.87 (3.41–4.41)	1.57 (1.39–1.79)	−1.22 (−1.36 to −1.09)
Central Sub-Saharan Africa	2.07 (1.85–2.31)	5.48 (4.95–6.08)	5.43 (4.86–6.05)	5.78 (5.24–6.40)	0.18 (0.17 to 0.19)	2.22 (1.88–2.59)	88.80 (76.46–101.71)	3.83 (2.94–4.83)	65.80 (50.45–81.32)	−1.04 (−1.10 to −0.98)	0.96 (0.81–1.13)	2.69 (2.29–3.10)	1.63 (1.26–2.08)	2.01 (1.58–2.51)	−0.99 (−1.05 to −0.94)
East Asia	42.30 (38.81–45.92)	3.76 (3.47–4.07)	70.14 (64.44–76.41)	3.77 (3.48–4.09)	−0.01 (−0.09 to 0.07)	33.76 (29.79–37.48)	40.81 (36.5–45.07)	29.81 (25.89–34.26)	15.99 (14.03–18.24)	−3.31 (−3.45 to −3.17)	13.64 (12.19–15.21)	1.34 (1.20–1.49)	10.62 (9.14–12.12)	0.55 (0.48–0.63)	−3.19 (−3.27 to −3.11)
Eastern Europe	16.11 (14.72–17.71)	6.37 (5.82–6.98)	17.02 (15.53–18.66)	6.47 (5.92–7.08)	−0.03 (−0.11 to 0.04)	6.88 (6.73–7.15)	25.85 (25.18–26.87)	13.22 (11.90–14.65)	42.68 (38.45–47.30)	1.77 (1.24 to 2.31)	2.61 (2.42–2.88)	1.00 (0.92–1.10)	4.66 (4.19–5.20)	1.65 (1.48–1.84)	1.76 (1.19 to 2.33)
Eastern Sub-Saharan Africa	6.61 (5.89–7.39)	5.34 (4.78–5.94)	15.88 (14.13–17.73)	5.51 (4.96–6.11)	0.10 (0.09 to 0.12)	7.75 (6.39–9.01)	93.94 (80.53–106.78)	12.60 (10.96–14.66)	73.14 (64.79–83.44)	−0.94 (−1.01 to −0.88)	3.15 (2.50–3.74)	2.75 (2.30–3.16)	4.94 (4.21–5.83)	2.07 (1.80–2.40)	−1.06 (−1.11 to −1.01)
High-income Asia Pacific	9.57 (8.81–10.46)	5.00 (4.60–5.44)	13.51 (12.46–14.72)	5.21 (4.81–5.67)	0.27 (0.18 to 0.36)	6.33 (6.06–6.48)	33.60 (31.86–34.52)	7.88 (6.59–8.61)	15.77 (13.91–16.92)	−2.74 (−2.91 to −2.57)	2.07 (1.93–2.23)	1.05 (0.98–1.13)	1.84 (1.64–2.06)	0.57 (0.49–0.65)	−2.28 (−2.42 to −2.15)

(Continued)

10.3389/fpubh.2023.1202980

TABLE 1 (Continued)

Characteristics	1990		2019		1990–2019	1990		2019		1990–2019	1990		2019		1990–2019
	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	Incidence cases Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	Death cases Nox10^4 (95%UI)	ASR per 100,000 No (95% UI)	EAPC No (95% CI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	DALYs Nox10^6 (95%UI)	ASR per 100,000 Nox10^3 (95% UI)	EAPC No (95% CI)
High-income North America	20.15 (18.40–22.09)	6.40 (5.85–7.02)	25.27 (23.11–27.73)	5.54 (5.05–6.10)	−0.53 (−0.64 to −0.41)	8.56 (8.09–8.81)	24.67 (23.41–25.33)	14.22 (13.20–14.81)	23.13 (21.76–23.97)	−0.17 (−0.21 to −0.13)	2.80 (2.57–3.10)	0.87 (0.79–0.97)	4.00 (3.72–4.36)	0.77 (0.71–0.85)	−0.25 (−0.32 to −0.17)
North Africa and Middle East	15.09 (13.41–16.8)	5.69 (5.11–6.30)	34.78 (31.19–38.5)	5.91 (5.36–6.51)	0.15 (0.14 to 0.15)	9.28 (8.55–9.87)	58.88 (53.6–64.47)	14.57 (11.26–17.59)	37.48 (29.66–44.82)	−1.50 (−1.57 to −1.42)	3.29 (2.87–3.69)	1.50 (1.38–1.63)	4.84 (3.85–5.80)	0.99 (0.80–1.18)	−1.37 (−1.42 to −1.32)
Oceania	0.15 (0.13–0.17)	2.99 (2.69–3.33)	0.34 (0.30–0.37)	3.02 (2.73–3.37)	0.03 (0.01 to 0.04)	0.12 (0.10–0.14)	37.52 (31.92–44.41)	0.22 (0.18–0.28)	29.04 (24.03–35.26)	−0.87 (−0.91 to −0.83)	0.05 (0.05–0.06)	1.22 (1.05–1.42)	0.10 (0.08–0.12)	0.97 (0.81–1.17)	−0.76 (−0.79 to −0.73)
South Asia	55.23 (49.52–61.19)	6.45 (5.85–7.09)	115.67 (104.59–127.26)	6.69 (6.09–7.33)	0.14 (0.11 to 0.17)	41.17 (37.53–44.46)	68.45 (60.96–75.75)	58.06 (51.76–66.06)	41.33 (36.75–47.02)	−1.94 (−2.11 to −1.78)	17.78 (16.03–19.36)	2.23 (2.02–2.40)	23.23 (20.53–26.28)	1.42 (1.26–1.61)	−1.68 (−1.79 to −1.57)
Southeast Asia	12.42 (11.20–13.7)	3.24 (2.95–3.58)	23.33 (21.21–25.80)	3.36 (3.06–3.70)	0.12 (0.10 to 0.13)	18.61 (16.86–19.99)	68.89 (62.15–75.88)	27.55 (24.70–30.34)	47.79 (43.09–52.39)	−1.37 (−1.41 to −1.33)	7.40 (6.44–8.21)	2.13 (1.93–2.29)	9.06 (8.11–10.09)	1.38 (1.24–1.52)	−1.62 (−1.66 to −1.58)
Southern Latin America	2.86 (2.57–3.19)	5.97 (5.36–6.65)	4.52 (4.08–5.01)	6.12 (5.52–6.81)	−0.04 (−0.09 to 0.01)	1.94 (1.88–1.99)	43.59 (41.88–44.76)	2.78 (2.58–2.92)	33.43 (31.23–35.10)	−0.82 (−0.94 to −0.69)	0.61 (0.57–0.66)	1.30 (1.23–1.40)	0.76 (0.70–0.83)	0.97 (0.89–1.06)	−0.95 (−1.08 to −0.82)
Southern Sub-Saharan Africa	2.34 (2.10–2.58)	5.69 (5.13–6.31)	4.28 (3.83–4.74)	5.81 (5.24–6.41)	0.06 (0.04 to 0.08)	1.34 (1.19–1.60)	45.19 (39.47–54.59)	2.05 (1.87–2.24)	36.92 (33.77–40.07)	−0.77 (−1.11 to −0.44)	0.57 (0.51–0.64)	1.51 (1.34–1.75)	0.79 (0.70–0.88)	1.17 (1.05–1.30)	−0.95 (−1.29 to −0.62)
Tropical Latin America	10.59 (9.58–11.55)	8.14 (7.47–8.81)	19.98 (18.26–21.64)	8.15 (7.46–8.79)	−0.03 (−0.09 to 0.04)	4.47 (4.33–4.59)	47.00 (44.87–48.42)	8.02 (7.50–8.38)	33.60 (31.28–35.17)	−1.08 (−1.14 to −1.02)	1.96 (1.82–2.14)	1.67 (1.56–1.81)	2.88 (2.63–3.20)	1.18 (1.08–1.31)	−1.20 (−1.23 to −1.17)
Western Europe	22.93 (21.08–25.10)	4.98 (4.56–5.45)	29.45 (27.07–32.15)	5.13 (4.69–5.61)	0.10 (0.07 to 0.13)	17.69 (16.91–18.15)	31.75 (30.26–32.56)	20.51 (18.49–21.68)	21.12 (19.38–22.14)	−1.55 (−1.61 to −1.50)	4.78 (4.48–5.15)	0.94 (0.88–1.02)	4.72 (4.32–5.18)	0.65 (0.59–0.73)	−1.48 (−1.55 to −1.42)
Western Sub-Saharan Africa	7.09 (6.33–7.90)	5.27 (4.72–5.87)	17.58 (15.67–19.60)	5.40 (4.85–6.01)	0.07 (0.06 to 0.08)	8.37 (6.77–10.36)	86.15 (68.77–108.73)	13.89 (10.90–17.55)	66.12 (53.56–81.88)	−0.82 (−0.92 to −0.73)	3.45 (2.90–4.12)	2.60 (2.11–3.21)	5.92 (4.64–7.47)	1.98 (1.58–2.48)	−0.87 (−0.94 to −0.81)

ASR, age-standardized incidence rate; EAPC, estimated annual percentage change; UI, uncertainty interval.

10.3389/fpubh.2023.1202980

inflammatory bowel disease to 97.35% for gallbladder and biliary diseases. While both increasing and decreasing trends for deaths and DALYs were observed for different causes, with the prominent increasing and decreasing trend occurring in vascular intestinal disorders (95.25%), gallbladder and biliary diseases (−84.85%) for deaths, and pancreatitis (49.34%) and appendicitis (−80.99%) for DALYs. The trends of ASRs were also different across regions for nine causes. The details are shown in Supplementary Tables S1–S9. In the global and regional levers, the highest EAPC in ASIR among nine causes of digestive diseases varied among locations, cirrhosis and other chronic liver diseases and appendicitis in four GBD regions; upper digestive system diseases and vascular intestinal disorders in one GBD region; inguinal femoral and abdominal hernia in five SDI regions, and eight GBD regions; and inflammatory bowel disease in three GBD regions (Figure 4A; Supplementary Figure S13A). The highest EAPC in ASDR was noticed for upper digestive system diseases at the global level, except for low and high-middle SDI regions and 11 GBD regions; for appendicitis in high-middle and low SDI regions and nine GBD regions; and for inguinal femoral and abdominal hernia in one GBD region (Figure 4B; Supplementary Figure S13B). As for the distribution of the prominent EAPC in ASDALYs, we found highest EAPC of cirrhosis and other chronic liver diseases occurred in three GBD regions; upper digestive system diseases in high, middle, and low-middle SDI regions, and three GBD regions; appendicitis in high-middle and low SDI regions, and 14 GBD regions; and gallbladder and biliary diseases in one GBD region (Figure 4C; Supplementary Figure S13C). The detailed description of the absolute number of incidences, deaths, DALYs, ASRs, and EAPC for nine causes of digestive diseases and the distribution of gender, age, and locations were shown in the online Supplementary files.

Factors correlated with the incidence, deaths, and DALYs of digestive diseases

Significant negative correlations between EAPC and baseline ASIR (R = -0.15, p = 0.033), as well as between EAPC and ASDR (R = −0.16, p = 0.027) in 1990, were observed (Supplementary Figures S14A,D). EAPC was positively correspond with the baseline ASDALYs (R = 0.23, p < 0.001, Supplementary Figure S14G). The ASDR (R = −0.68, p < 0.001 in 1990; R = −0.71, p < 0.001 in 2019, Supplementary Figures S14E,F) and ASDALYs (R = −0.69, p < 0.001 in 1990; R = −0.73, p < 0.001 in 2019, Supplementary Figures S14H,I) were strongly negatively correlated with the HDI in the corresponding year, while no significant relationship was observed between ASIR and HDI both in 1990 and 2019 (p > 0.05 for all, Supplementary Figures S14B,C). The associations among EAPC, ASRs, and HDI of each cause are shown in Supplementary Figures S15–S23.

Discussion

We roundly analyzed the national, regional, and global burdens of the overall digestive diseases and by causes from 1990 to 2019, based on the results of the GBD 2019 study. In the last 30 years, the cases of the incidence, deaths, and DALYs in 2019 increased by 74.44, 37.85, and 23.46%, respectively; however, the ASDR and ASDALYs of digestives decreased by an annual average of 1.38 and 1.32%, while the ASIR also slightly increased during this period. Upper digestive system diseases, gallbladder and biliary diseases, appendicitis, and inguinal femoral and abdominal hernia rank the top four cases of incidence, while cirrhosis and other chronic liver diseases, upper

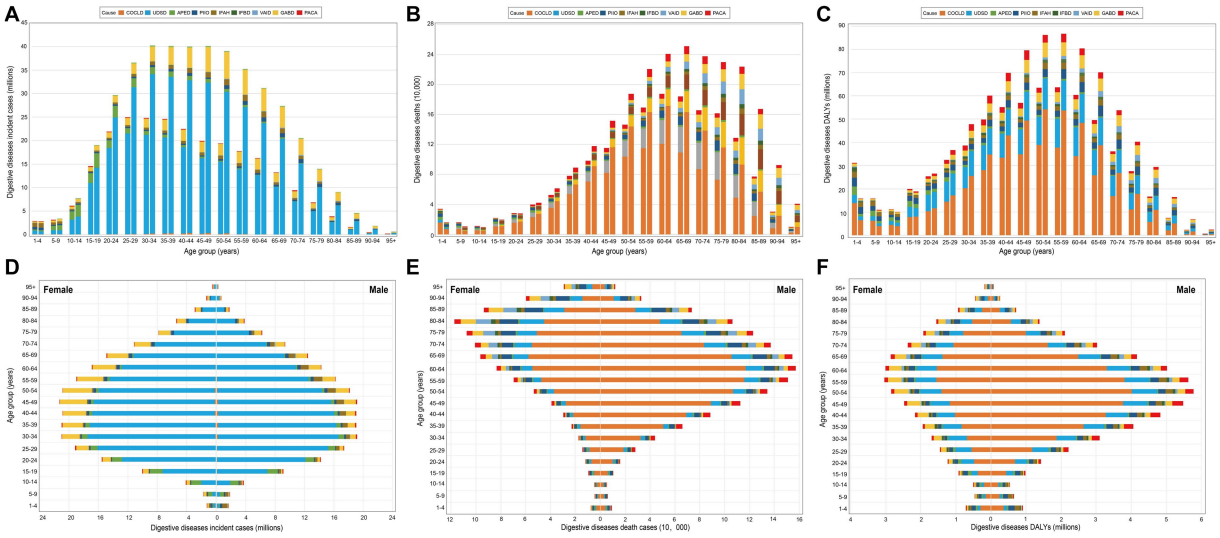


FIGURE 1
Global cases of incidence, deaths, and DALYs of digestive diseases by nine causes and 23 GBD age groups. **(A–C)** Global cases of incidence, deaths, and DALYs of digestive diseases by age for both sexes combined in 1990 and 2019. For each group, the left column shows case data in 1990 and the right column shows data in 2019. **(D–F)** Sex difference in global cases of incidence, deaths, and DALYs of digestive diseases by age in 2019. DALYs, disability-adjusted life-years; GBD, Global Burden of Disease; COCLD, Cirrhosis and other chronic liver diseases; UDSD, Upper digestive system diseases; APED, Appendicitis; PIIO, Paralytic ileus and intestinal obstruction; IFAH, Inguinal, femoral, and abdominal hernia; IFBD, Inflammatory bowel disease; VAID, Vascular intestinal disorders; GABD, Gallbladder and biliary diseases; PACA, Pancreatitis.

10.3389/fpubh.2023.1202980

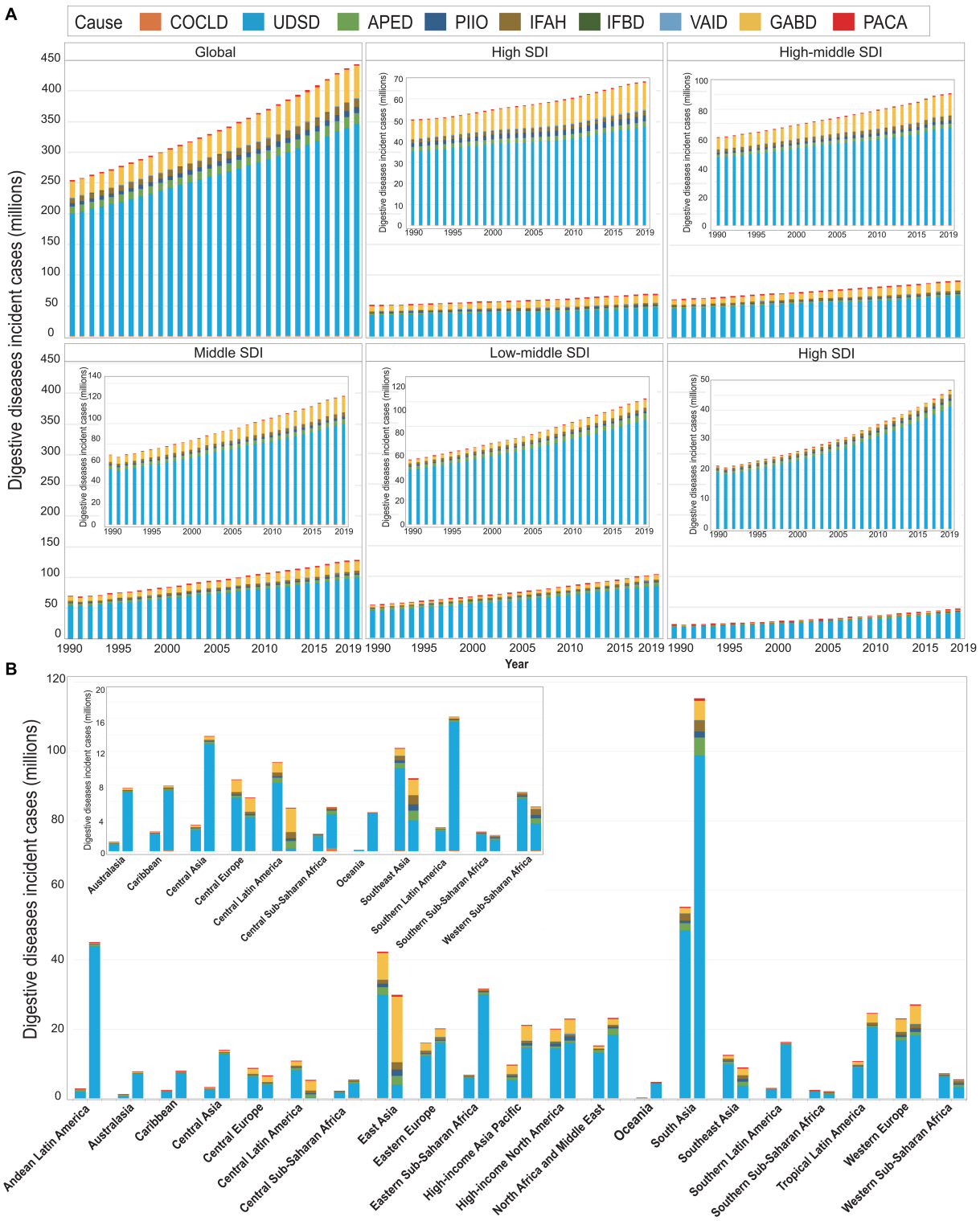


FIGURE 2
Global incident cases of digestive diseases by nine causes and regions for both sexes combined. **(A)** The incident cases of digestive diseases by nine causes and five SDI regions, from 1990 to 2019. **(B)** Incident cases of digestive diseases by nine causes and by 21 GBD regions in 1990 and 2019. For each group, the left column shows case data in 1990, and the right column shows data in 2019. Certain regions are magnified to the top-right of the panel. COCLD, cirrhosis and other chronic liver diseases; UDSD, Upper digestive system diseases; APED, Appendicitis; PIIO, Paralytic ileus and intestinal obstruction; IFAH, Inguinal, femoral, and abdominal hernia; IFBD, Inflammatory bowel disease; VAID, Vascular intestinal disorders; GABD, Gallbladder and biliary diseases; PACA, Pancreatitis.

digestive system diseases, paralytic ileus and intestinal obstruction, and gallbladder and biliary diseases rank the top four cases of both deaths and DALYs. The magnitude changes in the numbers were probably due to the aging trends and the growth of the world population. According to the reports from World Population Prospects 2019, the estimated number of populations had increased

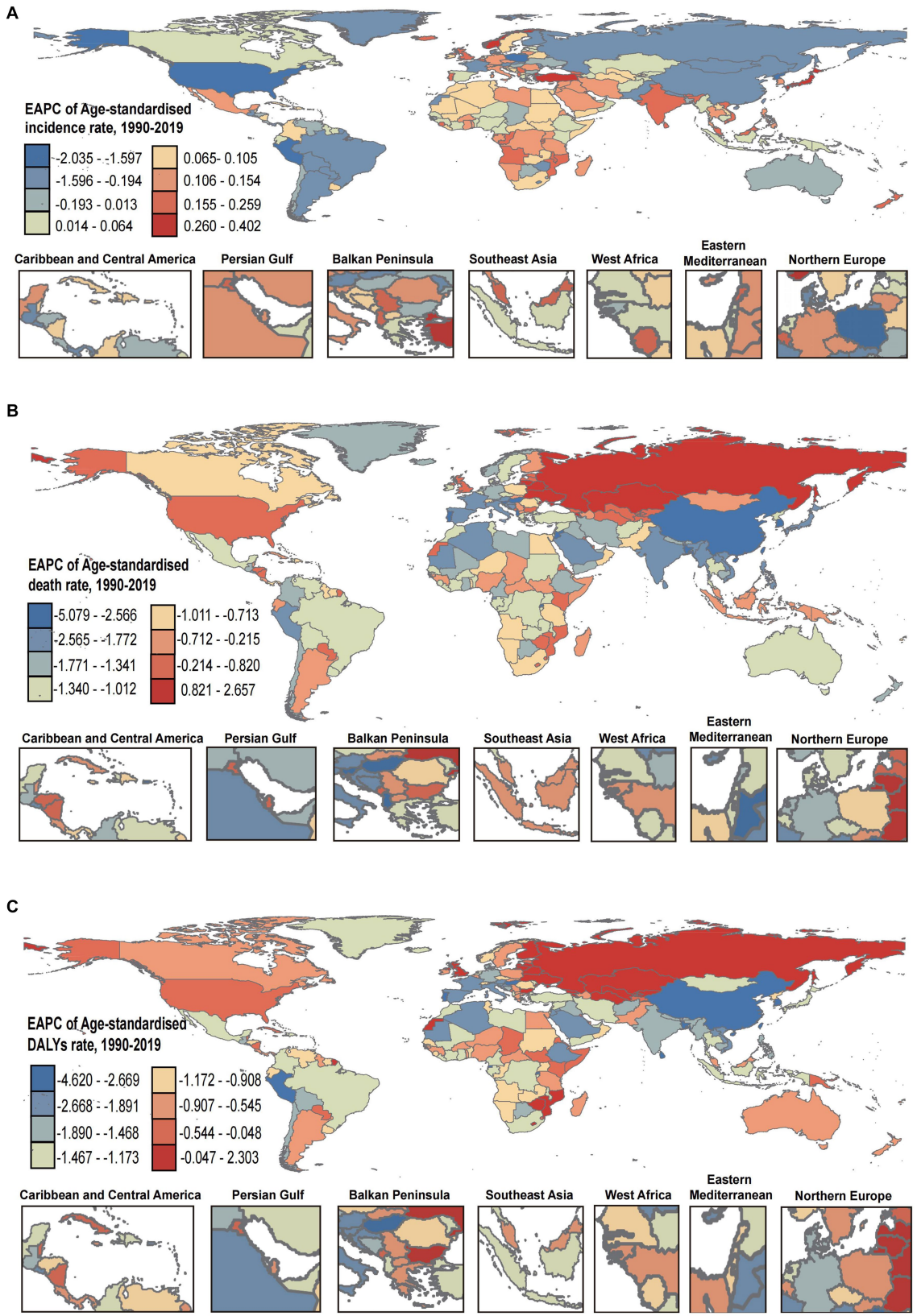


FIGURE 3
The EAPC in ASIR **(A)**, ASDR **(B)**, and ASDALYs **(C)** of digestive diseases from 1990 to 2019. DALYs, disability-adjusted life-years; ASIR, age-standardized incidence rate; ASDR, age-standardized deaths rate; ASDALYs, age-standardized DALYs rate. EAPC, estimated annual percentage change.

by 46.15%, from 5.33 billion to 7.79 billion from 1990 to 2019, and the scale of people over 60 years also increased significantly from 1990–2019 (9).

According to a previous study, there were nearly 135.9 billion dollars in the USA because of gastrointestinal diseases annually, including pancreatic, liver, and luminal, and the economic burdens are

likely to keep an increasing trend (10). Moreover, most diseases of the digestive system can lead to sepsis, it was considered a major public health problem and was estimated to cost the U.S. health care system more than $20 billion a year in 2011 (11–13). In the current study, although the ASDR and ASDALYs decreased during 1990–2019, the ASIR increased, and a high increase of ASIR, ASDR, and ASDALYs was observed in various regions, which suggests the burden of digestive diseases was still a global health problem in 2019, calling for the design of flexible and country-appropriate methods to reduce the disease burdens. Besides, the current study is the first study that explored the pertinence between the EAPC and ASRs in 1990 and between ASRs and HDI both in 1990 and 2019. We found the EAPCs were significantly associated with the baseline ASRs for the overall digestive diseases and most causes, and negative correlations between ASDR, ASDALYs, and HDI in the corresponding year were also noticed. In comparison, positive correlations were observed between baseline ASIR and HDI 1990 for paralytic ileus and intestinal obstruction, inflammatory bowel disease, vascular intestinal disorders, gallbladder and biliary diseases, and pancreatitis.

Since the studies comprehensively explored the temporal trend of the incidence, deaths, and DALYs of digestive diseases, it is difficult for the current results to be directly compared with previous studies. Nevertheless, several reports for GBD 2017 studies suggested that the deaths and DALYs of cirrhosis and other chronic liver diseases and inflammatory bowel disease had increased greatly from 1990–2017, even though the ASDR and ASDALYs decreased in most regions, which is consistent with the current study (4, 5). Besides, we also observed a substantial increase in incident cases as well as a decreasing trend in ASIR for cirrhosis and other chronic liver diseases and inflammatory bowel disease from 1990 to 2019. Similarly, we found rising all-age counts of incidence, death, and DALYs as well as decreasing trends of ASIR, ASDR, and ASDALYs of pancreatitis from 1990–2019, which contrasts with the increasing trends of the age-standardized years lived with disability and prevalence rates from 1990–2017 (6).

The temporal trends in ASRs were different across various causes of digestive diseases. The gallbladder and biliary diseases, appendicitis, and paralytic ileus and intestinal obstruction dominated the incident trend of digestive diseases, with the ASIR increasing by 59, 58, and 22% annually, while a decreasing trend of ASIR was noticed in cirrhosis and other chronic liver diseases, inguinal femoral and abdominal hernia, inflammatory bowel disease, vascular intestinal disorders, and pancreatitis, and a stable trend of ASIR was observed in upper digestive system diseases. Consistent with previous GBD 2017 studies, besides cirrhosis and other chronic liver diseases and inflammatory bowel disease, the trends of deaths and DALYs of the overall digestive diseases and other seven causes were also decreasing between 1990–2019 (4, 5). Cirrhosis and other chronic liver diseases and upper digestive system diseases were two causes that presented with the highest decreasing trend of ASDR and ASDALYs, which is promising since they dominated the deaths and DALYs burden of digestive diseases in 2019. However, a clear understanding of the incidence, deaths, and DALYs rates of each digestive disease's cause is essential for the policymakers of the healthcare system to apply systematic and target interventions that could prevent morbidity and premature deaths of digestive diseases.

Temporal trends in ASIR also varied at the regional and national levels. For overall digestive diseases and cirrhosis and other chronic liver diseases, upper digestive system diseases, inflammatory bowel disease, and vascular intestinal disorders, a slightly increasing and stable trend of ASIR was noticed in the middle, low-middle, and low SDI regions, while decreasing trends existed in other SDI regions. From 1990–2017, the increasing trends of ASYR and ASPR of pancreatitis suggested an increasing trend of burden over time, especially in regions with lower SDI (6), which is identical with the decreasing trend of ASIR for pancreatitis observed in the middle, high-middle, and high SDI regions in the current study. Although the decreasing trend of ASIR was noticed in higher SDI regions for most causes, the absolute cases and ASIR were also consistently higher in countries from higher SDI regions such as Australia, Canada, the USA, and the UK. The relatively lower incident cases and ASIR of various causes such as inflammatory bowel disease, pancreatitis, and vascular intestinal disorders in lower SDI regions might be due to the relatively lower shortages of tobacco and alcohol, and thus lower consumption of alcohol and smoking (6). The diverse dietary habits among different SDI regions may also contribute to such observing findings (14, 15). Alternatively, lower physical activity, more hygienic environments, urbanization, high BMI, and aging might contribute to higher incidence and ASIR in higher SDI regions (14, 15). Nevertheless, the general increasing trends of ASIR in lower SDI regions suggest that basic sanitation in many low-income countries is still a public issue. A promising finding is that the ASDR and ASDALYs of the nine causes declined in all SDI regions. The development of early diagnosis technology, the conduct of effective interventions at the optimal time, and improved supportive care may benefit in decreasing the global digestive burden (4, 16, 17) Additionally, the ASDR and ASDALYs also increased from 1990–2019 for the overall digestive diseases, cirrhosis and other chronic liver diseases, and vascular intestinal disorders in Eastern Europe and Central Asia, which suggests that digestive diseases are a global health problem, and not constrained to regions and countries with high or low SDI. Moreover, general negative correlations between EAPC and ASIR, as well as between ASIR and HDI in the corresponding year, were noticed, while positive correlations between ASIR and HDI both in 1990 and 2019 were observed for paralytic ileus and intestinal obstruction, inflammatory bowel disease, vascular intestinal disorders, gallbladder and biliary diseases, and pancreatitis. With the development of HDI global, our results may be partly explained by the fact that risk factors for digestive diseases, such as occupational and social factors, have changed considerably over the past 29 years, particularly in high HDI regions, while they have changed less in low HDI countries the (8). Future analysis focusing on the certain risk factors that contribute to the overall digestive diseases and by cause is required to better approach the prevention programs of digestive diseases.

In our findings, we observed gender and age differences in the global cases of incidence, deaths, and DALYs as well as the ASRs for digestive diseases by cause, with females having higher incident cases and ASIR for the overall digestive diseases, upper digestive system diseases, appendicitis, and gallbladder and biliary diseases at all ages. Particularly for gallbladder and biliary diseases, the frequency is more than two times higher in females than in males. Alternatively, the burden of deaths and DALYs were higher in males for the overall digestive diseases and most causes, except vascular intestinal disorders and gallbladder and biliary diseases. Traditionally, pancreatitis was

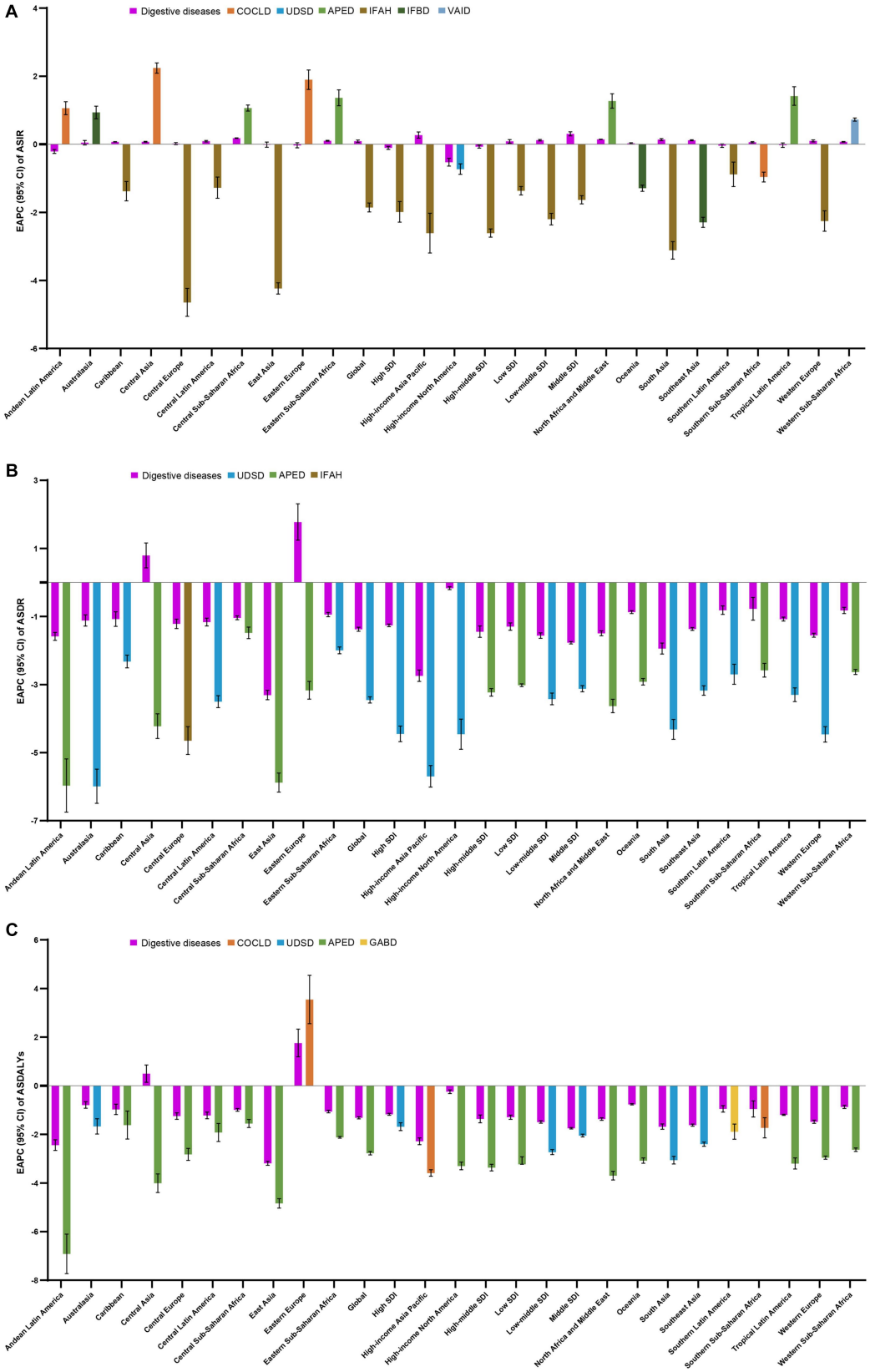


FIGURE 4
The EAPC in ASIR **(A)**, ASDR **(B)**, and ASDALYs **(C)** of digestive diseases from 1990 to 2019, by causes and by region, for both sexes combined. Those EAPCs in each of the regions are presented as the overall and the absolute maximum caused by a specific cause. DALYs, disability-adjusted life-years; ASIR, age-standardized incidence rate; ASDR, age-standardized deaths rate; ASDALYs, age-standardized DALYs rate. EAPC, estimated annual percentage change; COCLD, Cirrhosis and other chronic liver diseases; UDSD, Upper digestive system diseases; APED, Appendicitis; IFAH, Inguinal, femoral, and abdominal hernia; IFBD, Inflammatory bowel disease; VAID, Vascular intestinal disorders; GABD, Gallbladder and biliary diseases.

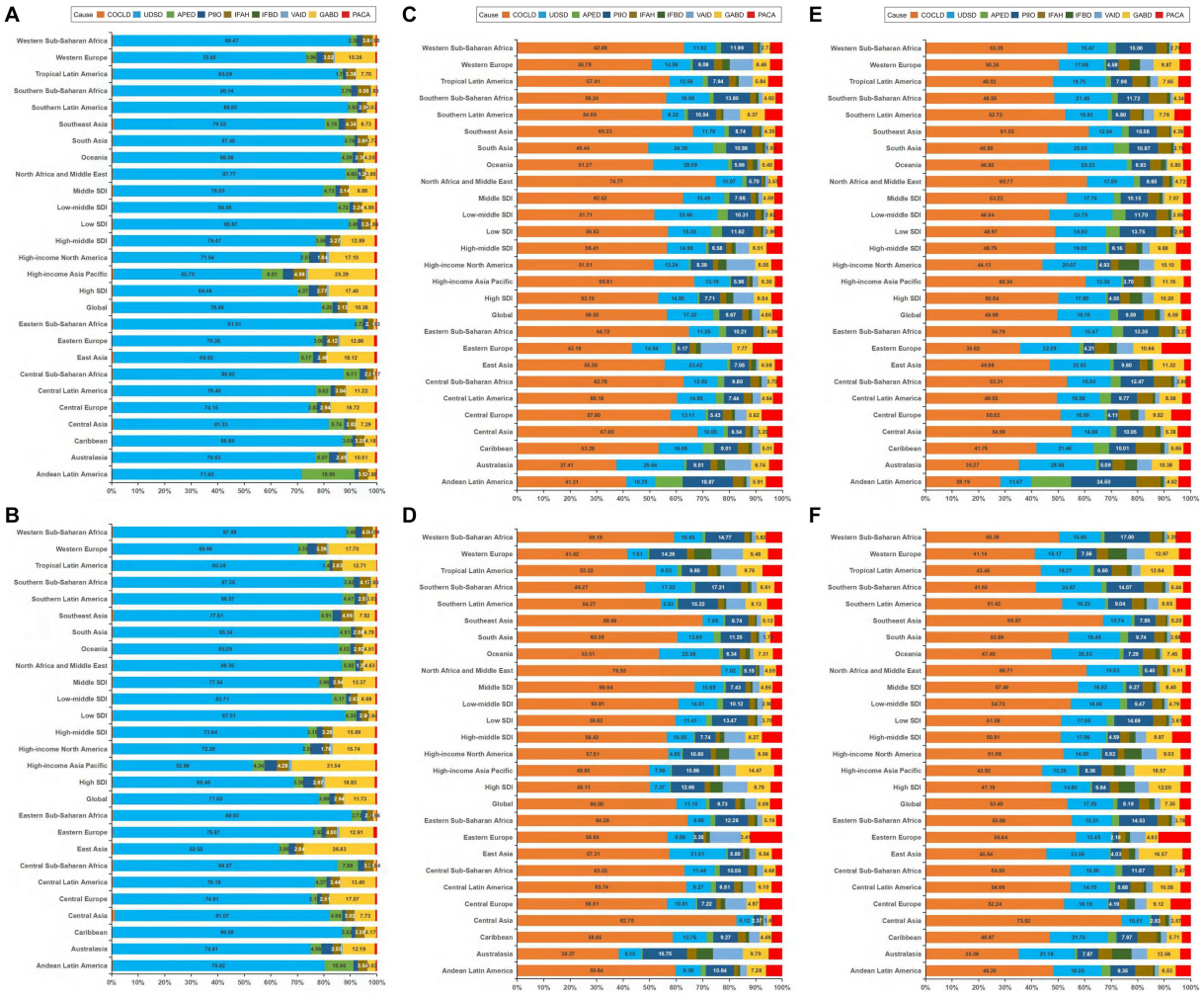


FIGURE 5
Contribution of specific causes to the cases of incidence, deaths, and DALYs of digestive diseases by regions for both sexes combined in 1990 and 2019. **(A)** The incidence in1990. **(B)** The incidence in 2019. **(C)** The deaths in1990. **(D)** The deaths in 2019. **(E)** The DALYs in1990. **(F)** The DALYs in 2019 DALYs. disability-adjusted life-years; COCLD, Cirrhosis and other chronic liver diseases; UDSD, Upper digestive system diseases; APED, Appendicitis; PIIO, Paralytic ileus and intestinal obstruction; IFAH, Inguinal, femoral, and abdominal hernia; IFBD, Inflammatory bowel disease; VAID, Vascular intestinal disorders; GABD, Gallbladder and biliary diseases; PACA, Pancreatitis.

considered a disease in men because of the higher cigarette and alcohol intake rate (6, 18). However, several studies have suggested that idiopathic causes, autoimmune diseases, and gallstones were more common in females, and factors such as hormonal and biological influences, post-partum, and pregnancy would contribute to the sex disparity of our findings (19, 20).

However, males had relatively lower incident cases but more frequent deaths compared with females. One possible explanation for this finding is that males are more likely to engage in riskier behaviors such as heavy alcohol consumption and smoking, which are known risk factors for many digestive diseases. These behaviors may contribute to a higher risk of developing severe forms of digestive diseases, which may result in more frequent deaths. In contrast, females may be more likely to seek medical attention earlier for digestive diseases, leading to earlier diagnosis and treatment, which may contribute to a lower risk of developing severe forms of the disease. Further research is needed to fully understand the underlying factors that contribute to this gender difference.

In GBD 2019, we observed that the highest burden of digestive diseases had shifted from 25–29 years in 1990 to 30–34 years in 2019 for incidence, from 60–64 years in 1990 to 65–69 years in 2019 for deaths, and remained stable in 55–59 years for DALYs, which implies that focusing on age-specific policies toward the early screening and target interventions would greatly reduce the global burden of digestive diseases. Of notice, higher deaths and DALYs burden were noticed in children aged 1–4 than 5–20, which might be due to the infantile hepatitis syndrome and biliary atresia in children. If these diseases had not been treated appropriately and timely, liver failure and worse life quality would have occurred. Therefore, additional health attention is required to minimize the digestive disease burden in children.

For all we know, the current study is the first that systematically and comprehensively explored the trends of digestive diseases at the global levels between 1990–2019, which would provide guidelines for follow-up studies and policies design. Nevertheless, several limitations require to be recognized. Firstly, since the current research is

secondary data from the GBD 2019 study, the precision of the findings largely hinges on the quantity and quality of data used in the modeling. Secondly, data about the incidence, deaths, and DALYs of other digestive diseases is exclusive of our research owing to the unavailability of the data. Thirdly, even within countries and territories with the same HDI, the substantial differentiation in health gains also varies, and the effect of the health systems and policies in various locations should also be evaluated. Moreover, the risk factors that contribute to each cause of digestive diseases should be comparatively investigated.

Conclusion

Globally, digestive diseases remained a major public health burden, with larger variation across countries, sexes, and age groups. The global ASIR of overall digestive diseases, gallbladder and biliary diseases, appendicitis, and paralytic ileus and intestinal obstruction had increased over the past three decades, whereas a decreasing and stable trend of ASIR was noticed in cirrhosis and other chronic liver diseases, upper digestive system diseases, inguinal femoral and abdominal hernia, inflammatory bowel disease, vascular intestinal disorders, and pancreatitis. Decreasing trends of ASDR and ASDALYs exist for the overall digestive diseases and by causes. Moreover, the generally negative associations between HDI and the burden of digestive diseases suggests that more aggressive and earlier medical interventions are needed in HDI-low regions. The current study's findings would guide the development of better prevention and management strategies as well as relevant health policies to reduce the future burden of digestive diseases.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

FW: conceptualization, methodology, and writing review and editing. DH: conceptualization, data curation, formal analysis, methodology, software, visualization, and writing an original draft. HS: methodology, software, and visualization. ZY, YW, LW, and TZ: conceptualization, data curation, validation, software, and visualization. NM, CZ, QZ, WH, and GY: data curation and supervision. YZ: software and writing review and editing. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the National Natural Science Foundation of China (81602115), the Research Fund of Anhui Institute of translational medicine (2022zhyx-C35), the Natural Science Foundation for the Higher Education Institutions of Anhui Province of China (2022AH051145), the Foundation of Supporting Program for the Excellent Young Faculties in Universities of Anhui Province in China (gxyq2019012), and the Outstanding Youth from the First Affiliated Hospital of Anhui Medical University.

Acknowledgments

We highly appreciated the work by the GBD 2019 collaborators.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1202980/full#supplementary-material

References

1. GBD 2017 DALYs and HALE Collaborators. Global, regional, and national disability-adjusted life-years (DALYs) for 359 diseases and injuries and healthy life expectancy (HALE) for 195 countries and territories, 1990-2017: a systematic analysis for the global burden of Disease study 2017. *Lancet*. (2018) 392:1859–922. doi: 10.1016/S0140-6736(18)32335-3

2. Gómez-Dantés H, Fullman N, Lamadrid-Figueroa H, Cahuana-Hurtado L, Darney B, Avila-Burgos L, et al. Dissonant health transition in the states of Mexico, 1990-2013: a systematic analysis for the Global Burden of Disease Study 2013. *Lancet*. (2016) 388:2386–2402. doi: 10.1016/S0140-6736(16)31773-1

3. Disease GBD, Injury I, Prevalence C. Global, regional, and national incidence, prevalence, and years lived with disability for 354 diseases and injuries for 195 countries and territories, 1990-2017: a systematic analysis for the global burden of Disease study 2017. *Lancet*. (2018) 392:1789–858. doi: 10.1016/S0140-6736(18)32279-7

4. GBD 2017 Cirrhosis Collaborators. The global, regional, and national burden of cirrhosis by cause in 195 countries and territories, 1990-2017: a systematic analysis for the global burden of Disease study 2017. *Lancet Gastroenterol Hepatol*. (2020) 5:245–66. doi: 10.1016/S2468-1253(19)30349-8

5. GBD 2017 Inflammatory Bowel Disease Collaborators. The global, regional, and national burden of inflammatory bowel disease in 195 countries and territories, 1990-2017: a systematic analysis for the global burden of Disease study 2017. *Lancet Gastroenterol Hepatol*. (2020) 5:17–30. doi: 10.1016/S2468-1253(19)30333-4

6. GBD 2017 Pancreatic Cancer Collaborators. The global, regional, and national burden of pancreatic cancer and its attributable risk factors in 195 countries and territories, 1990-2017: a systematic analysis for the global burden of Disease study 2017. *Lancet Gastroenterol Hepatol*. (2019) 4:934–47. doi: 10.1016/S2468-1253(19)30347-4

7. GBD 2019 Stroke Collaborators. Global, regional, and national burden of stroke and its risk factors, 1990-2019: a systematic analysis for the global burden of disease study 2019. *Lancet Neurol*. (2021) 20:795–820. doi: 10.1016/s1474-4422(21)00252-0

8. Jin Z, Wang D, Zhang H, Liang J, Feng X, Zhao J, et al. Incidence trend of five common musculoskeletal disorders from 1990 to 2017 at the global, regional and national level: results from the global burden of disease study 2017. *Ann Rheum Dis*. (2020) 79:1014–22. doi: 10.1136/annrheumdis-2020-217050

9. United nations, Department of Economic and social affairs, population division. World population prospects 2019 online edition, 2019. Available at: https://population.un.org/wpp/ (Accessed July 12, 2021).

10. Peery AF, Crockett SD, Murphy CC, Lund JL, Dellon ES, Williams JL, et al. Burden and cost of gastrointestinal, liver, and pancreatic diseases in the United States: update 2018. *Gastroenterology*. (2019) 156:254–272.e11. doi: 10.1053/j.gastro.2018.08.063

11. Singer M, Deutschman CS, Seymour CW, Shankar-Hari M, Annane D, Bauer M, et al. The third international consensus definitions for Sepsis and septic shock (Sepsis-3). *JAMA*. (2016) 315:801–10. doi: 10.1001/jama.2016.0287

12. Mulita F, Liolis E, Akinosoglou K, Tchabashvili L, Maroulis I, Kaplanis C, et al. Postoperative sepsis after colorectal surgery: a prospective single-center observational study and review of the literature. *Prz Gastroenterol*. (2022) 17:47–51. doi: 10.5114/pg.2021.106083

13. Taeb AM, Hooper MH, Marik PE. Sepsis: current definition, pathophysiology, diagnosis, and management. *Nutr Clin Pract*. (2017) 32:296–308. doi: 10.1177/0884533617695243

14. Kaplan GG. The global burden of IBD: from 2015 to 2025. *Nat Rev Gastroenterol Hepatol*. (2015) 12:720–7. doi: 10.1038/nrgastro.2015.150

15. Bernstein CN, Kraut A, Blanchard JF, Rawsthorne P, Yu N, Walld R. The relationship between inflammatory bowel disease and socioeconomic variables. *Am J Gastroenterol*. (2001) 96:2117–25. doi: 10.1111/j.1572-0241.2001.03946.x

16. Malik TA. Inflammatory bowel Disease: historical perspective, epidemiology, and risk factors. *Surg Clin North Am*. (2015) 95:1105–22. doi: 10.1016/j.suc.2015.07.006

17. Yadav D, Lowenfels AB. The epidemiology of pancreatitis and pancreatic cancer. *Gastroenterology*. (2013) 144:1252–61. doi: 10.1053/j.gastro.2013.01.068

18. Hirota M, Shimosegawa T, Masamune A, Kikuta K, Kume K, Hamada S, et al. The seventh nationwide epidemiological survey for chronic pancreatitis in Japan: clinical significance of smoking habit in Japanese patients. *Pancreatology*. (2014) 14:490–6. doi: 10.1016/j.pan.2014.08.008

19. Kleeff J, Whitcomb DC, Shimosegawa T, Esposito I, Lerch MM, Gress T, et al. Chronic pancreatitis. *Nat Rev Dis Primers*. (2017) 3:17060. doi: 10.1038/nrdp.2017.60

20. Alpizar-Rodriguez D, Pluchino N, Canny G, Gabay C, Finckh A. The role of female hormonal factors in the development of rheumatoid arthritis. *Rheumatology (Oxford)*. (2017) 56:kew318–kew1263. doi: 10.1093/rheumatology/kew318

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 31 August 2023
DOI 10.3389/fpubh.2023.1214066

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Lawrence Ulu Ogbonnaya,
Ebonyi State University, Nigeria
Katherine E. A. Semrau,
Ariadne Labs, United States

*CORRESPONDENCE
Wilbroad Mutale
✉ wmutale@yahoo.com

RECEIVED 28 April 2023
ACCEPTED 03 July 2023
PUBLISHED 31 August 2023

CITATION
Mutale W, Ayles H, Lewis J, Bosompraph S, Chilengi R, Tembo MM, Sharp A, Chintu N and Stringer J (2023) Protocol-driven primary care and community linkage to reduce all-cause mortality in rural Zambia: a stepped-wedge cluster randomized trial.
Front. Public Health 11:1214066.
doi: 10.3389/fpubh.2023.1214066

Protocol-driven primary care and community linkage to reduce all-cause mortality in rural Zambia: a stepped-wedge cluster randomized trial

Wilbroad Mutale[1]*, Helen Ayles[2], James Lewis[3], Samuel Bosompraph[4,5], Roma Chilengi[4], Margaret M. Tembo[2], Ab Sharp[2], Namwinga Chintu[6] and Jeffrey Stringer[7]

[1]Department of Health Policy and Management, School of Public Health, University of Zambia, Lusaka, Zambia, [2]Zambia AIDS Related Tuberculosis (ZAMBART), Lusaka, Zambia, [3]MRC Tropical Epidemiology Group, London School of Hygiene and Tropical Medicine, London, United Kingdom, [4]Centre for Infectious Disease Research in Zambia (CIDRZ), Lusaka, Zambia, [5]Department of Biostatistics, School of Public Health, University of Ghana, Accra, Ghana, [6]Society for Family Health in Zambia, Lusaka, Zambia, [7]University of North Carolina, Global Women Health, Chapel Hill, NC, United States

Introduction: While tremendous progress has been made in recent years to improve the health of people living in low- and middle-income countries (LMIC), significant challenges remain. Chief among these are poor health systems, which are often ill-equipped to respond to current challenges. It remains unclear whether intensive intervention at the health system level will result in improved outcomes, as there have been few rigorously designed comparative studies. We present results of a complex health system intervention that was implemented in Zambia using a cluster randomized design.

Methods: BHOMA was a complex health system intervention comprising intensive clinical training and quality improvement measures, support for commodities procurement, improved community outreach, and district level management support. The intervention was introduced as a stepped wedge cluster-randomized trial in 42 predominately rural health centers and their surrounding communities in Lusaka Province, Zambia. Baseline survey was conducted between January–May 2011, mid-line survey was conducted February–November, 2013 and Endline survey, February–November 2015.The primary outcome was all-cause mortality among those between 28 days and 60 years of age and assessed through community-based mortality surveys. Secondary outcomes included post-neonatal under-five mortality and service coverage scores. Service coverage scores were calculated across five domains (child preventative services; child treatment services; family planning; maternal health services, and adult health services). We fit Cox proportional hazards model with shared frailty at the cluster level for the primary analysis. Mortality rates were age-standardized using the WHO World Standard Population.

Results: Mortality declined substantially from 3.9 per 1,000 person-years in the pre-intervention period, to 1.5 per 1,000 person-years in the post intervention period. When we compared intervention and control periods, there were 174 deaths in 49,230 person years (age-standardized rate = 4.4 per 1,000 person-years) in the control phase and 277 deaths in 74,519 person years (age-standardized rate = 4.6 per 1,000 person-years) in the intervention phase. Overall, there was no evidence

for an effect of the intervention in minimally-adjusted [hazard ratio (HR) = 1.18; 95% confidence interval (CI): 0.88, 1.56; value of $p = 0.265$], or adjusted (HR = 1.12; 95% CI: 0.84, 1.49; value of $p = 0.443$) analyses.

Coverage scores that showed some evidence of changing with time since the cluster joined the intervention were: an increasing proportion of children sleeping under insecticide treated bed-net (value of $p < 0.001$); an increasing proportion of febrile children who received appropriate anti-malarial drugs (value of $p = 0.039$); and an increasing proportion of ever hypertensive adults with currently controlled hypertension (value of $p = 0.047$). No adjustments were made for multiple-testing and the overall coverage score showed no statistical evidence for a change over time (value of $p = 0.308$).

Conclusion: We noted an overall reduction in post-neonatal under 60 mortality in the study communities during the period of our study, but this could not be attributed to the BHOMA intervention. Some improvements in service coverage scores were observed.

Clinical Trial Registration: clinicaltrials.gov, Identifier NCT01942278.

KEYWORDS

health systems, mortality, stepped wedge, quality improvement, health system strengthening

Introduction

There has been unprecedented progress in global health in the past 20 years mostly driven by external global health actors (1). However, progress has not been uniform, especially in lower- and middle-income countries (LMICs) where the poorest sectors of the population often face the worst outcomes (2). While globally mortality rates have decreased across all age groups over the past five decades, with the largest improvements occurring among children younger than 5 years, the current rates remain unacceptably high. In 2015, about 5.9 million children died before reaching their 5th birthday; half of these resided in sub-Saharan Africa (3). Similarly, deaths among younger adults continues to increase (4). If current trends continue, more than 44 million lives will have been lost to avoidable death by 2030 (5).

The agenda to develop resilient health systems has become urgent as it has been seen as a key driver to achieving equitable and sustainable health outcomes for all. The UN Sustainable Development Goals (SDG) are ambitious and include targets to radically reduce maternal mortality, to end preventable child mortality, to end deaths from TB, AIDS and malaria, to curtail the burden of non-communicable diseases, and to achieve universal healthcare coverage (6). The services required to achieve these SDGs can only be delivered through a transformation of primary health care delivery. In many LMICs, primary health systems face inadequate financial and human resources and are overwhelmed by the needs of the ever-growing populations they serve. It is clear that system strengthening is needed, but it is unclear how best to do this approach daunting task. Zambia exemplifies the challenges facing LMIC primary health care systems (7).

The Better Health through Mentoring and Assessment (BHOMA) project was a complex public health intervention funded by the Doris Duke Charitable Foundation. BHOMA introduced a protocol-driven primary care and community linkage intervention, which aimed to improve clinical care at the primary care level and increase community demand through improved confidence in the health system. The hypothesis behind the intervention was that a systematic investment in improved clinical care would immediately improve outcomes and ultimately lead to better utilization at community level. Details of the multi-level BHOMA intervention have been published elsewhere (8). Development of the intervention was consultative and addressed most urgent local priorities, including reducing under-five and adult mortality. The primary goal was to reduce all-cause mortality in individuals between 28 days and 60 years old within the study area. We excluded neonates because the interventions necessary to improve survival in this population have been extensively studied. In this paper, we report the primary results of the BHOMA intervention focusing on post-neonatal adult mortality (PN-U60M), post neonatal under-five mortality (PN-U5M), and on service coverage.

Methods

The BHOMA intervention

BHOMA was conducted in 3 predominately rural districts within the Lusaka Province of Zambia. Details of the complex health systems intervention its underlying theory of change have been described in detail in prior publications (7–22). The intervention was based on the idea that the patient-provider interaction is critical to service quality and community trust, and that all aspects of an effective health system should be organized

around ensuring that this encounter is effective. Toward this end, BHOMA provided support for establishment of clear clinical management protocols, improved medical record keeping, intensive clinical mentorship, on-the-job training and iterative quality improvement (QI), bolstering the commodities supply chain, and innovative linkages between clinic and community. We briefly recount its salient features here.

Clinical care protocols

We began by convening technical personnel within the Zambian Ministry of health to review existing guidelines for clinical care in primary settings. In general these guidelines comprised local adaptations of the WHO's Integrated Management of Adolescent and Adult Illnesses (23), Integrated Management of Childhood Illness (24), and Emergency Obstetric and Newborn Care (25). From these guidelines we created simple, step-by-step care protocols that were supported by job aids, including checklists, wall charts, and a system of 7 clinical forms to guide clinicians through standardized patient evaluation and management. The project employed a new cadre of lay workers, known as "clinic support workers" – 2 or 3 individuals per facility – to support care delivery. These staff members assisted with patient navigation and check-in, obtained and documented vital signs, and maintained the clinic's paper medical record system by ensuring form completion and organized filing.

Support for improved record keeping

The project established an organized medical records system of patient charts that were kept on-site for each patient. At the conclusion of each patient visit, these paper records were transcribed into a comprehensive, purpose-built electronic system by dedicated data entry technicians supported by the study (CommCare® https://www.dimagi.com/commcare/). The system—which used low voltage touch screen computers networked through local cellular providers—included detailed reporting functionality to monitor a set of performance indicators and clinical outcomes. These reports were available on demand to clinic leadership and comprised a key aspect of the quality improvement (QI) intervention (#3, below). At the time of registration, the electronic system assigned each patient to a specific community health worker (CHW) based upon where they live. It also kept track of open/unresolved cases and alerted CHWs through linked cell phones to patients who missed follow-up appointments so they could be traced at home (13).

Training and quality improvement

We formed 6 quality improvement (QI) teams, each comprising a senior clinician, pharmacist, and data technician to guide an intensive effort in refresher training and implementation of the new protocols. An initial 1-month visit to each facility included an assessment of current staffing and equipment needs, strengthening of commodities tracking and requisition procedures, strategizing for improvement in patient flow, training in the clinical protocols, and implementation of improved record keeping. After the initial implementation phase, the QI teams returned to the facility monthly for 3 visits and then quarterly to conduct structured reviews of medical records (focusing on the accuracy of diagnosis and management) and review performance metrics with the facility's clinical officers, nurses, midwives, and other staff to develop specific goals and plans for improvement.

Support for commodity procurement

BHOMA provided targeted support for essential supplies and equipment needed by site-level clinicians to deliver quality care. This began with a pre-implementation assessment of each participating facility, followed by targeted equipment procurement. Part of the QI teams' mandate was to strengthen site-level forecasting and ordering.

Improved community linkages

BHOMA worked to increase linkages between each facility and the community it served through active patient referral and follow-up. We recruited more than 200 CHWs who participated in 4 weeks of initial implementation training at their respective facilities. Each CHW was trained in recognition of danger signs, including when and how to refer individuals who met specific criteria to health facilities. We also trained them in how to dispense ferrous sulfate and folic acid for treatment of anemia, prescribe oral rehydration salts for child diarrhea, and give anti-malarial medication.

CHWs were each assigned to a specific zone within the catchment geography of their respective clinic. They made quarterly visits to all households in their zone where they interviewed household members and referred those in need of care. In the home, the electronic system system—installed on their mobile phones—guided the CHWs through a series of questions to which they keyed in responses. If a referral was made, the appointment was registered electronically at the corresponding clinic and not resolved in the CWH's phone until the patient had presented. All household information, including interval patient outcomes, was transferred back to the clinic servers via mobile phone at the end of each home visit. Quarterly statistics on new pregnancies, illnesses, and deaths were aggregated and provided to neighborhood health committees to facilitate local solutions to health care access.

The CHWs also made *ad hoc* visits to patient homes when a clinic appointment had been missed. This was facilitated by the electronic health record system, which sent an alert to the mobile phone of the corresponding CWH. The system kept a running tally of each CHW's open cases and prioritized those who were diagnosed with specified danger signs at their clinic visit.

District level support

Continuously throughout the project—and thus not evaluated by the randomized intervention roll-out—we provided support at the district level in governance, management, site communication, and commodities forecasting. The project supported improved implementation of existing district management tools, including the Health Management Information System (HMIS), and the District Integrated Logistics and Supplies Assessment Tool (DILSAT). We also placed a dedicated pharmacy technician at each District Health Office to strengthen the district's ordering and supply system for equipment, supplies, diagnostics, and drugs. To ensure early ownership and integration into routine districts functions, the

10.3389/fpubh.2023.1214066

TABLE 1 BHOMA site-level implementation activities.

Week	Training activities	Trainees
1 and 2	• Diagnosis and management of common presentations • Clinical protocols	• Clinical staff • Clinic support workers • Community health workers
3	• Patient registration and triage • Clinical forms • Data entry • Medical record keeping	• Clinical staff • Clinic support workers • Community health workers
4	• Patient registration and triage • Clinical forms • Data entry • Medical record keeping • Antenatal care, postnatal care	• Clinical staff • Clinic support workers • Community health workers • Traditional birth attendants

implementation teams worked closely with a designated district clinical lead, who was involved in most trainings and quality improvement visits.

Intervention implementation phases

The intervention was introduced at the site level through structured on-site training and mentorship. During this implementation phase, the QI team spent 4 weeks training staff in a variety of quality-related skills and competences (Table 1). During the first 2 weeks, the QI teams conducted training on diagnosis and management of common illnesses and introduced relevant protocols for clinical case management. In week 2, we trained on patient triage and record keeping using standardized forms. In week 4, we incorporated pregnancy care. All members of staff at target health facility (clinical officers, nurses, midwives, clinic support workers, and CHWs) were engaged in the site-level training.

To assess the effectiveness of our intervention, we conducted three population-based household surveys (community surveys)—one at baseline and two at follow-up. Within each cluster households to be surveyed were randomly selected through a satellite mapping exercise where the catchment area of each facility was geographically outlined. In each cluster, squares of 900 m^2 were marked within a 3.8 km of the health facility. Computer-generated randomization was used to determine which squares would be visited and the order of visitation. All households in randomly selected squares where the survey was started were visited until the sample size was reached.

Trial design

The BHOMA intervention was delivered in a cluster-randomized fashion (8). The trial—formally categorized as a *stepped wedge trial of incomplete design with an implementation period*—is registered at clinicaltrials.gov (NCT01942278). Our primary unit of analysis was an implementation cluster, comprising one primary health care facility and the population that it served. All clusters were situated within three rural districts of Lusaka Province, Zambia (Figure 1). In these districts a total of 52 health facilities existed at the start of the trial and were initially eligible for inclusion. Ten clusters were excluded—three military facilities, six pilot sites, and one facility with no trained health care workers (Figure 2). The population estimates of the clusters varied from 1,501 to 44,658 people.

Randomization and masking

Forty-two clusters were randomly assigned to start the intervention in seven steps, each step having six clusters, 3 months apart. Randomization of the clusters into the seven steps was stratified by district. At each step, three clusters from district 1, two clusters from district 2 and one cluster from district 3 were randomly assigned to start the intervention. Randomization was done by a statistician (JL) based in London and not involved in implementation, who generated a random implementation schedule using Stata version 15 (StataCorp LLC; College Station, TX). The order of roll out of the intervention could not be blinded.

Outcomes assessment

Outcomes were measured in community and facility level surveys conducted at three time points during the study (Figure 1). Our pre-specified primary outcome—derived from community survey—was age-standardized mortality among individuals aged > 28 days and < 60 years (PN-U60M). Secondary outcomes included post-neonatal under-five mortality (PN-U5M).

The primary outcome of mortality was measured in a random sample of households (120 in the first survey and 300 in surveys 2 and 3). To estimate deaths occurring only within the cluster and to provide monthly mortality rates to allow for analysis of implementation timing in the stepped wedge roll-out, mortality rates were calculated using a retrospective household enumeration. The head of each household (or, if not available, another adult member) was asked to enumerate every person who had stayed the previous night in that household and then to go back month-by-month. We looked back 12 months for survey 1 and 24 months for surveys 2 and 3, identifying those that had been present or absent in each month. The respondent was also asked to include any individuals who had been present in the household for at least 1 month but were no longer present, either because they had left or because they had died. We collected the cause (if known) and date of all reported deaths.

The secondary outcome of PN-U5M was assessed in two ways: first by restricting the enumeration above to individuals under 5 years old and second from a separate birth history collected from women using the standard instrument employed by the Demographic and Health Survey.[1]

1 https://dhsprogram.com

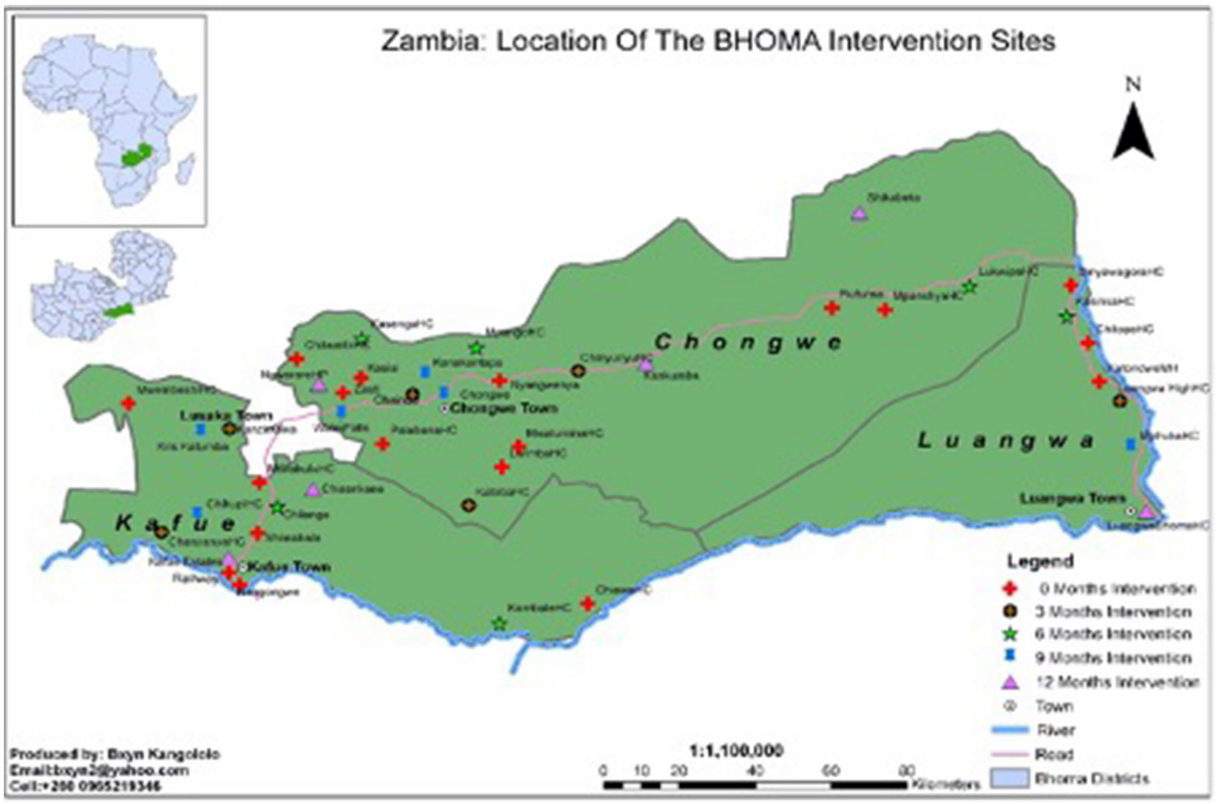


FIGURE 1
Map showing BHOMA intervention districts in Zambia.

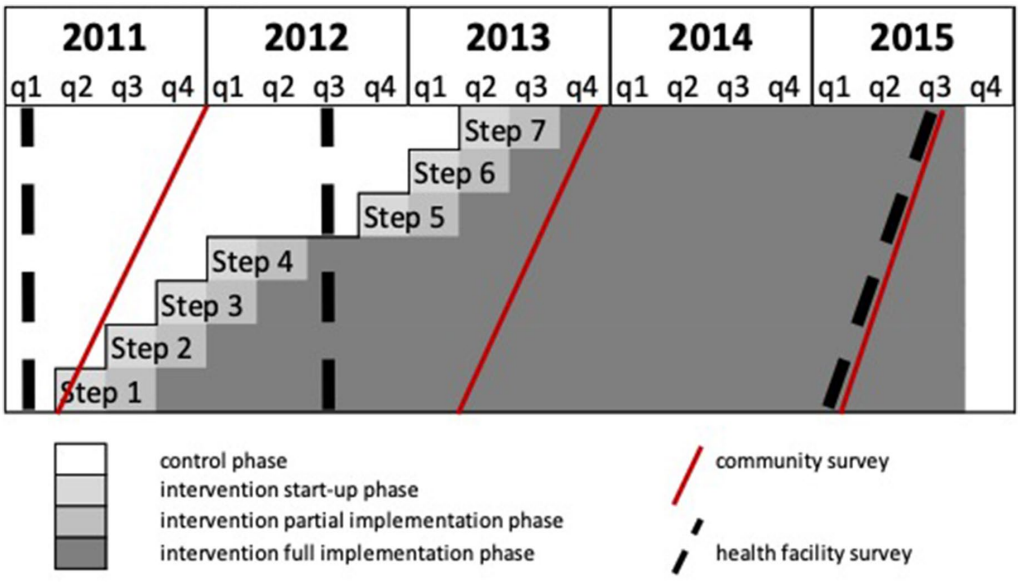


FIGURE 2
Schematic showing stepped-wedge trial design, with timing of community and health facility surveys.

For each facility, Coverage scores were constructed using the methods of Victora et al. (26) We adopted 2 or 3 domains for each coverage score and calculated the coverage gap. A full list of indicators and their definitions is available in the Appendix (Supplementary Table S1). Information on the coverage indicators was collected from individual questionnaires administered to all available adults in survey 1 and in 120 randomly selected households from the 300 per cluster in surveys 2 and 3.

Questionnaires were constructed to align with Demographic and Health Survey tools where possible (27).

Sample size

The sample size was based on standard formula for parallel cluster randomized trials, adjusted for the design effect of a stepped wedge design (based on the number of steps) (28). The plan was to conduct three surveys of the 42 clusters, each recruiting 150 households per cluster, of whom 6 members were assumed aged <60 years, among whom deaths within the household in the last 12 months would be ascertained. Assuming a mortality rate for those age < 60 years of 20/1000 person years and a coefficient of variation of 0.3 there would be at least 90% power to detect a 35% reduction in mortality. Assuming a post-neonatal child mortality rate of 35/1,000 person years (corresponding to under-5 mortality of 168/1,000) and that each participating household would have an average of two children under 5 years of age, there would be at least 90% power to detect a 35% reduction in the secondary outcome of post-neonatal under-5 mortality. After completion of the baseline survey, we observed mortality rates were lower than anticipated. We thus doubled the survey sample size to 300 households per cluster in survey rounds 2 and 3.

Statistical analysis

The primary outcome of all-cause mortality in those aged under 60 years was analyzed by constructing retrospective mortality cohorts, analyzed using a Cox proportional hazards model with shared frailty at the cluster level. The variable for intervention phase was coded as a quantitative variable with values: 0 for the control and intervention start-up phases; ½ for the intervention partial implementation phase; and 1 for the intervention full implementation phase. Sensitivity analyses were: using a Poisson model with a random effect for clustering and a categorical variable for time step; the same Poisson model, but restricted to the same time period as the Cox model; the Cox model excluding trauma deaths; Cox model excluding any persons who had not started the retrospective cohort in the community (i.e., excluding in-migrants); Cox model excluding the 3-month intervention start-up and partial implementation phases. Minimally adjusted models adjusted for district as the stratifying variable, age category (as age-adjusted rates were pre-specified) and calendar time (implicitly in the Cox model or explicitly in the Poisson model). Adjusted models also adjusted for baseline mortality rate at the cluster-level as this showed some imbalance at baseline. Mortality rates were age-standardized using the WHO World Standard Population.

Under-five mortality rates were analyzed firstly using detailed birth histories collected from all mothers in the surveys, which were used to construct retrospective cohorts. These were analyzed using Cox models as for mortality rates for those <60 years. Neonatal deaths were excluded, as were those who were alive and no longer living with the mother. Sensitivity analyses were: excluding the three-month intervention start-up and partial implementation phases; and using the primary analysis for mortality rates for those aged < 60 years, restricted to those aged under 5 years old.

Coverage scores were calculated across five domains (under-fives prevention; under-fives treatment; family planning; maternal health and adult health). Summary measures were calculated for each domain by averaging all scores within that domain; overall coverage was calculated by averaging across the five domains. As all clusters were in the control phase during the baseline survey and intervention phase at subsequent surveys, the time since the cluster joined the intervention phase was used as the exposure variable in 1 year categories. Since the order of clusters joining the intervention phase was randomized, the time since the cluster joined the intervention was also a randomized exposure variable. The coverage scores were measured at two surveys and so analysis accounted for this repeat measurement using generalized estimating equations in linear regression models.

All analyses were performed using Stata SE 15 (StataCorp, College Station, TX, United States). The trial was registered with clinicaltrials.gov, number NCT01942278.

Ethical statement

Permission for the study was sought at community level by traditional leaders such as chiefs and "head men" or counselors in urban areas. The Ministry of Health and district health management teams gave permission for their facilities to be included in the study. For all households randomly selected to take part in the outcome assessment survey, the head of the house or another responsible adult were asked to provide written informed consent for enumeration and collection of household characteristics. Each adult (18 years and older) was asked to complete an individual level questionnaire and to give individual written informed consent. All versions of the protocol were reviewed and approved by the ethics committees of the University of Zambia, London School of Hygiene and Tropical medicine, University of Alabama at Birmingham and subsequently the University of North Carolina, Chapel Hill. The Ministry of Health also reviewed the protocol and gave permission for the study to be undertaken.

Role of the funder

The Doris Duke Charitable Foundation (DDCF) funded the project, was involved in its planning, and monitored its progress. DDCF was not involved in implementation of the intervention or the surveys used to measure study outcomes. Neither was it involved in the interpretation of study results, the preparation of this manuscript, or the decision to submit it for publication.

Results

Data was collected at three time points: Baseline survey was conducted between January–May 2011, mid-line survey was

conducted February–November, 2013 and Endline survey, February–November 2015.

Across the three surveys, 30,472 were randomly selected for enumeration. 29,486 households were enumerated, 711 households were absent and 275 households refused consent (Figure 3). The 29,486 households enumerated 138,430 members, giving total person years of 49,240 in the control phase and 74,530 in the intervention phase. No clusters left or joined the study during its duration. Individuals recorded in the household census in the baseline survey were 50% male and 47.5% were aged 0–14 years, 21.4% were aged 15–24 years and 31.1% were aged 25–59 years (Table 2). The population was relatively stable with 84.7% having been in the household every month in the year prior to the survey. Reasonable baseline balance was observed on key characteristics (Table 2), although the weighted average of age-standardized mortality was 3.9 per 1,000 person-years in the control phase and 5.0 per 1,000 person-years in the intervention phase. Some imbalance in the opposite direction was observed when restricted to those under 5 years old, but this estimate was based on only 19 recorded deaths.

Over the period of interest (steps one to seven), the number of deaths recorded per cluster and per intervention phase varied from zero to 17 (Supplementary Table S1). Mortality declined substantially from 3.9 per 1,000 person-years in the pre-intervention period (2011), to 1.5 per 1,000 person-years in the post intervention period (2015; Figure 4). When restricted to the formal trial period, there were 174 deaths over 49,230 person years of follow-up (age-standardized rate = 4.4 per 1,000 person-years) in the control phase compared to 277 deaths over 74,519 person years (age-standardized rate = 4.6 per 1,000 person-years) in the intervention phase (Table 3). There was no clear pattern in mortality hazard observed across the steps (Supplementary Table S2). Overall, there was no evidence for an effect of the intervention in minimally-adjusted (hazard ratio [HR] = 1.18; 95% confidence interval [CI]: 0.88, 1.56; value of $p = 0.265$), or adjusted (HR = 1.12; 95% CI: 0.84, 1.49; value of $p = 0.443$) analyses (Table 3). These results remained consistent across a range of sensitivity analyses (Table 4). There was a trend observed for an intervention effect in a planned sensitivity analysis comparing the phase of >1 year full implementation to the control phase (aHR = 0.69; 95% CI: 0.44, 1.07; value of $p = 0.093$; Table 4).

Whether calculated from the birth cohorts or by restricting the primary analysis to those under-5 years, there was no evidence for an impact on mortality among under-fives (Table 4). However, in one sensitivity analysis there was weak evidence for a negative impact of the intervention on mortality among under-fives (aHR = 2.21; 95% CI: 1.01, 4.84; value of $p = 0.048$; Table 5).

Some, but not all, coverage scores showed statistical evidence of improvement as a result of the intervention, including: an increasing proportion of children sleeping under insecticide treated bed-net (value of $p < 0.001$); an increasing proportion of febrile children who received appropriate anti-malarial drugs (value of $p = 0.039$); and an increasing proportion of ever hypertensive adults with currently controlled hypertension (value of $p = 0.047$; Supplementary Tables S3 and S4). No adjustments were made for multiple-testing and the overall coverage score showed no statistical evidence for a change over time (value of $p = 0.308$) (Table 6).

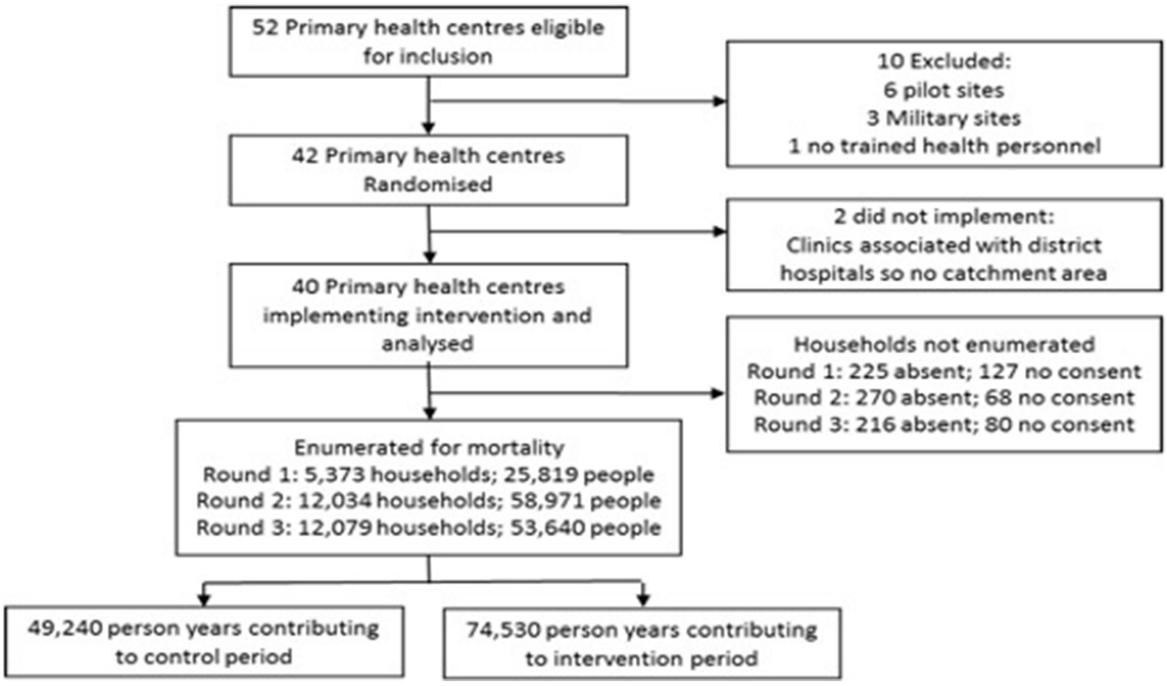


FIGURE 3
Consort diagram modified for cluster and stepped wedge.

10.3389/fpubh.2023.1214066

TABLE 2 Baseline characteristics of population enumerated in the control and intervention phases of the study.

	Cluster-level means*		
	Overall	Control-phase	Intervention-phase
Sex			
Male	49.8%	49.8%	49.9%
Female	50.2%	50.2%	50.1%
Age category (years)			
0–4	17.6%	17.5%	17.6%
5–9	15.4%	16.0%	15.1%
10–14	14.5%	14.7%	14.3%
15–24	21.4%	21.2%	21.4%
25–59	31.1%	30.6%	31.6%
Present in household for each month in prior year			
No	15.3%	13.8%	16.4%
Yes	84.7%	86.2%	83.6%
Mortality rate per 1,000 person years			
Under 60 years old	4.65	3.87	4.95
Under 5 years old	4.99	5.41	4.76
Participation in adult survey			
No	4.4%	4.9%	4.0%
Yes	41.5%	42.1%	41.1%
Ineligible	23.5%	21.6%	24.9%
Absent at time of survey	30.1%	31.0%	29.4%
Died	0.5%	0.4%	0.5%
Socioeconomic status of household			
1-poorest	19.6%	18.5%	19.9%
2	19.8%	20.6%	18.8%
3	20.3%	20.8%	20.2%
4	20.2%	21.1%	19.7%
5-least poor	20.1%	19.0%	21.5%

*As all clusters were in the control phase during the baseline survey and are all in the intervention phases by surveys 2 and 3, the usual approach to presenting baseline summaries do not apply. Instead cluster-level summaries were calculated from the baseline survey and then weighted averages were calculated separately for control and intervention phases, such that the weights were the proportion of follow-up time that each cluster contributed to that phase.

Discussion

Our study findings indicate mixed results for the BHOMA health system intervention. While we observed a general decline in post-neonatal under 60 mortality (from 3.9 to 1.5 per 1,000 person-years) over the period of surveillance, we were unable to directly attribute this reduction to our intervention. We similarly did not observe an effect on post-neonatal under 5 mortality. We did, however, observe significant improvement in facility-level coverage scores for a number of key indicators.

Our findings are consistent with prior work in Rwanda and Ghana (29, 30), where health system interventions have been associated with substantial improvement in process indicators. Most prior studies have employed "before and after" comparisons, which require caution in their interpretation because potential bias may be introduced through secular trends. We attempted to mitigate this bias through a cluster randomized stepped wedge design, but cannot completely rule out such an effect.

Another issue to consider when interpreting these findings is the complex and dynamic nature of the intervention that was implemented (11, 12). Our intervention attempted simultaneous intervention upon multiple "building blocks" (7, 11) of the health system, some of which occurred at a level above that of the randomization. For instance, the efforts we made to strengthen management capacity at the district level could not be evaluated through the stepped wedge randomization, and may have biased our outcomes toward the null. Furthermore, the complexity and scope of our multi-faceted intervention may have invited opportunistic adaptation at the district or provincial level with some "leakage" of benefits to study sites prior to formal intervention. For example, our work at the district level led to shared benefit across the control sites thus potentially diluting expected or desired effect (14). We also supported the district planning and supply chains, which could have benefited control sites, even before we introduced the intervention (14, 30). Trials are embedded within an already existing health system which tend to be hierarchical, with primary centers being supervised by districts which are in turn are supervised by provincial health teams who report to the national level. This is true for the Zambian health system. This hierarchical interdependence could potentially have introduced an element of complexity which statistical models in this analysis may not account for (31).

We used retrospective assessment of child survival *via* birth history analysis, which has potential bias relating to event omission or event displacement recall biases. In addition, there are well-described cultural beliefs in Zambia that prevent people from talking about stillbirth and child death (32). This phenomenon could have contributed to under reporting particularly for infants (31).

An important limitation for our study is inherent in its stepped-wedged design (33). As in our study, stepped-wedge cluster randomized trials are often conducted on a large scale and are therefore sensitive to external challenges that cannot directly be influenced by the researchers such as changes in the local context (33). Our study communities experienced several competing interventions during the study period (7, 11, 14). These could have impacted on the outcome measures we intended (7) (33)

Our intervention may also have been dependent on the temporal nature of the intervention; it may have taken time for the improvements to fully manifest. Delay in achieving the desired effect could result in loss of power for the stepped wedge design, especially if the intervention is not fully effective in the time interval in which the evaluation was conducted 34. Such delays

10.3389/fpubh.2023.1214066

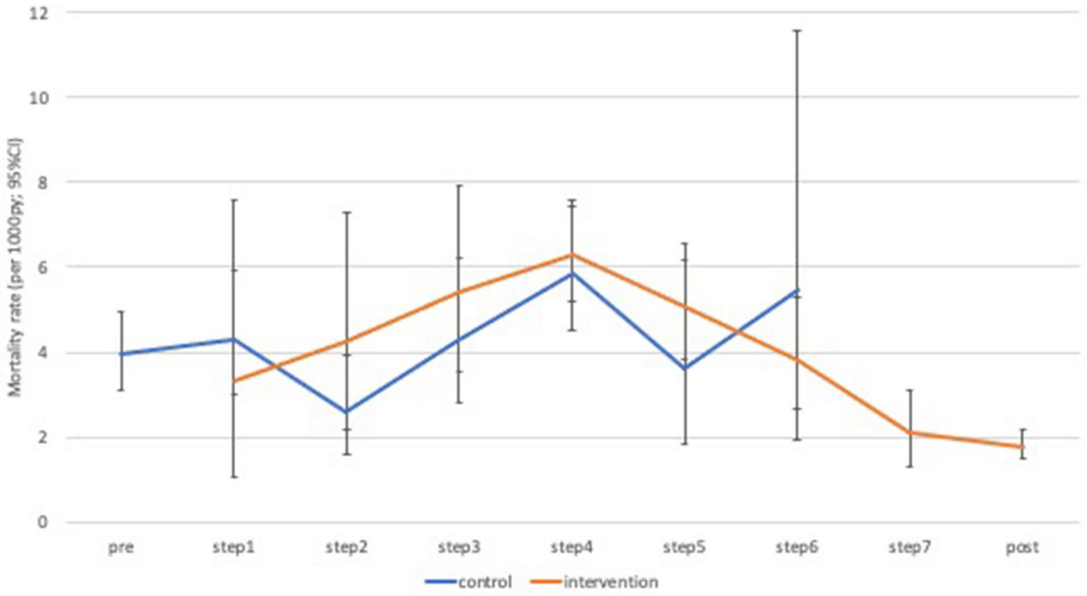


FIGURE 4
Age-standardized mortality rates by time-step and intervention phase. py, person years; CI, confidence interval.

TABLE 3 Analyses of mortality rates by control versus intervention phase.

	Control phase[1]			Intervention phase[2]			Minimally adjusted analysis[3]		Adjusted analysis[4]	
Analysis	Deaths, n	Person-years of follow-up (1000)	Mortality Rate[5] (per 1000 pyrs)	Deaths, n	Person years of follow-up (1000)	Mortality Rate[5] (per 1000 pyrs)	aHR (95% CI)	*p*-value	aHR (95% CI)	*p*-value
Cox model	174	49,230	4.37	277	74,519	4.62	1.18 (0.88, 1.56)	0.265	1.12 (0.84, 1.49)	0.443
Poisson model	251	72,028	4.23	391	150,239	3.18	1.05 (0.80, 1.37)	0.733	0.98 (0.75, 1.27)	0.860
Poisson model, restricted to same time period as Cox	174	49,230	4.37	277	74,519	4.62	1.16 (0.87, 1.55)	0.315	1.10 (0.82, 1.48)	0.508
Cox model; non-trauma deaths only	156	49,230	3.90	243	74,519	4.08	1.15 (0.86, 1.55)	0.344	1.07 (0.80, 1.44)	0.641
Cox model; excluding in-migrants	156	47,967	4.07	228	70,772	4.10	1.11 (0.82, 1.49)	0.511	1.07 (0.79, 1.45)	0.659
Cox model; excluding 6m intervention set-up period	138	38,388	4.45	214	60,881	4.32	1.27 (0.91, 1.77)	0.152	1.21 (0.87, 1.68)	0.263

[1]Control phase and intervention start-up phase combined; [2]partial and full implementation phases combined; [3]adjusted for district as the stratifying variable, age category and calendar time; [4]adjusted for district as the stratifying variable, age category, gender, calendar time and baseline mortality rate; [5]age standardised.

10.3389/fpubh.2023.1214066

TABLE 4 Analysis of mortality rates by the different phases of implementation.

Phase	Deaths, n	Person-years of follow-up (1000)	Mortality Rate[1] (per 1000 pyrs)	Minimally adjusted analysis[2]		Adjusted analysis[3]	
				aHR (95% CI)	*p*-value	aHR (95% CI)	*p*-value
Control	138	38,388	4.45	1	0.091	1	0.047
Intervention start-up and partial implementation	99	24,564	5.12	1.16 (0.87, 1.55)	0.306	1.13 (0.85, 1.51)	0.410
Full implementation <1 y	182	53,152	4.19	1.05 (0.77, 1.42)	0.771	0.98 (0.73, 1.33)	0.921
Full implementation ≥1 y	102	55,873	2.27	0.77 (0.49, 1.19)	0.236	0.69 (0.44, 1.07)	0.093

[1]age standardised; [2]adjusted for district as the stratifying variable, age category and calendar time; [3]adjusted for district as the stratifying variable, age category, gender, calendar time and baseline mortality rate.

TABLE 5 Analyses of mortality rates among those aged under five years by control versus intervention phase.

	Control phase[1]			Intervention phase[2]			Minimally adjusted analysis[3]		Adjusted analysis[4]	
Analysis	# deaths	Person years	Mortality Rate (per 1000 pyrs)	# deaths	Person years	Mortality Rate (per 1000 pyrs)	aHR (95% CI)	*p*-value	aHR (95% CI)	*p*-value
Birth history	33	5,373	6.14	30	5,647	5.31	1.52 (0.77, 3.00)	0.232	1.44 (0.73, 2.86)	0.295
Birth history; excluding 6m intervention set-up period	25	4,347	5.75	26	4,420	5.88	2.43 (1.12, 5.28)	0.025	2.21 (1.01, 4.84)	0.048
Household census, restricted to <5years	33	6,374	5.18	59	9,757	6.05	1.34 (0.73, 2.46)	0.344	1.09 (0.60, 1.98)	0.770

[1]Control phase and intervention start-up phase combined; [2]partial and full implementation phases combined; [3]adjusted for district as the stratifying variable, age category (in years) and calendar time; [4]adjusted for district as the stratifying variable, age category (in years), gender, calendar time and baseline mortality rate among those <60 years.

TABLE 6 Analysis of coverage by the duration of full implementation.

Period of full implementation phase	Number of clusters	Coverage		Unadjusted analysis [1,3]		Adjusted analysis[2,3]	
		mean	standard deviation	difference (95% CI)	*p*-value	difference (95% CI)	*p*-value
Control	40	45.6%	6.0%				
0-11 months	22	44.5%	6.4%	0	0.321	0	0.308
12-23 months	24	45.9%	7.1%	1.8% (-1.8%, 5.4%)		1.4% (-2.0%, 4.8%)	
24-35 months	18	47.4%	5.4%	2.6% (-0.2%, 5.3%)		2.7% (-0.1%, 5.4%)	
36+ months	16	46.2%	6.9%	2.2% (-1.7%, 6.1%)		1.7% (-1.9%, 5.4%)	

[1]Adjusted for district as the stratifying variable; [2]adjusted for district as the stratifying variable and baseline coverage; [3]linear regression model with generalised estimating equations to give robust standard errors accounting for two measurements of each cluster.

can be caused by a slower than expected intervention rollout or by intrinsic lag between introduction of the intervention and its effect on the outcome. Our trial had two challenges that fit well with this observation. Firstly, we had a 6-month delay in introducing the 5th of the 7 clusters due to administrative issues with funding. A second challenge was related to the outcome we aimed to improve. Improvements in all-cause mortality may have taken more than the 3 months we used per implementation step to manifest. Perhaps longer implementation steps and longer follow-up time would have yielded different results 34. The observation that a few short-term outcomes in our study, such as coverage scores, showed significant improvement across the steps, may support this argument. We have similarly reported positive health systems impact of the BHOMA intervention in the corresponding publication.

Our findings have public health and research significance, first we utilized a gold standard randomized approach to evaluate this multi-faceted intervention. Despite the challenges outlined, this is one

of the few complex health system interventions that have employed both a randomized design and mortality outcomes to evaluate efficacy. The fact that our chosen outcome measure of mortality was not demonstrated, but instead demonstrated a change in the process indicators such as coverage and health system indicators (Mutale, BHOMA paper 2), indicate that allowing longer term follow-up is crucial to making definitive conclusion. It will be important for future studies to consider varying periods of follow-up time to in order to estimate minimum time required to establish effect of similar large health system interventions on mortality. Our study had a very short follow-up time and is therefore not able to estimate such lead time. Other modern approaches such as modeling the period and effect size should be considered in future studies.

Finally, the study clearly demonstrate the importance of carefully choosing indicators and allowing sufficient follow-up time when evaluating complex health system interventions. Our findings may be generalizable to other settings but we caution that follow-up time need to be sufficient and that chosen indicators must be realistic within the study time frame in order to demonstrate meaningful health system impact.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by University of Zambia Bioethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

WM, HA, JL, SB, RC, MT, AS, NC, and JS participated in the design and implementation of the intervention. JL and SB conducted the analysis. WM drafted the manuscript. All authors contributed to the article and approved the submitted version.

Funding

This work was supported by Doris Duke Charitable Foundation (DDCF).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1214066/full#supplementary-material

References

1. Marchal B, Cavalli A, Kegels G. Global health actors claim to support health system strengthening: is this reality or rhetoric? *PLoS Med*. (2009) 6:e1000059–9. doi: 10.1371/journal.pmed.1000059

2. Collaborators GS. Measuring progress and projecting attainment on the basis of past trends of the health-related sustainable development goals in 188 countries: an analysis from the global burden of disease study 2016. *Lancet*. (2017) 390:1423–59. doi: 10.1016/S0140-6736(17)32336-X

3. Liu L, Oza S, Hogan D, Chu Y, Perin J, Zhu J, et al. Global, regional, and national causes of under-5 mortality in 2000–15: an updated systematic analysis with implications for the sustainable development goals. *Lancet*. (2016) 388:3027–35. doi: 10.1016/S0140-6736(16)31593-8

4. Collaborators GBDM. Global, regional, and national under-5 mortality, adult mortality, age-specific mortality, and life expectancy, 1970-2016: a systematic analysis for the global burden of disease study 2016. *Lancet*. (2017) 390:1084–150. doi: 10.1016/S0140-6736(17)31833-0

5. Secretary-General. *Global sustainable development report 2019: The future is now – Science for achieving sustainable development*. New York: United Nations publication issued by the Department of Economic and Social Affairs (2019).

6. Kruk ME, Gage AD, Arsenault C, Jordan K, Leslie HH, Roder-DeWan S, et al. High-quality health systems in the sustainable development goals era: time for a revolution. *Lancet Glob Health*. (2018) 6:e1196–252. doi: 10.1016/S2214-109X(18)30386-3

7. Mutale W, Ayles H, Bond V, Chintu N, Chilengi R, Mwanamwenge MT, et al. Application of systems thinking: 12-month postintervention evaluation of a complex health system intervention in Zambia: the case of the BHOMA. *J Eval Clin Pract*. (2017) 23:439–52. doi: 10.1111/jep.12354

8. Stringer JS, Chisembele-Taylor A, Chibwesha CJ, Chi HF, Ayles H, Manda H, et al. Protocol-driven primary care and community linkages to improve population health in rural Zambia: the better health outcomes through mentoring and assessment (BHOMA) project. *BMC Health Serv Res*. (2013) 13:S7. doi: 10.1186/1472-6963-13-S2-S7

9. Hensen B, Lewis JJ, Schaap A, Tembo M, Vera-Hernández M, Mutale W, et al. Frequency of HIV-testing and factors associated with multiple lifetime HIV-testing among a rural population of Zambian men. *BMC Public Health*. (2015) 15:960. doi: 10.1186/s12889-015-2259-3

10. Mutale W, Ayles H, Bond V, Mwanamwenge MT, Balabanova D. Measuring health workers' motivation in rural health facilities: baseline results from three study districts in Zambia. *Hum Resour Health*. (2013) 11:8. doi: 10.1186/1478-4491-11-8

11. Mutale W, Balabanova D, Chintu N, Mwanamwenge MT, Ayles H. Application of system thinking concepts in health system strengthening in low-income settings: a proposed conceptual framework for the evaluation of a complex health system intervention: the case of the BHOMA intervention in Zambia. *J Eval Clin Pract*. (2016) 22:112–21. doi: 10.1111/jep.12160

12. Mutale W, Bond V, Mwanamwenge MT, Mlewa S, Balabanova D, Spicer N, et al. Systems thinking in practice: the current status of the six WHO building blocks for health system strengthening in three BHOMA intervention districts of Zambia: a baseline qualitative study. *BMC Health Serv Res*. (2013) 13:291. doi: 10.1186/1472-6963-13-291

13. Mutale W, Chintu N, Amoroso C, Awoonor-Williams K, Phillips J, Baynes C, et al. Improving health information systems for decision making across five sub-Saharan African countries: implementation strategies from the African health initiative. *BMC Health Serv Res*. (2013) 13:S9. doi: 10.1186/1472-6963-13-S2-S9

14. Mutale W, Cleary S, Olivier J, Chilengi R, Gilson L. Implementing large-scale health system strengthening interventions: experience from the better health outcomes through mentoring and assessments (BHOMA) project in Zambia. *BMC Health Serv Res*. (2018) 18:795. doi: 10.1186/s12913-018-3619-3

15. Mutale W, Godfrey-Fausset P, Mwanamwenge MT, Kasese N, Chintu N, Balabanova D, et al. Measuring health system strengthening: application of the balanced scorecard approach to rank the baseline performance of three rural districts in Zambia. *PLoS One*. (2013) 8:e58650. doi: 10.1371/journal.pone.0058650

16. Mutale W, Masoso C, Mwanza B, Chirwa C, Mwaba L, Siwale Z, et al. Exploring community participation in project design: application of the community conversation approach to improve maternal and newborn health in Zambia. *BMC Public Health*. (2017) 17:277. doi: 10.1186/s12889-017-4187-x

17. Mutale W, Mwanamwenge MT, Balabanova D, Spicer N, Ayles H. Measuring governance at health facility level: developing and validation of simple governance tool in Zambia. *BMC Int Health Hum Rights*. (2013) 13:34. doi: 10.1186/1472-698X-13-34

18. Mutale W, Stringer J, Chintu N, Chilengi R, Mwanamwenge MT, Kasese N, et al. Application of balanced scorecard in the evaluation of a complex health system intervention: 12 months post intervention findings from the BHOMA intervention: a cluster randomised trial in Zambia. *PLoS One*. (2014) 9:e93977. doi: 10.1371/journal.pone.0093977

19. Mwanza M, Zulu J, Topp SM, Musonda P, Mutale W, Chilengi R. Use of lot quality assurance sampling surveys to evaluate community health worker performance in rural Zambia: a case of Luangwa district. *BMC Health Serv Res*. (2017) 17:279. doi: 10.1186/s12913-017-2229-9

20. Schuttner L, Sindano N, Theis M, Zue C, Joseph J, Chilengi R, et al. A mobile phone-based, community health worker program for referral, follow-up, and service outreach in rural Zambia: outcomes and overview. *Telemed J E Health*. (2014) 20:721–8. doi: 10.1089/tmj.2013.0240

21. Yan LD, Chi BH, Sindano N, Bosomprah S, Stringer JSA, Chilengi R. Prevalence of hypertension and its treatment among adults presenting to primary health clinics in rural Zambia: analysis of an observational database. *BMC Public Health*. (2015) 15:933. doi: 10.1186/s12889-015-2258-4

22. Yan LD, Chirwa C, Chi BH, Bosomprah S, Sindano N, Mwanza M, et al. Hypertension management in rural primary care facilities in Zambia: a mixed methods study. *BMC Health Serv Res*. (2017) 17:111. doi: 10.1186/s12913-017-2063-0

23. Vasan A, Ellner A, Lawn SD, Gove S, Anatole M, Gupta N, et al. Integrated care as a means to improve primary care delivery for adults and adolescents in the developing world: a critical analysis of integrated Management of Adolescent and Adult Illness (IMAI). *BMC Med*. (2014) 12:6. doi: 10.1186/1741-7015-12-6

24. Daelmans B, Seck A, Nsona H, Wilson S, Young M. Integrated community case Management of Childhood Illness: what have we learned? *Am J Trop Med Hyg*. (2016) 94:571–3. doi: 10.4269/ajtmh.94-3intro2

25. Otolorin E, Gomez P, Currie S, Thapa K, Dao B. Essential basic and emergency obstetric and newborn care: from education and training to service delivery and quality of care. *Int J Gynecol Obstet*. (2015) 130:S46–53. doi: 10.1016/j.ijgo.2015.03.007

26. Victora CG, Fenn B, Bryce J, Kirkwood BR. Co-coverage of preventive interventions and implications for child-survival strategies: evidence from national surveys. *Lancet*. (2005) 366:1460–6. doi: 10.1016/S0140-6736(05)67599-X

27. Bakibinga P, Matanda D, Kisia L, Mutombo N. Factors associated with use of injectables, long-acting and permanent contraceptive methods (iLAPMs) among married women in Zambia: analysis of demographic and health surveys, 1992-2014. *Reprod Health*. (2019) 16:78–8. doi: 10.1186/s12978-019-0741-6

28. Hayes RJ, Moulton LH. *Cluster randomised trials, second edition*. Boca Raton, Florida, United states of America: CRC Press (2017).

29. Thomson DR, Amoroso C, Atwood S, Bonds MH, Rwabukwisi FC, Drobac P, et al. Impact of a health system strengthening intervention on maternal and child health outputs and outcomes in rural Rwanda 2005-2010. *BMJ Glob Health*. (2018) 3:e000674–4. doi: 10.1136/bmjgh-2017-000674

30. Garchitorena A, Miller AC, Cordier LF, Rabeza VR, Randriamanambintsoa M, Razanadrakato HTR, et al. Early changes in intervention coverage and mortality rates following the implementation of an integrated health system intervention in Madagascar. *BMJ Glob Health*. (2018) 3:e000762. doi: 10.1136/bmjgh-2018-000762

31. Bawah AA, Awoonor-Williams JK, Asuming PO, Jackson EF, Boyer CB, Kanmiki EW, et al. The child survival impact of the Ghana essential health interventions program: a health systems strengthening plausibility trial in northern Ghana. *PLoS One*. (2019) 14:e0218025. doi: 10.1371/journal.pone.0218025

32. Haws RA, Mashasi I, Mrisho M, Schellenberg JA, Darmstadt GL, Winch PJ. "These are not good things for other people to know": how rural Tanzanian women's experiences of pregnancy loss and early neonatal death may impact survey data quality. *Soc Sci Med*. (2010) 71:1764–72. doi: 10.1016/j.socscimed.2010.03.051

33. Eichner FA, Groenwold RHH, Grobbee DE, Oude Rengerink K. Systematic review showed that stepped-wedge cluster randomized trials often did not reach their planned sample size. *J Clin Epidemiol*. (2019) 107:89–100. doi: 10.1016/j.jclinepi.2018.11.013

34. Hughes JP, Granston TS, Heagerty PJ. Current issues in the design and analysis of stepped wedge trials. *Contemp Clin Trials*. (2015) 45:55–60. doi: 10.1016/j.cct.2015.07.006

frontiers | Frontiers in Public Health

TYPE Opinion
PUBLISHED 07 September 2023
DOI 10.3389/fpubh.2023.1259110

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Héctor Armando Rincón León,
Mexican Social Security Institute (IMSS), Mexico

*CORRESPONDENCE
Esteban Ortiz-Prado
✉ e.ortizprado@gmail.com
Juan S. Izquierdo-Condoy
✉ juan1izquierdo11@gmail.com

RECEIVED 15 July 2023
ACCEPTED 22 August 2023
PUBLISHED 07 September 2023

CITATION
Ortiz-Prado E, Izquierdo-Condoy JS, Vasconez-Gonzalez J and Garcia-Bereguiain MA (2023) Upholding academic freedom: a call to protect freedom of expression and science in Ecuador and beyond. *Front. Public Health* 11:1259110. doi: 10.3389/fpubh.2023.1259110

Upholding academic freedom: a call to protect freedom of expression and science in Ecuador and beyond

Esteban Ortiz-Prado*, Juan S. Izquierdo-Condoy*, Jorge Vasconez-Gonzalez and Miguel Angel Garcia-Bereguiain

One Health Research Group, Faculty of Medicine, Universidad de Las Américas, Quito, Ecuador

KEYWORDS

academic freedom, freedom of expression, science, low income, Ecuador

We are writing to express our concern regarding the challenges to freedom of expression and scientific advances currently experienced by public health professionals in Ecuador.

Freedom of expression, a human right enshrined in most democratic nations since the last century, is vital for empowering individuals to openly share data, information, suggestions, and constructive criticism about their governments and organizations. While freedom of expression is not an absolute right and may be subject to certain limitations and regulations, public health professionals must be familiar with their organization's policies and procedures concerning communication and expression of opinions in the workplace. Employers, in turn, should foster a respectful and inclusive work environment that values diverse opinions and encourages constructive dialogue and debate.

It is well-established that science and innovation are essential drivers for the progress and development of nations and need to be supported particularly in low- and middle-income countries (LMICs). Nonetheless, scientific advances often encounter resistance not only from academic groups but also from governments and communities. It is crucial to foster and safeguard academics, particularly in fields where innovation and creativity are paramount (1), without fear of discrimination or retaliation from authority figures.

Regrettably, in numerous countries, public health professionals or university faculty, in general, face pressures and reprisals related to job stability, hindering their ability to freely express their opinions (2). In the realm of health sciences, it is not uncommon to hear accounts from physicians unable to publicly discuss resource or supply shortages in hospitals or from researchers unable to publish their findings due to political interference, particularly in the context of democratic LMICs.

We wish to express our deep concern about the recent encroachments on freedom of expression and scientific thought in Ecuador. It is troubling to learn that doctors in public hospitals cannot voice concerns about insufficient medicines or supplies due to pressure from authorities dictating what can and cannot be expressed about this situation, even when those concerns are properly addressed not only in mass media but also in specialized public health journals. For instance, it is unacceptable that health professionals could not discuss the limitations they face in their work practices due to inadequate personal protective equipment and safety measures during the COVID-19 pandemic. This constitutes a clear violation of the right to freedom of expression and a challenge for scientific advances.

Moreover, there was a recent striking case of persecution involving members of the main Ecuadorian public health who challenged academic freedom in Ecuador. These individuals sought to publish research on the region's first reported case of H5N1 influenza infection, which, despite exposing weaknesses in the epidemiological surveillance and control system, provides valuable information for authorities to implement control and surveillance programs for a new issue (3). The impact of this publication made one of the main newspapers in Spanish ("El Pais") publish a report about this study. By contrast, mid-level authorities from the Ministry of Health in Ecuador started a disciplinary process against some of the authors of this study with unfounded accusations of ethical misconduct. They never addressed neither the scientific journal with any concerns nor the universities involved in the study. Moreover, in their disciplinary report, they made the authors responsible for the report in the newspaper, made by an independent journalist. The professional misconduct and bias in this fake disciplinary were finally corrected by superior authorities from the Ministry of Health after an active social network debate. The fact that they were persecuted for simply sharing scientific knowledge without any conflict of interest is a blatant violation of their right to freedom of expression and scientific thought, no matter whether there was a happy end to this story.

In light of these developments, we urge the Ecuadorian Public Health authorities to recognize the importance of protecting and promoting freedom of expression, scientific advances, and academic freedom. It is essential to create a society of openness and transparency that encourages citizens to express scientific knowledge freely and without fear of reprisals or repercussions of any kind, and public health practice cannot be excluded from that. Moreover, science must provide the necessary foundation for informed decision-making by the authorities in public health policy and beyond. Considering the incalculable consequences of silencing scientists and the numerous challenges faced by science in Ecuador and other LMICs, progress and social development depend on securing academic freedom (4, 5).

In conclusion, we call on the Ecuadorian government to promote actions to protect the right to freedom of expression and support scientific advances. Ensuring that individuals can express their opinions freely without fear of retaliation, and that scientific knowledge can be shared without fear of persecution, is vital for promoting the progress and development of any nation.

Author contributions

EO-P: Conceptualization, Formal analysis, Investigation, Methodology, Project administration, Writing—original draft, Writing—review and editing. JI-C: Investigation, Methodology, Validation, Writing—original draft, Writing—review and editing. JV-G: Formal analysis, Investigation, Methodology, Writing—original draft. MG-B: Conceptualization, Formal analysis, Investigation, Resources, Supervision, Writing—original draft, Writing—review and editing.

Funding

The author(s) declare financial support was received for the research, authorship, and/or publication of this article. We express our gratitude to Universidad de las Américas for financially supporting the publication of this work.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Science Europe S. *Joint Statement on Academic Freedom and Institutional Autonomy*. (2019). Available online at: https://scienceeurope.org/our-resources/joint-statement-on-academic-freedom-and-institutional-autonomy/ (accessed May 27, 2023).

2. Martha K, Rudy M. Five *Cases of Political Threats against Scientific Integrity | Brennan Center for Justice*. (2019). Available online at: https://www.brennancenter.org/our-work/analysis-opinion/five-cases-political-threats-against-scientific-integrity (accessed May 27, 2023).

3. Bruno A, Alfaro-Núñez A, de Mora D, Armas R, Olmedo M, Garcés J, et al. First case of human infection with highly pathogenic H5 avian influenza a virus in South America: a new zoonotic pandemic threat for 2023? *J Travel Med*. (2023) taad032. doi: 10.1093/jtm/taad032

4. Druckman JN. Threats to science: politicization, misinformation, and inequalities. *Ann Am Acad Political Soc Sci*. (2022) 700:8–24. doi: 10.1177/00027162221095431

5. Karr JR. When government ignores science, scientists should speak up. *BioScience*. (2006) 56:287–8. doi: 10.1641/0006-3568(2006)56-287:WGISSS-2.0.CO;2

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 25 September 2023
DOI 10.3389/fpubh.2023.1210255

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Pedro R. Palos Sanchez,
Sevilla University, Spain
Umberto Moscato,
Catholic University of the Sacred Heart, Rome, Italy

*CORRESPONDENCE
Minhao Xiang
✉ xiangminhao1@gmail.com

RECEIVED 22 April 2023
ACCEPTED 29 August 2023
PUBLISHED 25 September 2023

CITATION
Lv K, Luo X, Shan J, Guo Y and Xiang M (2023) Research on the collaborative evolution process of information in public health emergencies based on complex adaptive system theory and social network analysis: a case study of the COVID-19 pandemic. *Front. Public Health* 11:1210255. doi: 10.3389/fpubh.2023.1210255

Research on the collaborative evolution process of information in public health emergencies based on complex adaptive system theory and social network analysis: a case study of the COVID-19 pandemic

Kun Lv[1], Xingyu Luo[1], Jiaoqiao Shan[2], Yuntong Guo[1] and Minhao Xiang[1]*

[1]School of Business, Ningbo University, Ningbo, China, [2]School of International Trade and Economics, University of International Business and Economics, Beijing, China

Introduction: This review aimed to elucidate the significance of information collaboration in the prevention and control of public health emergencies, and its evolutionary pathway guided by the theory of complex adaptive systems.

Methods: The study employed time-slicing techniques and social network analysis to translate the dynamic evolution of information collaboration into a stage-based static representation. Data were collected from January to April 2020, focusing on the COVID-19 pandemic. Python was used to amass data from diverse sources including government portals, public commentary, social organizations, market updates, and healthcare institutions. Post data collection, the structures, collaboration objectives, and participating entities within each time slice were explored using social network analysis.

Results: The findings suggest that the law of evolution for information collaboration in public health emergencies primarily starts with small-scale collaboration, grows to full-scale in the middle phase, and then reverts to small-scale in the final phase. The network's complexity increases initially and then gradually decreases, mirroring changes in collaboration tasks, objectives, and strategies.

Discussion: The dynamic pattern of information collaboration highlighted in this study offers valuable insights for enhancing emergency management capabilities. Recognizing the evolving nature of information collaboration can significantly improve information processing efficiency during public health crises.

KEYWORDS

epidemic response, collaborative networks, adaptive dynamics, social interactions analysis, pandemic management

1. Introduction

Public health emergencies pose a substantial threat to global health security, economic stability, and societal well-being. These events, marked by their sudden onset and unpredictability, require a proficient and comprehensive information collaboration mechanism to facilitate effective response strategies. The COVID-19 pandemic serves as a salient illustration of the crucial role of information collaboration and communication in managing public health crises. Italy, as an example, as one of the first countries outside China to experience a significant outbreak, found itself dealing with a swiftly escalating situation. The Italian healthcare system, reputed as one of the most robust in Europe, was quickly overwhelmed by the surge of patients, leading to severe resource and personnel constraints. The national response was significantly influenced by the quality and timeliness of information shared among a range of stakeholders. Government agencies, public health organizations, healthcare providers, and the general public collaborated, sharing data, resources, and responsibilities to manage the crisis. This scenario highlighted the essential role of information collaboration in public health emergencies management. Notably, this predicament was not confined to Italy; similar challenges were faced worldwide. Italy serves as a notable example, yet the dynamics and outcomes of information collaboration differ significantly among major nations, underscoring the critical importance of such collaboration in addressing public health crises. In the United States, a decentralized healthcare system combined with the politicization of the pandemic resulted in disparate approaches and levels of information-sharing across states. South Korea swiftly established a comprehensive information-sharing system among the government, medical institutions, and the public, ensuring quick contact tracing and testing. In contrast, the United Kingdom initially struggled with timely information dissemination before adopting a more centralized strategy for managing and disseminating pandemic-related data. In countries such as India, the immense and varied population posed challenges to consistent and transparent information dissemination, leading to diverse regional responses. A comparison of these distinct experiences from pivotal nations offers insights into the factors and consequences of information collaboration during global health crises. Thus, the diverse responses to COVID-19 globally provide instructive insights into the role of information collaboration in public health emergencies. From a theoretical perspective, information collaboration in such emergencies is viewed as a complex adaptive system, characterized by complexity, nonlinearity, and adaptability. It is thus hypothesized that this system will undergo an evolutionary process throughout the public health emergency. This theoretical framework forms the foundation for the ensuing analysis and guides the subsequent empirical investigation. The main objectives of this research are: (a) to analyze the evolutionary pattern of information collaboration in public health emergencies, (b) to reveal the internal dynamics and characteristics of the collaboration network, and (c) to deliver insights and recommendations for enhancing information collaboration efficiency during public health emergencies. Building on the case study of the COVID-19 pandemic, this research aims to elucidate these pivotal issues and contribute to the continuing discussion on information collaboration in public health emergencies. It is anticipated that this timely and relevant research will serve as a valuable resource for policymakers, healthcare professionals, and researchers in this domain.

2. Literature review

From the appearance of the Antonine Plague in AD 165 to the current COVID-19 pandemic, the war between humanity and epidemics has been ongoing throughout history. Due to the continuous occurrence of various sudden public health events, scholars have paid extensive attention to the information coordination of these emergencies (1). Information coordination plays a pivotal role in public health emergencies, affecting the efficiency and effectiveness of response measures (2). Recent studies have highlighted different aspects of this topic. For instance, Anita and Sukomal explored the role of social media platforms in disseminating information during crises, emphasizing the need for verified information from authoritative sources (3). On the other hand, the study by Balaji et al. underscores the importance of diversity in information coordination mechanisms, arguing for an adaptable and inclusive approach that caters to different regions and demographic groups (4).

In terms of method selection, Saura, Reyes-Menendez, and Palos-Sanchez illustrate how Twitter sentiment analysis can be effectively used to gauge public reaction to events such as Black Friday sales, a technique that could also be applied to public health crises (5). Similarly, Palos-Sánchez, Folgado-Fernández, and Rojas-Sánchez applied text and opinion mining techniques in analyzing the discourse surrounding virtual reality technology, demonstrating their usefulness in extracting actionable insights from large volumes of text data (6). Additionally, Saura, Palos-Sanchez, and Grilo used sentiment analysis through text data mining to identify indicators of startup business success, reinforcing the potential of these analytical methods in various research fields (7). As for methods, significant advancements have been made in the development and application of computational and analytical tools to enhance information coordination. Sarker demonstrated the use of machine learning algorithms in mining social media data for real-time tracking of public sentiment and misinformation spread during health crises (8). Furthermore, an emerging body of literature focuses on the application of complex adaptive systems theory in understanding and improving information coordination processes (9).

This study draws on these previous works to examine the evolution of information coordination in public health emergencies. The first aspect of this research is the feature analysis and definition of information coordination in sudden public health events. Waugh et al. (10) suggest that the information coordination of sudden public health events is a multi-party information dissemination process based on information flow, which includes four dimensions: information, information personnel, information environment, and information technology. Luo et al. (11) pointed out that emergency information for sudden events has three essential characteristics: speed (immediacy and real-time), quality (accuracy and reliability), and efficacy (applicability and value). Currier et al. (12) summarized the experience of responding to Hurricane Katrina and found that collaborative cooperation among various departments and multiple parties is necessary in the emergency management process. Park (13) argues for the necessity of information coordination in sudden public health events and believes that horizontal cross-organizational

information coordination is advantageous for improving organizational output efficiency and flexibility in complex situations.

The second aspect of this research is the analysis and identification of problems in the information collaboration mode during public health emergencies. At the level of information subjects, Zhou (14) suggested that grassroots communities have limited capacity in information collaboration during public health emergencies, medical institutions are geographically dispersed with severe information technology deficiencies, resulting in the widespread existence of information islands. At the information environment level, Ramon et al. (15) summarized the influencing factors of information collaboration, including policies and institutions, management and organization, information and technology, and environment. For this purpose, Salmon et al. (16) studied the multi-agency coordination process during emergency response and emphasized that the coordination level between military and civilian organizations is crucial for the efficiency of multi-agency systems in responding to large-scale emergencies. They identified factors that affect information sharing such as untimely sharing of information, inaccurate and unreliable information, incomplete information, and unclear organizational responsibilities. Fan et al. (17) studied the cross-organizational information sharing and utilization mechanisms in joint emergency actions and suggested that a structurally sound cross-organizational network and a leadership department with good information accessibility are key factors that significantly affect the efficiency of emergency collaboration and the ability to absorb information. Lencucha et al. (18) proposed that information sharing is a key factor in effectively responding to infectious disease outbreaks, and the international coordination system largely depends on timely and accurate information provided by governments during health risks in epidemics. This information supports the decision-making process for declaring a public health emergency of international concern by the World Health Organization, as well as assisting the WHO in cooperating with governments to coordinate the containment of cross-border epidemics.

The third aspect of this research is the optimization of the mechanism of information collaboration during public health emergencies. Collaborative governance theory combines collaborative theory and governance theory, and Donahue et al. (19) suggested that "the essence of collaborative governance is that government organizations and non-government organizations actively and fully participate in the governance process in a free and voluntary manner to achieve consensus on a specific goal and outcome, and play their respective roles." Gil-Garcia et al. (20) argued that in the future, cross-organizational cooperation and information sharing will be increasingly needed to address complex public problems. The information needs of different cooperating organizations may vary significantly in terms of completeness and timeliness, and these differences require a clear definition of the roles and responsibilities of all parties involved in the cooperation and information sharing processes between government organizations. In this process, the participating parties need to consider both government and non-government organizations. Kapucu et al. (21) studied the relationships between governments and organizations in collaborative emergency management and suggested that emergency management work requires the integration of the organizational culture, structure, and processes of various stakeholders. Additionally, effective use of resources by the collaborative network of stakeholders is required to meet the high expectations of the public and stakeholders for emergency and disaster management. Kim (22) suggested that information collaboration based on effective collaboration between institutions and members can help organizations achieve common goals, such as efficiently responding to public health emergencies.

In summary, research on information collaboration in public health emergencies has mostly focused on its fixed features, static structures, and optimization paths, with limited attention given to its dynamic characteristics from an evolutionary perspective. To address this gap, the present study employs the theory of complex adaptive systems and introduces a time-slicing approach to segment information collaboration in public health emergencies into distinct stages. Social network analysis methods are then utilized to examine the information collaboration process at each phase, uncover its evolutionary patterns, and pinpoint the evolution cycle of information collaboration in such emergencies. The ultimate goal of this study is to serve as a reference for enhancing emergency strategies for public health emergencies in China.

3. Analysis of information coordination in public health emergencies

3.1. Definition of information coordination in public health emergencies

In the era of informatization, the role of information coordination in public health emergencies has become indispensable, as the urgency of timely information sharing and data analysis is paramount for event prevention, control, and treatment. To fully appreciate the intricacies of information coordination, it is imperative to clarify certain terminologies, especially the term 'preparedness' which holds significant weight in discussions about public health emergencies. 'Preparedness' in the context of public health refers to the systematic and continuous process of planning and implementing measures to prevent, respond to, and recover from potential public health threats and emergencies. It encompasses a wide range of activities, from risk assessments and capacity building to the establishment of communication channels and the formation of response strategies. A key facet of preparedness is the ability to anticipate potential crises and have protocols in place that ensure quick and effective action. Intertwined with the notion of preparedness is information coordination. Information coordination is not solely about the dissemination and transmission of data. It emphasizes enhancing the utilization efficiency of the shared information through intricate interactions among various information entities and between these entities and their environment (23). This process involves not just augmenting the collaboration among these entities through efficient transmission methods but also focusing on extracting the utmost value from the shared information. The intricacies of information coordination in public health emergencies encompass a multitude of information entities. The modes and types of coordination among these entities can be vast and multifaceted, highlighting the need for meticulous information sharing mechanisms to ensure optimal preparedness (24). Given the inherent unpredictability of public health crises, such coordination becomes a linchpin in ensuring that

accurate and relevant information is disseminated to appropriate entities promptly, facilitating swift and pertinent responses.

3.2. Characteristics of information coordination in public health emergencies

This study uses the theory of complex adaptive systems to determine whether the information coordination process in public health emergencies can undergo self-evolution. According to the theory of complex adaptive systems, entities in a system have learning capabilities. They continually "learn" and "accumulate experience" in their interactions with the environment and other entities, which is known as adaptability (25). Thus, as individual and environmental adaptive behaviors occur, the system undergoes self-evolution (26). If the information coordination in public health emergencies belongs to a complex adaptive system, it will undergo evolution. The following section analyzes whether the development of information coordination in public health emergencies exhibits the five basic characteristics of aggregation, nonlinearity, flow, diversity, and internal mechanisms to further determine whether it belongs to a complex adaptive system.

3.2.1. Diversity

Diversity is an inherent characteristic of complex adaptive systems that refers to the continuous differentiation among individuals during the adaptation process, leading to a diverse array of responses within the system (27). In the context of information coordination in public health emergencies, diversity manifests as variations in chosen methods of coordination by different entities across various regions, and even temporal variations within the same region. This diversity is pivotal for public health emergency preparedness and response as it mirrors the heterogeneity of such crises. Diverse methods of information coordination not only reflect the unique characteristics and capacities of the involved entities, but they also accommodate the varying nature of emergencies across different contexts. For instance, the response to an emerging infectious disease might require different coordination strategies compared to a chronic public health issue. Even within the same public health emergency, the stages of the crisis may call for different approaches, such as rapid response in the initial phase and recovery efforts in the aftermath. Moreover, from a gender perspective, it is worth noting that diversity can also denote differential impacts of public health emergencies on different genders. Men and women often have different roles and responsibilities in their communities, which can lead to variations in their exposures and vulnerabilities during public health crises. As such, recognizing and incorporating this gender-based diversity in information coordination can contribute to more equitable and effective emergency responses. By identifying and respecting these diverse facets of information coordination, decision-makers can devise more tailored strategies, improving the resilience and efficacy of public health emergency responses. Therefore, diversity is not just an observable phenomenon, but a necessary characteristic that warrants careful consideration in the information coordination process of public health emergencies.

3.2.2. Aggregation

Aggregation, as a key characteristic of complex adaptive systems, signifies the formation of larger aggregates through "adhesion" between individuals during the adaptation process (28). In public health emergencies, this translates into how various entities (like the government, public, social organizations, market, and healthcare institutions) come together to form a unified front for coordinated response efforts. The aggregation of these entities is more than a mere summation of their individual parts; it creates a synergy that allows for a more comprehensive, coordinated response to public health emergencies. It enables a multi-faceted approach to information coordination, where each entity brings its unique perspective and resources to the table, enhancing the richness and reach of the shared information. In the context of preparedness, the process of aggregation promotes a unity of effort and purpose, fostering collective decision-making and responsibility sharing. This collaborative approach allows for the harnessing of a wider range of resources and knowledge, paving the way for more robust responses to public health emergencies. Moreover, aggregation in information coordination is not only about the convergence of entities but also the convergence of different types of information. This could include epidemiological data, health system capacities, social determinants of health, and local community insights, among others. By aggregating diverse data sources, a more holistic view of the emergency can be achieved, supporting evidence-informed decision-making. Therefore, in the context of information coordination during public health emergencies, aggregation is not merely an inherent attribute, but a crucial operational principle that promotes effective response coordination. It underscores the need for broad-based collaborations, fostering a synergy that is critical for comprehensive and effective emergency management.

3.2.3. Flow

Flow is a crucial feature of complex adaptive systems, referring to the exchange of matter, energy, and information between individuals and their environment (29). In public health emergencies, the concept of flow can be understood as the circulation of information amongst different entities and stakeholders. The flow of information is not a unidirectional transmission, but a dynamic process of exchange, interpretation, and feedback. It plays an indispensable role in the timely and effective response to public health emergencies, ensuring that crucial data and insights reach the right people at the right time. The importance of flow in preparedness cannot be overstated. It directly impacts the speed of response, the accuracy of actions, and ultimately, the effectiveness of interventions. For instance, quick and accurate flow of epidemiological data can expedite the detection and understanding of a novel disease, leading to timely and targeted interventions. However, information flow in public health emergencies is also fraught with challenges, including information overload, misinformation, and disparities in information access. These issues underscore the need for well-coordinated mechanisms to manage the flow of information, including verification systems to ensure data accuracy, strategies to disseminate clear and consistent messages, and equitable information access strategies. Moreover, the concept of flow also points to the need for interoperable data systems that allow seamless sharing and integration of data across different platforms and entities. This ensures that information is not siloed within individual entities, but can be effectively used and built upon by others. In conclusion, the characteristic of flow in the information coordination process during public health emergencies is not only about the exchange of information but also about the management of that

exchange. It emphasizes the need for well-coordinated mechanisms to facilitate effective and equitable information flow, underscoring the interconnectedness and interdependence of all entities involved in emergency response.

3.2.4. Non-linearity

Non-linearity is a fundamental characteristic of complex adaptive systems, pointing out that the interactions between entities in the system do not follow simple linear relationships but are non-linear (30). This is particularly evident in the context of public health emergencies, where multiple entities with different roles and responsibilities interact and coordinate in a non-linear and dynamic manner. In public health emergencies, the success of information coordination does not directly correlate with the improvement of a single entity's ability. For instance, focusing only on enhancing the capability of medical departments in assimilating and transmitting information may not necessarily lead to an improved overall information coordination efficiency. This is because the efficiency of information coordination relies not just on the capacity of a single entity, but on the collective capabilities of all entities involved, including communities, markets, government institutions, and the public. The concept of non-linearity also illuminates the interconnected nature of the entities in the system. It emphasizes that all entities in the system are interdependent and that changes in one entity can have ripple effects on others. This underscores the need for a comprehensive and holistic approach in improving information coordination. Strategies should not just target individual entities but should consider the system as a whole, ensuring that enhancements in one area support and are supported by enhancements in other areas. In conclusion, the non-linear nature of information coordination in public health emergencies highlights the importance of a systemic approach in enhancing information coordination. It draws attention to the interconnectedness and interdependence of all entities involved, reinforcing the need for collective capabilities and cooperative efforts in managing information in public health emergencies.

3.2.5. Internal model

The internal model mechanism of complex adaptive systems refers to the fixed models or protocols for problem-solving that entities adhere to when they encounter new information or challenges within the system (31). The capacity to develop, adopt, and modify internal models in response to new information is crucial in the context of information coordination during public health emergencies. Take, for example, the city of Wuhan after suffering a major blow from the 2020 epidemic. The city summarized its experiences, strengthened information infrastructure, and created the "Wuhan Health Code." This was an innovative solution that ensured the interconnection and interoperability of information across multiple sectors, thereby improving information transmission in prevention and control efforts. It served as an internal model that effectively optimized the overall information coordination mechanism in the face of an unprecedented public health crisis. The internal model mechanism underlines the importance of learning and adaptability in public health emergencies. Entities need to continuously learn from their experiences, adapt their models and strategies, and be prepared to devise new models in response to changing circumstances. This adaptability not only improves the efficiency of information coordination but also enhances the resilience of the system to future public health emergencies. In summary, the internal model mechanism characteristic of complex adaptive systems accentuates the need for continuous learning, adaptability, and innovative problem-solving in information coordination during public health emergencies. It exemplifies the role of effective internal models in enhancing the efficiency of information coordination and the overall resilience of the system.

Based on the above analysis, information coordination in public health emergencies belongs to complex adaptive systems. Therefore, the information coordination process of public health emergencies exhibits adaptive characteristics of complex adaptive systems and can undergo autonomous evolution. On this basis, the following section introduces time slicing, transforming the dynamic changes of the information coordination process into planar slices, and further analyzing its evolutionary process.

4. Materials and methods

4.1. Research tool

In this study, cohesive subgroups in social network analysis are selected as the analytical tool to investigate the information collaboration and evolution process. Cohesive subgroup analysis is a type of social structure research that examines the existing or potential relationship patterns between social actors. These relationship patterns can take various forms, including dyadic relationships, triadic relationships, and subgroup-level relationships. A cohesive subgroup in a network is characterized by the following features: (1) strong ties among nodes within the subgroup and weak ties between subgroups, and (2) a subgroup is a set of individuals in a network that are tightly connected within the subgroup but loosely connected outside the subgroup.

As a result of the impact of public health emergencies on transportation, education, healthcare, production, and other fields, information collaboration during such emergencies is also extremely complex, with significant differences in the ways actors communicate, the frequency of communication, and the content of information exchanged. Analyzing the cohesive subgroups in the information collaboration network during public health emergencies can help identify closely connected actors in the collaboration process, thereby clarifying the distribution of rights and responsibilities among different actors and the structure of the information collaboration network. This is of significant importance for analyzing complex networks.

4.2. Selection of research objectives

In January 2020, the COVID-19 outbreak occurred in China, posing a significant threat to people's lives, health, and property. Various sectors of society have participated in the prevention and control of the epidemic in different ways. Due to the complex relationships between the organizations and individuals involved in epidemic prevention and control, there has been a large amount of related information, in various forms and with different transmission paths. Therefore, this study

TABLE 1 Framework of user health information requirements.

Information entities	Information entities
Government	National Health Commission, Centers for Disease Control and Prevention, Ministry of Finance, Ministry of Industry and Information Technology, Ministry of Civil Affairs, State Council, National Development and Reform Commission, Life Necessities Security Group, Ministry of Agriculture and Rural Affairs, Ministry of Commerce, Ministry of Education, China Banking and Insurance Regulatory Commission, Medical Administration Bureau, etc.
Market	Operating Stores, Online Course Platforms, Farmer's Markets, Seafood Markets, China Railway Group Limited, Pharmaceutical Companies, Supply and Marketing Cooperatives, Recreational Agriculture, Rural Tourism Operators, Enterprises, etc.
Social Organizations	World Health Organization, Chinese Academy of Engineering, schools, Chinese Academy of Medical Sciences, Chinese Academy of Sciences, Academy of Military Medical Sciences, Xinhua News Agency, People's Daily Online, Chao Wen Tian Xia, People's Daily, Red Cross Society of Hubei Province, Hubei Charity Federation, Hubei Youth Development Foundation, etc.
Healthcare	Medical Institutions, Medical and Health Institutions, Cabin Hospitals, Fever Clinics, Designated Medical Institutions, Provincial Hospitals, Community Health Service Centers, Designated Medical Points, etc.
General Public	Village Committees, Communities, Neighborhood Committees, Citizens, Village Self-Governing Organizations, etc.

chooses various types of information generated by the actors involved in the COVID-19 epidemic as research objects.

4.3. Data sources

Data for this research was predominantly informed by the provisions of the "Emergency Response Law of the People's Republic of China" and the "National Management Specifications for Reporting Relevant Information on Public Health Emergencies (Trial)." These statutes identify the key information producers during public health emergencies as the government, public, social organizations, the market, and medical institutions. Hence, the study classifies the actors engaged in information collaboration during public health emergencies into these five categories. This classification necessitates sourcing data from the official websites of various organizations that disseminate epidemic-related information. Given the urgent nature of public health emergencies, these sites are acknowledged as reliable and timely data sources. The rapid evolution of situations such as the COVID-19 pandemic underscores the importance of immediate and accurate sources, which considerably influenced the decision to utilize these platforms for this study. To facilitate data collection, a set of search terms, aligned with the identified actor categories, was established. These terms guided the systematic exploration and collection of information from the relevant websites, as detailed in Table 1.

While this approach primarily confines the study's data sources to governmental websites, it nonetheless provides a comprehensive overview of collaborative processes during public health emergencies. Despite the limitations in the diversity of data sources, this methodology ensures reliability, timeliness, and direct relevance to the research question. As such, it holds considerable value in comprehending the evolution of information collaboration in such critical contexts.

In this study, Python software was employed to collect daily epidemic-related text data from the official websites of various ministries, which included the National Health Commission, the Chinese Government, the Ministry of Education, the Ministry of Transport, the Ministry of Finance, the Ministry of Public Security, and the Ministry of Civil Affairs. The data collection spanned from January 11, 2020, to April 15, 2020. Specific Python libraries, including Beautiful Soup for web scraping, Pandas for data manipulation and analysis, and NLTK for natural language processing, were employed for the task. The selection of these libraries was based on their proficiency in handling and processing web data and text analysis, respectively. Subsequently, search fields within the sites were established to optimize data collection. The study additionally involved the extraction of publishing agencies and the departments referred to in the text. When two departments co-published a text or were mentioned within the same text, they were deemed to be involved in the same collaboration. To enhance comprehension of the study's methodology, a flowchart (Figure 1) detailing each step of the data collection and analysis process has been included.

4.4. Time slicing selection

This study introduced time slicing to explain the temporal evolution cycle of information collaboration in the epidemic. On January 11, 2020, the National Health Commission officially reported the outbreak of unknown pneumonia in Wuhan, marking the beginning of the COVID-19 epidemic. However, it had not yet developed into a major public health emergency threatening the whole country. On April 15, 2020, the epidemic in Hubei, which was the first area to experience a large-scale outbreak, was under basic control with zero new confirmed cases of COVID-19 and no imported cases. Based on these objective facts, this study focused on the temporal variation patterns of information collaboration related to the epidemic from January 11 to April 15, 2020.

To determine the number of time slices and the time span, this study analyzed three indicators: the number of departments, network density, and the average path length of the network. The number of departments represents the number of departments involved in the information collaboration network during a certain period. The overall network density represents the degree of closeness among the departments participating in the collaboration. The higher the network density, the closer the connection between the departments. The formula for calculating network density is $D_i = \frac{N}{M(M-1)}$, where M represents the number of nodes, and N represents the actual number of links. The average path length of the network represents

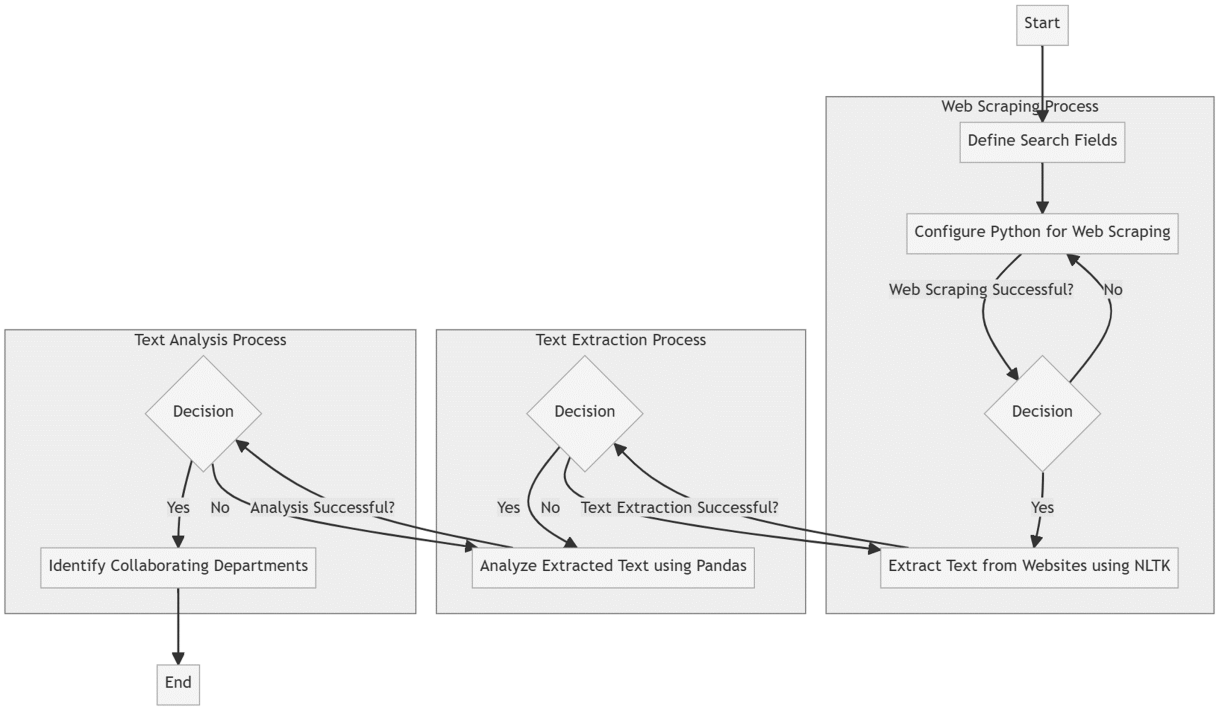


FIGURE 1
Flowchart illustrating the methodological steps used for web scraping, text extraction, and text analysis in the study.

the average collaboration distance between any two departments. The formula for calculating the average path length is $L = \frac{1}{C_N^2} \sum_{1 \le i \le j \le N} d_{ij}$, where N represents the number of departments, and d_{ij} represents the collaboration distance between department i and department j. The calculation results are shown in Table 2.

The analysis results indicate that the number of departments showed a steady increasing trend in the early stage, with the first significant increase occurring on February 1st, when the number of participating departments reached 34. Subsequently, there were small fluctuations in the number of departments. On February 23rd, the number of departments showed a sharp decrease, twice the magnitude of the previous decline, but gradually recovered to a steady downward trend. On March 15th, the number of departments increased sharply again, followed by a continuous downward trend, with a large decrease occurring on March 29th.

The network density was initially high, reaching 0.548. Around February 1st, the network density decreased for the first time, dropping to 0.401, followed by a steady upward trend until around February 22nd, reaching a maximum of 0.537. On February 23rd, the network density showed a significant decrease to 0.46, and continued to decline until around March 15th. Then, the network density increased slightly and showed small fluctuations between March 15th and March 28th.

The average path length was initially high but showed a decreasing trend. There was a significant increase in the average path length around February 2nd, followed by a downward trend until around February 22nd when it reached 1.463. Then, it increased to 1.54 around February 24th and showed small fluctuations within a narrow range. Around March 15th, the average path length experienced a significant fluctuation, increasing from 1.391 to 1.511, and then continued to show small fluctuations around this value.

In summary, the information collaboration network experienced significant fluctuations on February 1st, February 22nd, March 14th, and March 28th, indicating significant changes in network status. Therefore, this paper divides the COVID-19 process into five time slices based on the dates of significant fluctuations: T1: January 11th – February 1st, T2: February 2nd – February 22nd, T3: February 23rd – March 14th, T4: March 15th – March 28th, T5: March 29th – April 11th.

5. Results

This article uses Python software to collect the occurrence frequency of each search field and the frequency of their associations based on the search fields. If two organizations participate in the same prevention and control measure, it is regarded as a collaborative effort, and the collected data is used as the basis for constructing the information collaboration network. The collected data is then processed by normalization. First, invalid fields are removed, and then duplicate fields in the content are manually filtered and irrelevant fields are cleared. The fields are then classified according to different time periods to obtain the information collaboration frequency for T1-T5. Finally, the corresponding information collaboration network graphs for T1-T5 are generated.

5.1. Time period T1

Based on the data collected from the National Health Commission's official website, the total number of collaborations between information subjects during T1 is 9,478, involving 40

10.3389/fpubh.2023.1210255

TABLE 2 Analysis of information collaboration network.

Date	Number of Departments	Network Density	Average Path Length
1.11–1.17	6	1	1
1.18–1.25	14	0.446	1.619
1.26–2.1	22	0.548	1.452
2.2–2.8	34	0.401	1.615
2.9–2.15	38	0.45	1.55
2.16–2.22	41	0.537	1.463
2.23–2.29	32	0.46	1.54
3.1–3.7	29	0.426	1.574
3.8–3.14	24	0.408	1.391
3.15–3.21	38	0.489	1.511
3.22–3.28	34	0.466	1.534
3.29–4.4	26	0.489	1.511
4.5–4.11	27	0.499	1.501

information subjects. Among them, the community and fever clinics have the highest number of collaborations in the same prevention and control measures, with a total of 322 times. In addition, the community and medical institutions have the second-highest number of collaborative efforts, with a total of 318 times. The specific information collaboration network is shown in Figure 2.

Subsequently, the concordance subgroup analysis algorithm in the Ucinet software was employed to analyze the overall collaborative network structure, resulting in the identification of eight subgroups as shown in Table 3.

To better illustrate the information coordination within different subgroups during the T1 period, Gephi software was used to generate the following network diagram. Figures 3A–H show the interactions among various departments within 8 cohesive subgroups:

Figure 3A demonstrates the information coordination within Cohesive Subgroup 1, which includes government, market, and social organizations as information nodes. Government information nodes, represented by the Committee of Patriotic Health Movement and the Municipal Construction Committee, are closely linked to market information nodes, represented by the Agricultural Products Market, while also maintaining close relationships with social organizations, represented by schools. Based on relevant reports associated with these fields, it is clear that these departments had obvious information coordination in environmental disinfection tasks. Figure 3B shows the information coordination within Cohesive Subgroup 2, which includes medical, government, and social organizations as information nodes. Social organizations, represented by the World Health Organization, have close information exchanges with domestic medical institutions and the State Council for international information exchanges, according to the corresponding reports. The coordination among these nodes aims to achieve international information exchange. Figure 3C shows the information coordination within Cohesive Subgroup 3, where all nodes belong to social organizations, mainly including various research institutes with virus research as the primary goal. Cohesive Subgroup 4 (Figure 3D) mainly includes the public and medical information nodes. This subgroup includes citizens and fever clinics, and according to relevant reports, their main information coordination content is related to diagnosis and treatment of cases. Figure 3E demonstrates the information coordination within Cohesive Subgroup 5, which mainly includes public and government information nodes. The primary purpose of their information coordination is to monitor public health and promote disease prevention. Cohesive Subgroup 6 (Figure 3F) includes only one information node, the Centers for Disease Control and Prevention, and according to relevant reports, the CDC has information coordination with other nodes, and the frequency is similar. Therefore, it can be inferred that there is a great demand for the CDC's information processing ability during a public health emergency in the T1 phase. Figure 3G shows the information coordination within Cohesive Subgroup 7, which mainly includes medical, market, and government information nodes, with the main purpose of coordinating the movement of people. As the novel coronavirus is transmitted through droplets, reducing gatherings and avoiding contact is crucial for stopping the spread of the virus. Figure 3H demonstrates the information coordination within Cohesive Subgroup 8, which includes only medical information nodes and represents information coordination between grassroots hospitals and higher-level hospitals.

Based on the above analysis, it can be concluded that there was no overall information coordination during the T1 period, but multiple small-scale information coordination networks were formed. In addition, the properties of information nodes within each cohesive subgroup were relatively homogeneous. Cohesive Subgroup 1 had the largest number of nodes and the most frequent coordination, making it the main component of the information coordination network during this period. According to the corresponding news reports for Subgroup 1, the focus of epidemic prevention and control during this phase was on disinfection of key locations and protection of special populations, with overall coordination centered around the market and networking at different levels. Based on these coordination situations and related reports, it can be inferred that there was no comprehensive participation in information coordination by the whole society during this stage, and different information nodes played their own roles, with information coordination involving relatively narrow areas. The epidemic did not pose a serious threat to society at that time.

5.2. Time period T2

The total number of information collaborations in T2 was 39,540, involving 51 search fields. Among them, the closest associations were observed between enterprises and the State Council, with a collaboration count of 1,516. In addition, the collaboration counts between enterprises and the National Health Commission were 1,260, while those between enterprises and the National Development and Reform Commission, as well as the Ministry of Industry and Information Technology, were both 1,256. The specific information collaboration network is shown in Figure 4.

The concordance subgroup analysis algorithm in the Ucinet software was used to analyze the overall information collaboration structure, and eight subgroups were identified as shown in Table 4.

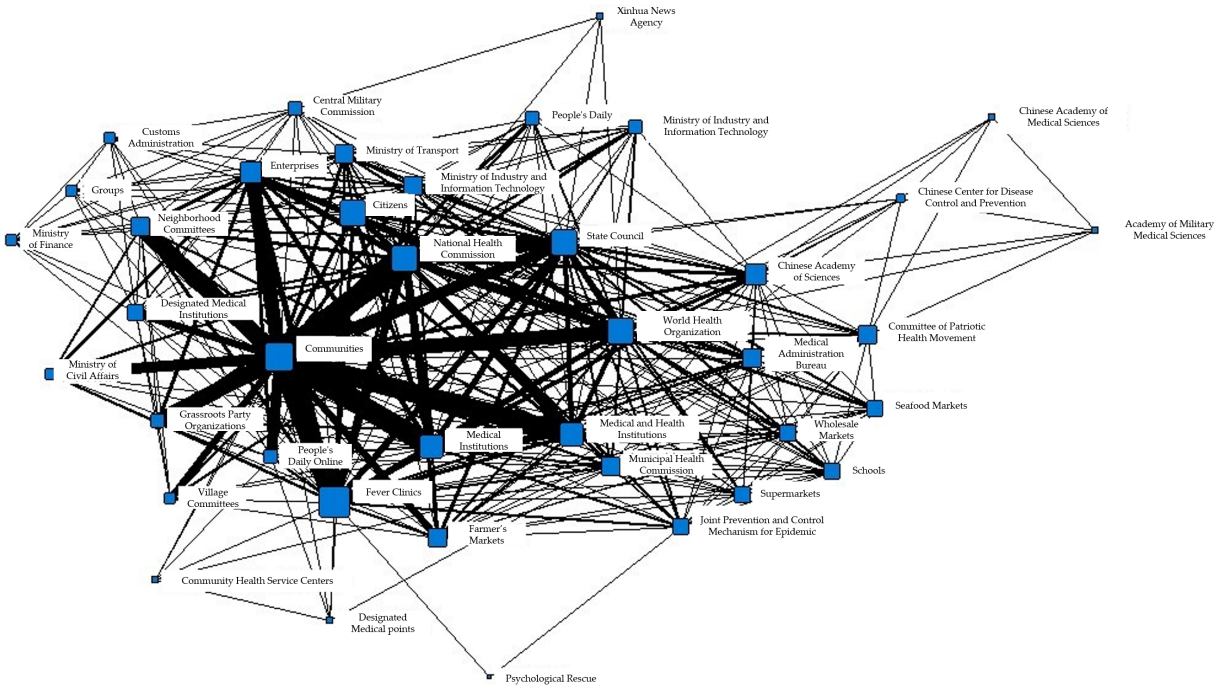


FIGURE 2
Collaborative network of epidemic information in T1 period.

To better illustrate the information collaboration among different information entities within each subgroup during the T2 period, the Gephi software was used to generate the following network diagrams. Figures 5A–H respectively show the interaction among various departments in the eight concordance subgroups.

Based on Figure 5A, it can be seen that the five main information entities in Cohesive Subgroup 1 are closely related. The government information entities represented by the Civil Aviation Administration, the Ministry of Civil Affairs, and the Centers for Disease Control and Prevention; the social organization information entities represented by schools, and the market information entities represented by agricultural markets are the most closely linked. Combining the relevant reports on the appearance of the fields, it can be inferred that the main purpose of information synergy in Cohesive Subgroup 1 is to block transmission channels, reduce population gatherings, and reduce the probability of virus transmission through patriotic hygiene campaigns.

Figure 5B shows that Cohesive Subgroup 2 only includes government information entities – the People's Court and the People's Procuratorate. By searching for corresponding reports, it can be known that the main purpose of synergy in this subgroup is to establish regulations to ensure the safety of medical personnel and maintain good medical order.

Figure 5C shows that Cohesive Subgroup 3 mainly includes government and market information entities. The Ministry of Commerce, wholesale markets, the Ministry of Public Security, and the living materials guarantee group under the epidemic prevention and control mechanism are the most closely linked. By searching for corresponding reports, it can be known that the information synergy task in this subgroup is to guarantee the production and transportation of daily necessities and medical protective equipment.

Figure 5D shows the information synergy situation in Cohesive Subgroup 4, which mainly involves government and medical information entities, including the Ministry of Agriculture and Rural Affairs, fever clinics, and the State Council. According to Figure 5D and corresponding reports, it can be known that the planting and animal husbandry bureaus under the Ministry of Agriculture and Rural Affairs participate most frequently, and the main purpose of information synergy in this subgroup is to ensure the normal spring plowing and stable production of important agricultural products.

Figure 5E shows that Cohesive Subgroup 5 mainly consists of information synergy within the government information entities. Based on relevant reports, it can be known that the main purpose of information synergy is to maintain financial security and market stability from a macro perspective, and ensure that epidemic prevention and control funds, employee salaries, and basic livelihoods are not affected.

Figure 5F shows the information synergy situation in Cohesive Subgroup 6, which includes government, public, market, and medical information entities. It can be observed from the figure that enterprises and other information entities are most frequently linked. According to corresponding reports, the main purpose of information synergy in this subgroup is to support resumption of work and ensure stable production line operation.

Figure 5G shows the information synergy situation in Cohesive Subgroup 7, which mainly includes social organization and market information entities, with various research institutions as the main social organization entities. Since this round of epidemic is believed to have originated from a seafood market in Wuhan, the seafood market inevitably became a key research object in the study of the virus. Combining relevant reports, it can be determined that the main purpose of information synergy in this subgroup is virus research.

TABLE 3 Classification of cohesive subgroups in T1 period.

Cohesive subgroup	Search terms
1	Committee of Patriotic Health Movement, National Health Commission, Medical Administration Bureau, Joint Prevention and Control Mechanism for Epidemic, Psychological Rescue, Seafood Markets, Wholesale Markets, Farmers' Markets, Schools, Chinese Academy of Sciences (Collaboration on Disinfection Action Information)
2	World Health Organization, Medical Institutions, State Council, National Health Commission (International Exchange Information Collaboration)
3	Military Medical Institute of Academy of Military Science, Chinese Academy of Medical Sciences (Virus Research Information Collaboration)
4	Citizens, Communities, Fever Clinics, People's Daily (Collaboration on Disease Treatment Information)
5	People's Daily Online, Grassroots Party Organizations, Ministry of Civil Affairs, Village Committees (Collaboration on Health Monitoring Information)
6	Chinese Center for Disease Control and Prevention
7	Customs Administration, Ministry of Finance, Enterprises, Designated Medical Institutions, Ministry of Transport, Central Military Commission, Ministry of Industry and Information Technology, Neighborhood Committees
8	Community Health Service Centers, Designated Medical Institutions

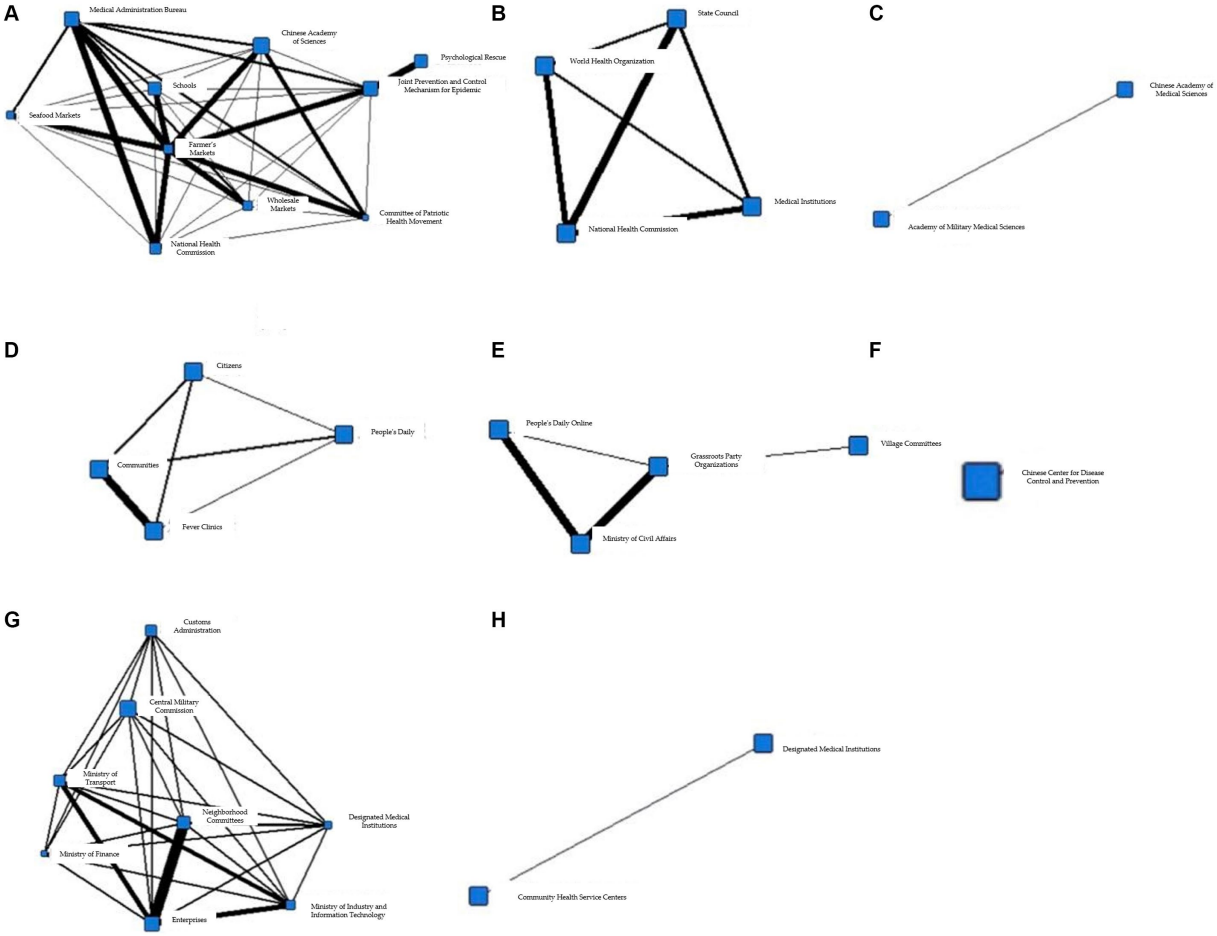


FIGURE 3
(A) Coherent subgroup 1 information collaboration network diagram during T1 period. **(B)** Coherent subgroup 2 information collaboration network diagram during T1 period. **(C)** Coherent subgroup 3 information collaboration network diagram during T1 period. **(D)** Coherent subgroup 4 information collaboration network diagram during T1 period. **(E)** Coherent subgroup 5 information collaboration network diagram during T1 period. **(F)** Coherent subgroup 6 information collaboration network diagram during T1 period. **(G)** Coherent subgroup 7 information collaboration network diagram during T1 period. **(H)** Coherent subgroup 8 information collaboration network diagram during T1 period.

Figure 5H shows the information synergy situation in Cohesive Subgroup 8, which includes government, medical, and social organization information entities. It can be seen from the figure that the Fangcang Hospital is at the center of information synergy. In the T2 stage, with the sudden increase in cases, Fangcang Hospital gradually became an important response measure. According to corresponding reports, the main purpose of information synergy in this subgroup is to ensure the normal operation of Fangcang Hospital.

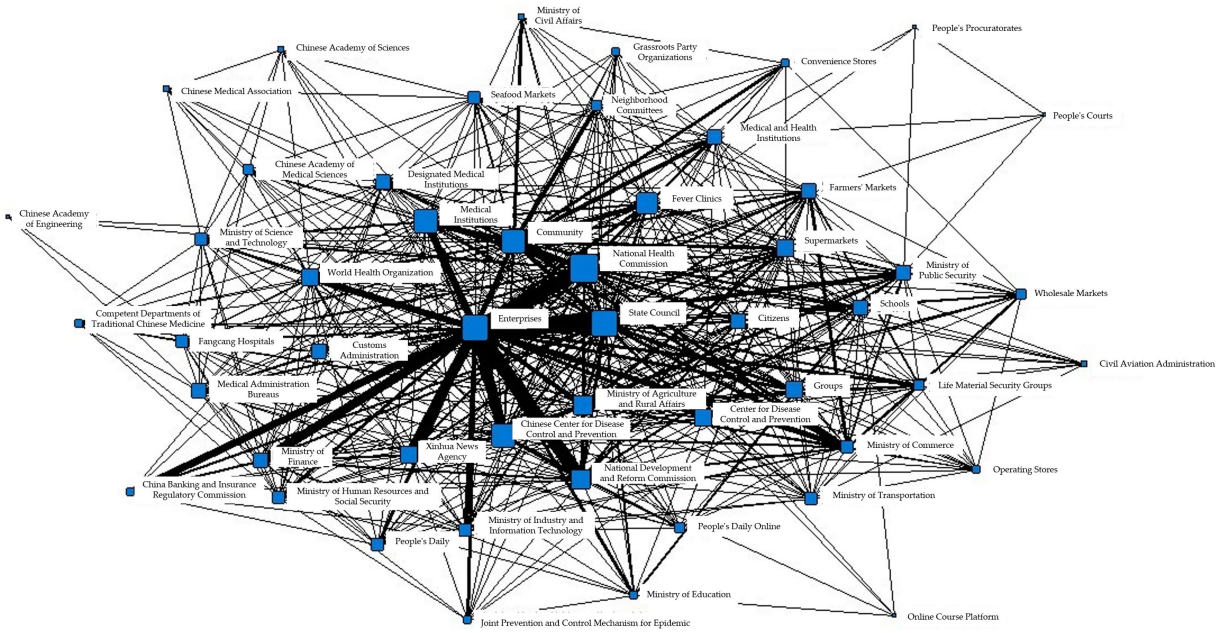


FIGURE 4
Collaborative network of epidemic information in T2 period.

Based on the above analysis, it can be seen that the complexity within each sub-cluster has increased during the T2 phase. The high degree of overlap in node attributes within different sub-clusters indicates that a single entity may participate in multiple tasks simultaneously (e.g., the government may participate in the information collaboration of sub-clusters a, b, c, d, e, h), resulting in information collaboration involving multiple sectors, such as legal, medical, economic, transportation, and education. As shown in the figure, the government departments are located at the core positions within sub-clusters a, c, and g, while enterprises and hospitals are at the core positions in sub-clusters f and h, respectively. This analysis suggests that during this period, the influence of the epidemic had gradually expanded to the social scope, and the government, enterprises, and hospitals played important roles in the overall information collaboration.

5.3. Time period T3

The total number of collaborations in T3 was 28,829, with 46 search fields appearing in the above figure. The most closely related collaborations included 1,206 collaborations between enterprises and the State Council, and 1,918 collaborations between enterprises and the National Health Commission, as shown in Figure 6.

Furthermore, the concor analysis algorithm in the Ucinet software was used to analyze the overall information collaboration structure and generate the following eight cohesive subgroups, as shown in Table 5.

The cohesive subgroup network generated during the T3 phase is shown in Figure 7, with a-h demonstrating the information collaboration situation of each department in the eight cohesive subgroups, respectively.

From Figure 7A, it can be seen that the information synergy within Cohesion Subgroup 1 includes information subjects such as government, market, the public, and social organizations. Based on corresponding reports, the main purpose of information synergy in this subgroup is to ensure the transportation and distribution of daily necessities. Figure 7B shows the information synergy situation within Cohesion Subgroup 2, which includes information subjects such as the public and the market. As can be seen from the figure, information synergy has been generated due to the resumption of work and production and the consequent movement of people. Cohesion Subgroup 3, as shown in Figure 7C, mainly involves information synergy between government and the public, with the main purpose being to maintain the supply of necessities such as vegetables, meat, eggs, and milk, as well as to stabilize market prices. Figure 7D shows the information synergy involved in Cohesion Subgroup 4, which is between the market, the Ministry of Public Security, and the Ministry of Civil Affairs. According to corresponding reports, the main purpose of information synergy in this subgroup is to crack down on illegal wildlife markets and trade, and cut off the transmission of the epidemic virus at the source. Figure 7E shows the information synergy within Cohesion Subgroup 5, which includes government and medical information subjects. According to the figure, the Ministry of Industry and Information Technology is at the center of information synergy, and based on reports, the main purpose of information synergy is to support the resumption of work and ensure the stable operation of production lines. Figure 7F shows the information synergy within Cohesion Subgroup 6, which is mainly between government and social organizations, including the Customs Administration, the Civil Aviation Administration, and schools. According to corresponding reports, this subgroup focuses on the problem of returning Chinese people who are stranded in epidemic-stricken countries and regions due to reasons such as studying, working, tourism, or visiting relatives. Figure 7G shows the information synergy within Cohesion Subgroup 7, mainly between government and medical information subjects. From the figure, it can be seen that the Fangcang Hospitals are at the center of information synergy. In Stage T3, Fangcang Hospitals are still an important measure to deal with the epidemic.

TABLE 4 Classification of cohesive subgroups in T2 period.

Cohesive Subgroup	Search Terms
1	Convenience Stores, Grassroots Party Organizations, Chinese Center for Disease Control and Prevention, Medical and Health Institutions, Ministry of Civil Affairs, Citizens, Farmers' Markets, Civil Aviation Administration, Neighborhood Committees, Online Course Platforms, Schools.
2	People's Courts, People's Procuratorates.
3	Wholesale Markets, Operating Stores, Ministry of Public Security, Supermarkets, Ministry of Transportation, Ministry of Commerce, Life Material Security Groups, Groups.
4	Ministry of Agriculture and Rural Affairs, Fever Clinics, State Council.
5	People's Daily, Joint Prevention and Control Mechanism for Epidemic, People's Daily Online, China Banking and Insurance Regulatory Commission, National Development and Reform Commission, Ministry of Industry and Information Technology.
6	Community, Medical Institutions, Designated Medical Institutions, Health Commissions, Chinese Center for Disease Control and Prevention, World Health Organization, Enterprises.
7	Ministry of Science and Technology, Seafood Markets, Chinese Academy of Medical Sciences, Chinese Medical Association, Chinese Academy of Sciences.
8	Fangcang Hospitals, Medical Administration Bureaus, Customs Administration, Chinese Academy of Engineering, Ministry of Human Resources and Social Security, Ministry of Industry and Information Technology, Ministry of Finance, Competent Departments of Traditional Chinese Medicine.

According to corresponding reports, the information synergy objective of this subgroup is the same as that in Stage T2, which is to ensure the normal operation of Fangcang Hospitals. Figure 7H shows the information synergy within Cohesion Subgroup 8, mainly for information synergy within government information subjects. The National Health Commission and the State Council have played important coordinating roles in overall epidemic prevention and control, and information synergy between the two departments is also very frequent.

Based on the above analysis, it can be seen that in Stage T3, the overlap of node attributes in different cohesion subgroups is still high, but the internal structural complexity has been reduced compared to the previous stage. Information synergy mainly focuses on Cohesion Subgroups a, e, and g, and the focus of information synergy has also shifted, mainly to economic and medical activities, with the main purpose being to restore economic and social order.

5.4. Time period T4

The total number of T4 collaborations was 27,426, with 44 search terms appearing as shown in the figure above. Among them, the collaboration frequency between enterprises and the State Council was 1,358, and that between enterprises and the National Health Commission was 1,192. The specific information collaboration networks are shown in Figure 8.

Then, the concor analysis algorithm in the Ucinet software was used to analyze the overall information collaboration structure and obtain the following 8 subgroups, as shown in Table 6.

To better illustrate the internal information collaboration within each subgroup, Gephi was used to transform them into the following network diagrams. Figures 9A–H respectively show the interactions between various departments within the eight subgroups.

Figure 9A depicts the information collaboration within cohesive subgroup 1, which includes government, medical, and public information entities. As shown in the figure, medical institutions are positioned at the center of the information collaboration. According to related reports, the main goal of this subgroup's information collaboration was to diagnose and treat cases. Figure 9B illustrates the information collaboration within cohesive subgroup 2, which mainly consists of social organizations and government information entities. During this period, schools reopened one after another, and various industries gradually resumed work. The main goal of this subgroup's collaboration was to ensure the health of people returning to work or school. Figure 9C demonstrates the information collaboration within cohesive subgroup 3, which mainly involves information collaboration within the government information entities. The National Health Commission and the State Council both played important coordinating roles in overall epidemic prevention and control, and there was frequent information collaboration between the two departments. Figure 9D shows the information collaboration within cohesive subgroup 4, which mainly includes government and social organization information entities. Social organization information entities, such as various research institutes, were the main players in this subgroup's information collaboration, indicating that the main purpose of this subgroup's collaboration was to research and develop vaccines, medicines, and testing reagents. Figure 9E displays the information collaboration within cohesive subgroup 5, which involves the collaboration between government and market information entities. According to corresponding reports, the main goal of this subgroup's information collaboration was to restore the circulation of goods and commercial order and to ensure the orderly resumption of work and production in society from the aspects of meteorology and food supply. Figure 9F depicts the information collaboration within cohesive subgroup 6, which includes public and government information entities. The main purpose of their information collaboration was to maintain social order and provide consolation and subsidies to people who suffered losses during the epidemic. Figure 9G illustrates the information collaboration within cohesive subgroup 7, which mainly involves information collaboration within government information entities. Its main collaborative purpose was to support

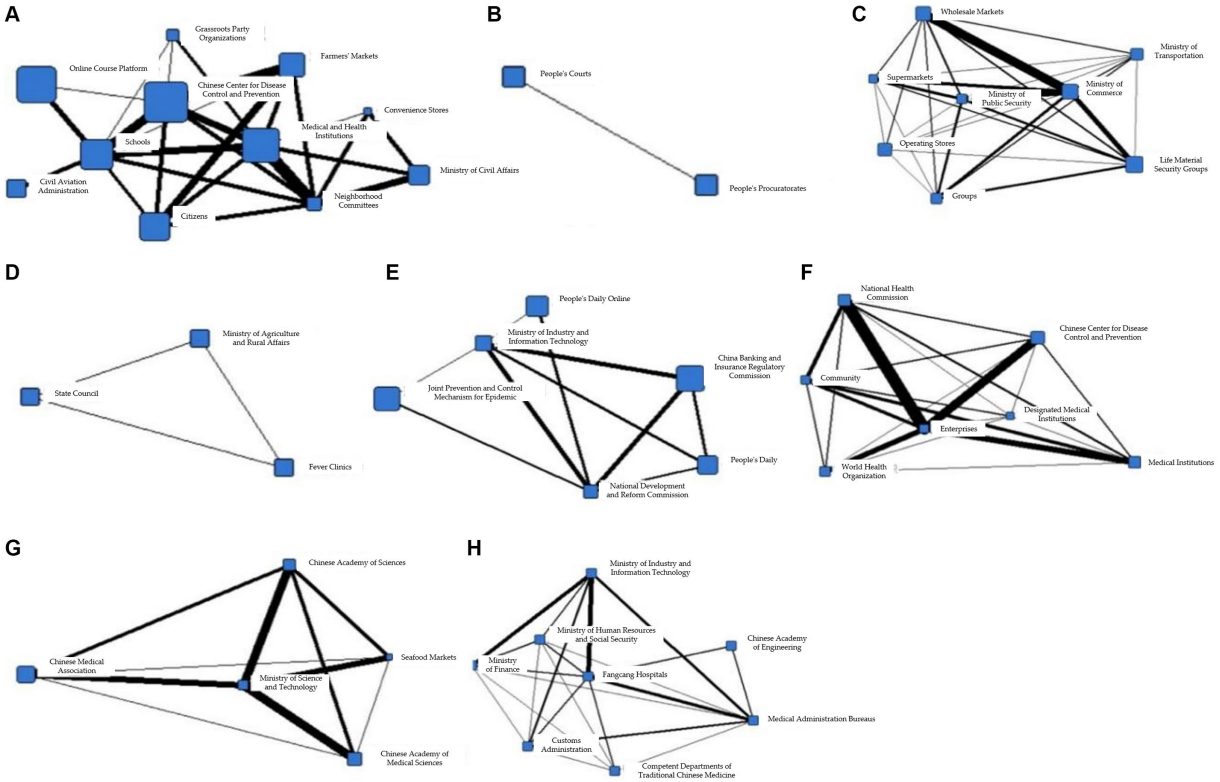


FIGURE 5
(A) Coherent subgroup 1 information collaboration network diagram during T2 period. **(B)** Coherent subgroup 2 information collaboration network diagram during T2 period. **(C)** Coherent subgroup 3 information collaboration network diagram during T2 period. **(D)** Coherent subgroup 4 information collaboration network diagram during T2 period. **(E)** Coherent subgroup 5 information collaboration network diagram during T2 period. **(F)** Coherent subgroup 6 information collaboration network diagram during T2 period. **(G)** Coherent subgroup 7 information collaboration network diagram during T2 period. **(H)** Coherent subgroup 8 information collaboration network diagram during T2 period.

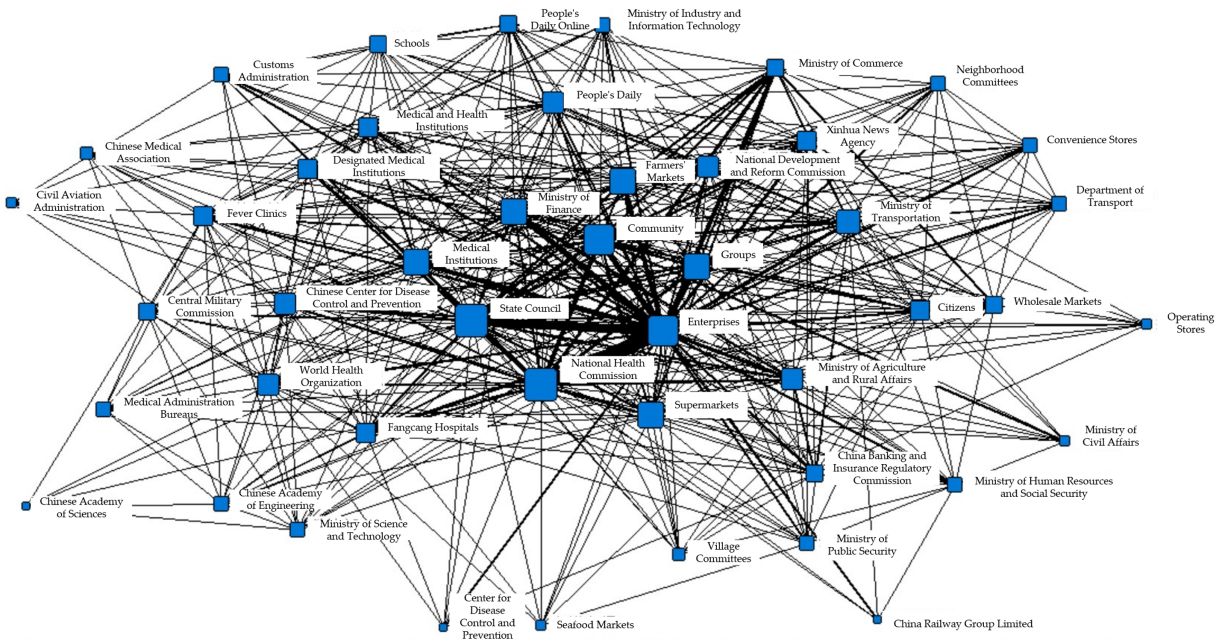


FIGURE 6
Collaborative network of epidemic information in T3 period.

TABLE 5 Classification of cohesive subgroups in T3 period.

Cohesive Subgroup	Search Terms
1	Convenience Stores, Farmers' Markets, Department of Transport, Wholesale Markets, Neighborhood Committees, National Development and Reform Commission, People's Daily, Ministry of Transport, Ministry of Commerce, Citizens
2	Communities, Enterprises, Supermarkets
3	China Banking and Insurance Regulatory Commission, Village Committees, Ministry of Agriculture and Rural Affairs, Ministry of Industry and Information Technology, Ministry of Human Resources and Social Security
4	Ministry of Civil Affairs, Ministry of Public Security, Seafood Markets
5	Designated Medical Institutions, People's Daily, Ministry of Industry and Information Technology, Medical Institutions, Ministry of Finance, Fever Clinics
6	Customs Administration, Civil Aviation Administration, Schools
7	World Health Organization, Central Military Commission, Fangcang Hospitals, Center for Disease Control and Prevention, Health Commission, Chinese Center for Disease Control and Prevention, Chinese Academy of Engineering, Ministry of Science and Technology, Chinese Academy of Sciences
8	National Health Commission, State Council.

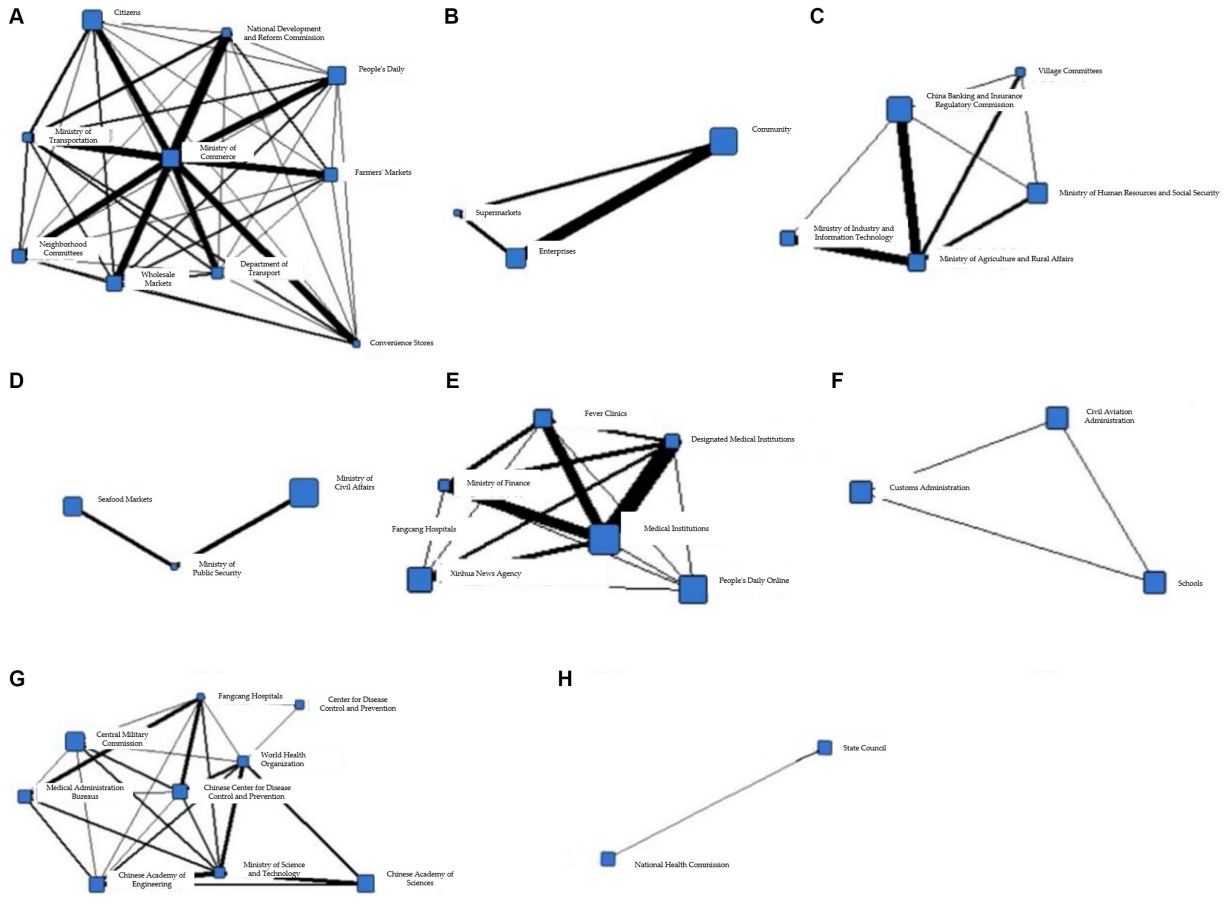


FIGURE 7
(A) Coherent subgroup 1 information collaboration network diagram during T3 period. **(B)** Coherent subgroup 2 information collaboration network diagram during T3 period. **(C)** Coherent subgroup 3 information collaboration network diagram during T3 period. **(D)** Coherent subgroup 4 information collaboration network diagram during T3 period. **(E)** Coherent subgroup 5 information collaboration network diagram during T3 period. **(F)** Coherent subgroup 6 information collaboration network diagram during T3 period. **(G)** Coherent subgroup 7 information collaboration network diagram during T3 period. **(H)** Coherent subgroup 8 information collaboration network diagram during T3 period.

the orderly resumption of work and production from the perspective of financial policies. Figure 9H displays the information collaboration within cohesive subgroup 8, which involves the collaboration between market and government information entities. The main goal of this subgroup's collaboration was to guard against imported cases and stabilize the international supply chain.

Based on the above analysis, it can be concluded that in phase T4, the types of node attributes within cohesive subgroups

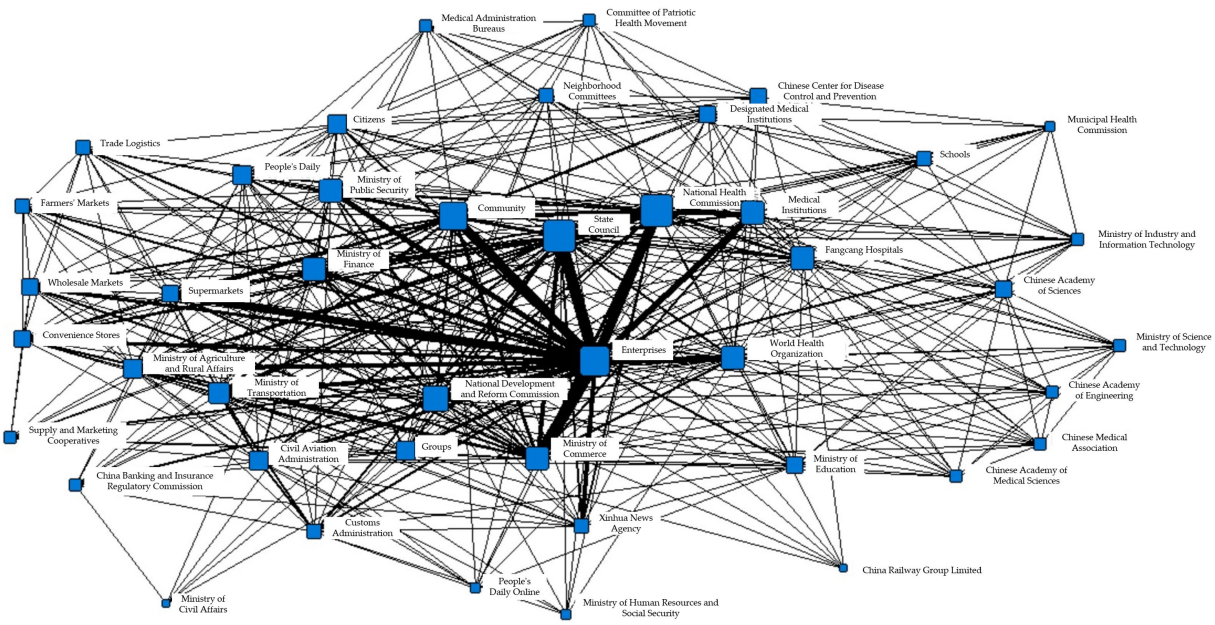


FIGURE 8
Collaborative network of epidemic information in T4 period.

TABLE 6 Classification of cohesive subgroups in T4 period.

Cohesive Subgroup	Search Terms
1	Committee of Patriotic Health Movement, Chinese Center for Disease Control and Prevention, Medical Institutions, Designated Medical Institutions, Health Management Bureaus, Community Committees.
2	Municipal Health Commission, Ministry of Industry and Information Technology, schools.
3	State Council, National Health Commission.
4	Ministry of Education, World Health Organization, Chinese Academy of Sciences, Ministry of Science and Technology, Chinese Academy of Engineering, Chinese Medical Association, Chinese Academy of Medical Sciences.
5	Supermarkets, National Development and Reform Commission, Supply and Marketing Cooperatives, Ministry of Agriculture and Rural Affairs, convenience stores, Ministry of Commerce, Agricultural Markets, Ministry of Transport, Wholesale Markets.
6	Communities, Ministry of Finance, Ministry of Public Security, Citizens.
7	Ministry of Human Resources and Social Security, People's Daily Online, Ministry of Industry and Information Technology, People's Daily, Ministry of Civil Affairs, China Banking and Insurance Regulatory Commission.
8	Enterprises, Civil Aviation Administration of China, Customs Administration.

continued to decrease compared to the previous phase, and the complexity of internal structure also decreased. Information collaboration shifted from full societal participation to small-scale participation within main entities. At this time, the core of the information collaboration network was within cohesive subgroups a, d, and e, where medical departments and economic activity management departments still occupied a central position. In addition, some research-oriented social organizations also occupied a central position. During this period, the main goal of information collaboration was still to restore circulation and consumption while also taking into account epidemic prevention and control as well as resumption of work and business. Compared to the previous period, the division of labor in economic activities became more detailed, providing support for resumption of work and production from multiple aspects such as meteorology, financial policies, market prices, and supply of daily necessities. Additionally, summarizing the post-epidemic experience and prevention was also one of the focuses of T4 phase information collaboration.

5.5. Time period T5

The total number of collaborations in T5 is 19,738, involving 39 search terms as shown in the above figure. The collaboration frequency between enterprises and the Ministry of Industry and Information

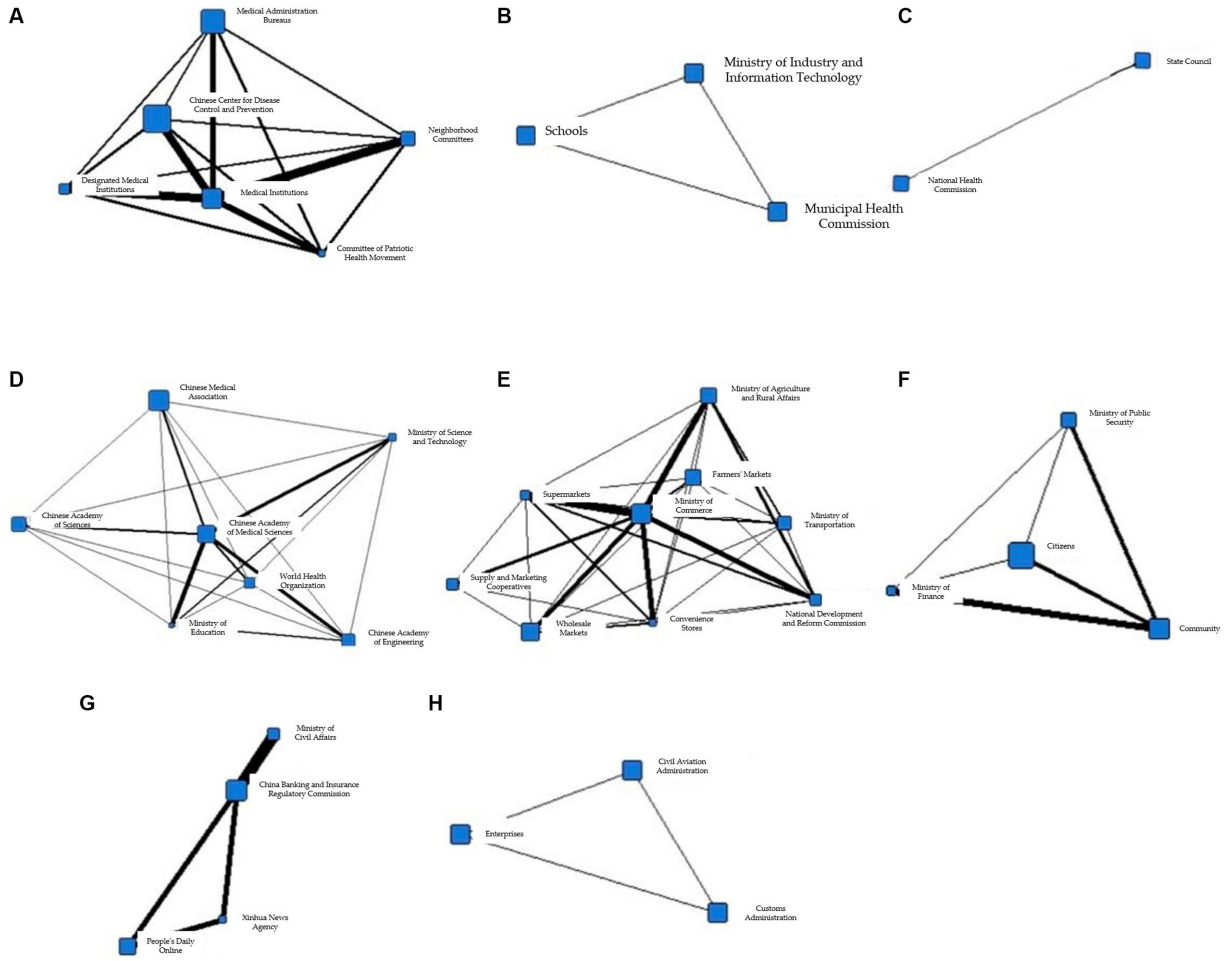


FIGURE 9
(A) Coherent subgroup 1 information collaboration network diagram during T4 period. **(B)** Coherent subgroup 2 information collaboration network diagram during T4 period. **(C)** Coherent subgroup 3 information collaboration network diagram during T4 period. **(D)** Coherent subgroup 4 information collaboration network diagram during T4 period. **(E)** Coherent subgroup 5 information collaboration network diagram during T4 period. **(F)** Coherent subgroup 6 information collaboration network diagram during T4 period. **(G)** Coherent subgroup 7 information collaboration network diagram during T4 period. **(H)** Coherent subgroup 8 information collaboration network diagram during T4 period.

Technology is 416, while that between enterprises and the State Council is 340. The specific information collaboration network is shown in Figure 10.

Next, the concor analysis algorithm in the Ucinet software was used to conduct a cohesive subgroup analysis of the overall information collaboration structure, resulting in eight subgroups as shown in Table 7.

To better display the information collaboration within each cohesive subgroup, Gephi was used to transform them into a network structure diagram as shown in Figure 11.

The table in Figure 11A illustrates the information collaboration among the public, medical institutions, and government in Cohesive Subgroup 1. The primary objective of this collaboration is to monitor the health condition of the public and prevent the recurrence of the epidemic. Figure 11B demonstrates the information collaboration among medical institutions, social organizations, markets, and government in Cohesive Subgroup 2. During T5, students resumed classes, and various markets gradually returned to normal operation, which drew considerable attention to schools and markets as gathering places for people. Both Figures 11C,D comprise information collaboration among government and social organizations and their primary objective is the research and application of vaccines and drugs. Figure 11E shows the information collaboration among market and government entities in Cohesive Subgroup 5, which mainly focuses on international economic activities, particularly import and export trade. Figure 11F illustrates the information collaboration between the market and government entities in Cohesive Subgroup 6. The primary objective of information collaboration in this subgroup is to restore the flow of goods and commercial order. Figure 11G displays the information collaboration among government entities in Cohesive Subgroup 7, which includes the internal information collaboration within the government. The National Health Commission and the State Council played a vital coordinating role in overall epidemic prevention and control. Thus, similar to T3 and T4, the information collaboration between these two departments remained frequent during T5.

Based on the above analysis, it can be inferred that the information collaboration during T5 has basically returned to the state similar to that during T1. The information collaboration network is primarily composed of Cohesive Subgroup b, where medical institutions are the core participating entities. By this time, the epidemic has been largely

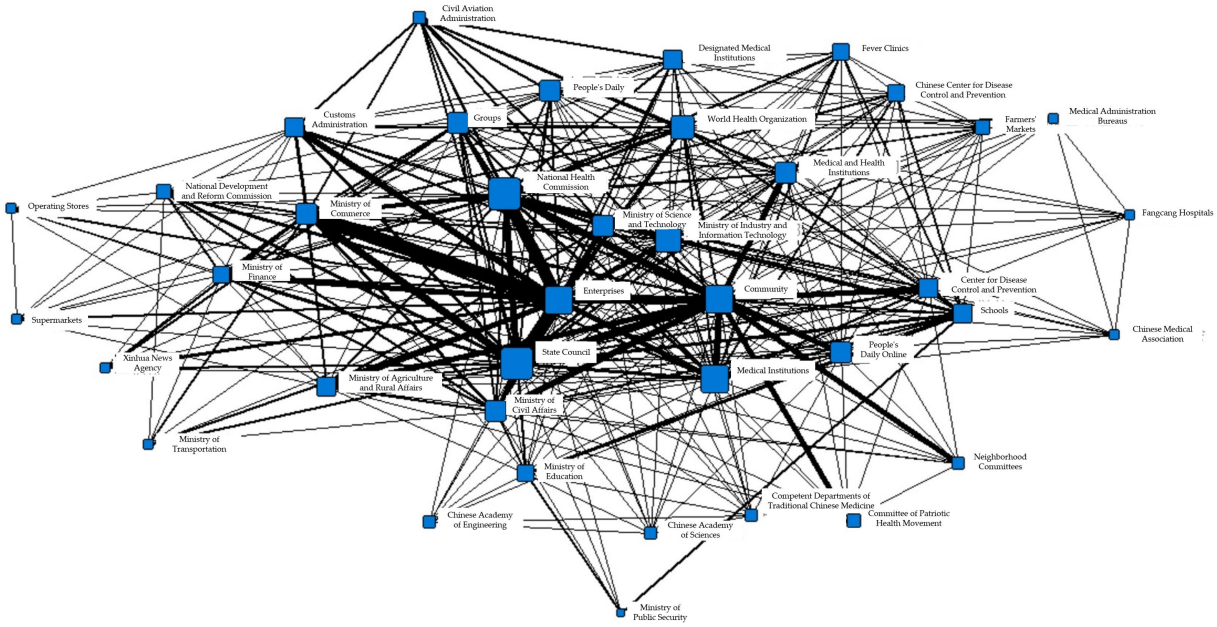


FIGURE 10
Collaborative network of epidemic information in T5 period.

TABLE 7 **Classification of cohesive subgroups in T5 period.**

Cohesive Subgroup	Search Terms
1	Committee of Patriotic Health Movement, Neighborhood Committees, People's Daily Online, Medical Institutions, Communities.
2	Fever Clinics, Farmers' Markets, Chinese Center for Disease Control and Prevention, Medical and Health Institutions, World Health Organization, Ministry of Science and Technology, Schools, Designated Medical Institutions, Disease Control Centers, People's Daily.
3	Health Administration and Medical Management Bureau, Chinese Medical Association.
4	Traditional Chinese Medicine Regulatory Authorities, Ministry of Education, Chinese Academy of Engineering, Chinese Academy of Sciences, Ministry of Public Security.
5	Enterprises, Customs Administration, Ministry of Commerce, Groups, Civil Aviation Administration, Ministry of Finance.
6	Ministry of Civil Affairs, Ministry of Agriculture and Rural Affairs, Ministry of Industry and Information Technology, Ministry of Transport, Supermarkets, Business Stores, National Development and Reform Commission.
7	State Council, National Health Commission.

brought under control, and the information collaboration mainly focuses on the medical sector. At the same time, it exists in the form of small-scale entity participation, with clear task division.

6. Discussion

Through the application of the subgroup coalescing method to analyze the information collaboration structure, collaboration goals, and collaboration paths in different time slices, the overall process of information collaboration evolution for this event has been constructed, as shown in Figure 12.

The initiation of the public health emergency saw information coordination largely limited and typically confined within small networks. Likely due to the early concentration of knowledge and resources within select key institutions, this trend led to localized coordination efforts, a pattern also discernible in preceding public health crises. With the passage of time, the complexity of information networks increased, and the sphere of collaboration extended beyond medical departments, encompassing various societal sectors. This expansion of scope aligns with the consensus in the literature, which states that the increasingly complex nature of health crises necessitates broader sector participation. Some studies assert a consistently high level of societal participation throughout crises; however, the findings of this research indicate a reorientation towards medical departments once the epidemic was under control. This discrepancy could potentially be ascribed to various factors, such as the epidemic's unique characteristics or the efficiency of the implemented measures, hence warranting further exploration. Furthermore, the pivotal role of government bodies in information collaboration at different stages was observed, reinforcing the importance of robust governmental systems for effective emergency management. The prevalent communication methods between public and governmental information subjects

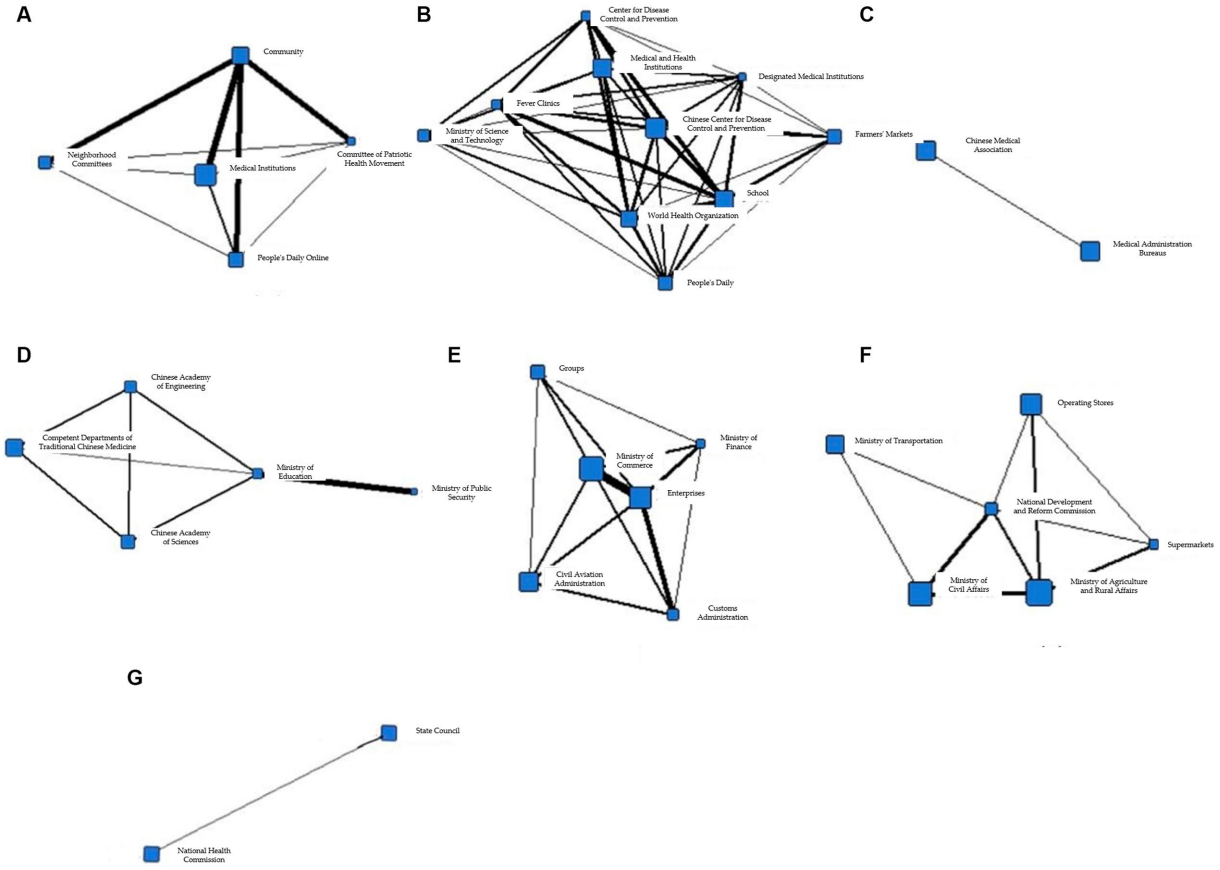


FIGURE 11
(A) Coherent subgroup 1 information collaboration network diagram during T5 period. **(B)** Coherent subgroup 2 information collaboration network diagram during T5 period. **(C)** Coherent subgroup 3 information collaboration network diagram during T5 period. **(D)** Coherent subgroup 4 information collaboration network diagram during T5 period. **(E)** Coherent subgroup 5 information collaboration network diagram during T5 period. **(F)** Coherent subgroup 6 information collaboration network diagram during T5 period. **(G)** Coherent subgroup 7 information collaboration network diagram during T5 period.

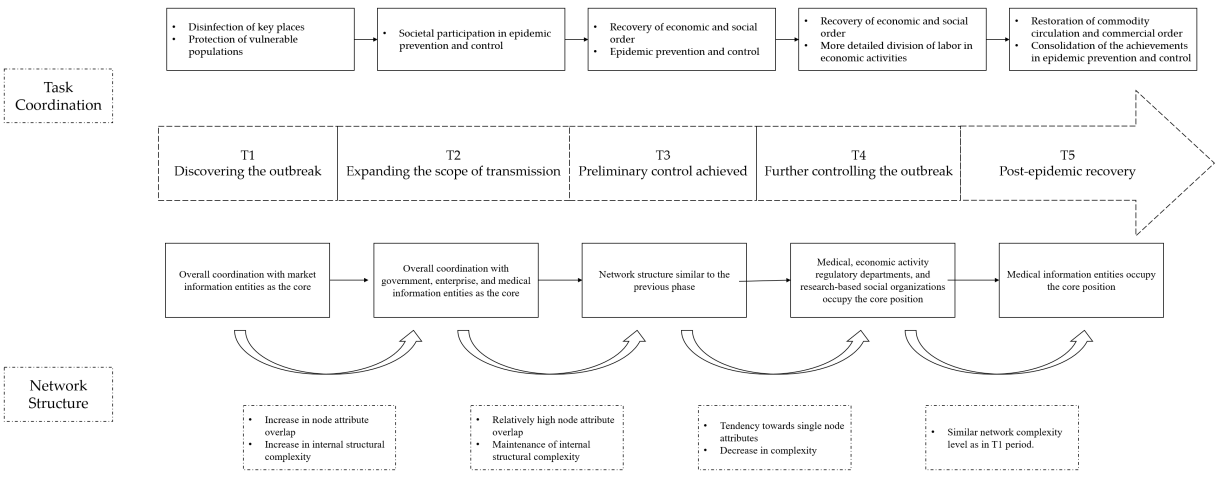


FIGURE 12
Information collaboration network evolution process diagram.

were found to be inefficient despite frequent collaborations, thereby highlighting the need for improvements in existing information collection and transmission systems. This requirement echoes a recurring theme in the literature on public health emergency management. The dynamic nature of collaborative tasks, goals, and methods over time further underscored the necessity for

adaptability in information collaboration strategies, a concept widely endorsed.

Examining the evolution of the network structure revealed that the network's complexity initially increased and later decreased during the public health emergency. As the outbreak progressed, the information collaboration scope broadened to involve various societal sectors. However, once the epidemic was under control, the focus of information collaboration shifted back to medical departments. Throughout this evolution process, diverse information subjects continuously adjusted their information needs to align with the collaboration environment, fostering the evolution of information collaboration. Government information subjects were involved most frequently, and their connections with other information subjects were quite regular, suggesting the urgent need to improve government information collection and transmission systems. The existing mode of communication between public information subjects and government information subjects primarily involves form filling, a time-consuming and inefficient process. Market information subjects confront unique challenges, including dispersed locations and inconsistent information formats, further complicating information collaboration. Therefore, establishing an efficient communication platform among the public, market, and government sectors is pivotal for enhancing information collaboration efficiency during public health emergencies.

Considering the dynamic nature of collaborative tasks during the evolution process, collaborative tasks, goals, and methods evolved over time as the public health emergency unfolded, influencing the network structure and collaboration paths at different stages. Among these tasks, epidemic prevention and control, along with economic recovery, were the most critical throughout the entire information collaboration process. This emphasizes the need to continually adjust the participating information subjects, their collaborative methods, and tasks according to changing collaborative goals. Such adaptability facilitates the construction of a flexible information collaboration mechanism capable of handling cyclical changes in public health emergencies, thus enhancing a country's emergency management capabilities.

To conclude, this research provides a nuanced understanding of the evolution of information collaboration during sudden public health emergencies. It underscores the importance of future research focusing on enhancing the efficiency of information collaboration, particularly between public and governmental information subjects, and highlights the pivotal role of adaptability in the information collaboration process.

7. Conclusion

7.1. Potential contributions

Grounded in the theoretical framework of complex adaptive systems, this study presents a novel approach to understanding the dynamics and evolution of information collaboration during public health emergencies. By leveraging rich data generated during the COVID-19 pandemic from January to April 2020, the research provides critical insights into the adaptation and evolution of information collaboration processes in response to the interactions between information subjects and their environments. A salient finding of this study involves the understanding of transformations within information collaboration networks during a crisis. Initial collaboration was concentrated in localized outbreak areas and medical departments, echoing patterns observed in previous health crises. As the crisis escalated, the information collaboration network expanded to encompass a broad array of societal sectors, indicating the involvement of non-medical entities in crisis management. Interestingly, once the epidemic was under control, the focus of information collaboration reverted back to medical departments, suggesting a potential pattern in health emergency crisis management.

Additionally, this research illuminates the critical role of governmental entities in information collaboration at various crisis stages. This finding underscores crisis management literature, highlighting the importance of robust governmental systems for effective public health emergency management. Yet, the study also uncovers certain inefficiencies in the current information communication practices, particularly between public and government information subjects. These findings have the potential to contribute significantly to the refinement and improvement of emergency management policies during public health crises, focusing on enhancing information collaboration's efficiency and effectiveness.

7.2. Limitations and future directions

Despite its contributions, this research acknowledges certain limitations. A primary limitation is the study's reliance on a single data source, the National Health Commission, which may result in potential omissions of certain aspects of information collaboration, thus presenting an incomplete view of the information collaboration network. Additionally, the analysis is constrained to the early period of the COVID-19 pandemic, which may not encapsulate the full complexity of information collaboration over the course of the entire pandemic.

Future research should, therefore, aim to diversify data sources to provide a more comprehensive and accurate depiction of information collaboration networks during public health emergencies. This may involve utilizing data from various governmental bodies, private sector organizations, and public opinion surveys to capture a broader range of information subjects. Furthermore, research should focus on developing efficient communication platforms connecting public, market, and governmental sectors. Such platforms could potentially address identified inefficiencies in information communication and significantly enhance the efficiency and effectiveness of information collaboration during public health emergencies. The vast potential of digital technology in bolstering information collaboration and crisis management is an area that warrants further exploration in future research.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MX and KL conceptualized the study. XL and YG curated the data. MX and JS performed formal analysis. KL acquired funding, reviewed and edited the manuscript. MX, XL, and KL developed the methodology. XL and JS validated the results. XL created the visualizations. MX wrote the original draft. All authors contributed to the article and approved the submitted version.

Funding

This study was supported by the National Social Science Foundation of China (22CTQ028).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Cao Y, Shan J, Gong Z, Kuang J, Gao Y. Status and challenges of public health emergency Management in China Related to COVID-19. *Front Public Health*. (2020) 8:250. doi: 10.3389/fpubh.2020.00250

2. Soujaa I, Nukpezah JA, Benavides AD. Coordination effectiveness during public health emergencies: an institutional collective action framework. *Adm Soc*. (2021) 53:1014–45. doi: 10.1177/0095399720985440

3. Saroj A, Pal S. Use of social media in crisis management: a survey. *Int J Disaster Risk Reduct*. (2020) 48:101584. doi: 10.1016/j.ijdrr.2020.101584

4. Balaji TK, Annavarapu CS, Bablani A. Machine learning algorithms for social media analysis: a survey. *Comput Sci Rev*. (2021) 40:100395. doi: 10.1016/j.cosrev.2021.100395

5. Saura JR, Reyes-Menendez A, Palos-Sanchez P. Are black Friday deals worth it? Mining twitter users' sentiment and behavior response. *J Open Innov Technol Mark Complex*. (2019) 5:58. doi: 10.3390/joitmc5030058

6. Palos-Sanchez P, Folgado-Fernández JA, Rojas-Sánchez M. Virtual reality technology: analysis based on text and opinion mining. *Math Biosci Eng*. (2022) 19:7856–85. doi: 10.3934/mbe.2022367

7. Saura JR, Palos-Sanchez P, Grilo A. Detecting indicators for startup business success: sentiment analysis using text data mining. *Sustainability*. (2019) 11:917. doi: 10.3390/su11030917

8. Sarker IH. Machine learning: algorithms, real-world applications and research directions. *SN Comput Sci*. (2021) 2:160. doi: 10.1007/s42979-021-00592-x

9. Chew AMK, Gunasekeran DV. Social media big data: the good, the bad, and the ugly (un)truths. *Front Big Data*. (2021) 4:623794. doi: 10.3389/fdata.2021.623794

10. Waugh WL. Terrorism, homeland security and the national emergency management network. *Public Organ Rev*. (2003) 3:373–85. doi: 10.1023/B:PORJ.0000004814.35884.a3

11. Tongyuan L, Chao W. Safety information cognition: a new methodology of safety science in urgent need to be established. *J Clean Prod*. (2019) 209:1182–94. doi: 10.1016/j.jclepro.2018.10.311

12. Currier M, King DS, Wofford MR, Daniel BJ, deShazo R. A Katrina experience: lessons learned. *Am J Med*. (2006) 119:986–92. doi: 10.1016/j.amjmed.2006.08.021

13. Park H, Bellamy MA, Basole RC. Structural anatomy and evolution of supply chain alliance networks: a multi-method approach. *J Oper Manag*. (2018) 63:79–96. doi: 10.1016/j.jom.2018.09.001

14. Zhou L, Ouyang F. Innovate emergency governance mechanism of urban communities in response to major public health events: a qualitative study from multiple principals in Guangzhou, China. *Front Public Health*. (2023) 11:1008378. doi: 10.3389/fpubh.2023.1008378

15. Gil-Garcia JR, Sayogo DS. Government inter-organizational information sharing initiatives: understanding the main determinants of success. *Gov Inf Q*. (2016) 33:572–82. doi: 10.1016/j.giq.2016.01.006

16. Salmon P, Stanton N, Jenkins D, Walker G. Coordination during multi-agency emergency response: issues and solutions. *Disaster Prev Manag*. (2011) 20:140–58. doi: 10.1108/09653561111126085

17. Fan B, Liu R, Huang K, Zhu Y. Embeddedness in cross-agency collaboration and emergency management capability: evidence from Shanghai's urban contingency plans. *Gov Inf Q*. (2019) 36:101395. doi: 10.1016/j.giq.2019.101395

18. Lencucha R, Bandara S. Trust, risk, and the challenge of information sharing during a health emergency. *Glob Health*. (2021) 17:1–7. doi: 10.1186/s12992-021-00673-9

19. Donahue JD, Zeckhauser RJ. Collaborative governance: private roles for public goals in turbulent times. *Am Rev Public Adm*. (2013) 43:493–6. doi: 10.1177/0275074013484792

20. Gil-Garcia JR, Guler A, Pardo TA, Burke GB. Characterizing the importance of clarity of roles and responsibilities in government inter-organizational collaboration and information sharing initiatives. *Gov Inf Q*. (2019) 36:101393. doi: 10.1016/j.giq.2019.101393

21. Kapucu N, Arslan T, Demiroz F. Collaborative emergency management and National Emergency Management Network. *Disaster Prev Manag Int J*. (2010) 19:452–68. doi: 10.1108/09653561011070376

22. Kim D. The application of inclusive management to collaboration among organizations in emergency management. *Korean Public Manag Rev*. (2012) 26:105–29. doi: 10.24210/kapm.2012.26.3.005

23. Buijs J. Modelling product innovation processes, from linear logic to circular chaos. *Creat Innov Manag*. (2003) 12:76–93. doi: 10.1111/1467-8691.00271

24. Meier KJ. Collaborative governance: private roles for public goals in turbulent times by John D. Donahue and Richard J. Zeckhauser. *Int Public Manag J*. (2011) 14:464–7. doi: 10.1080/10967494.2011.657120

25. Philip A, Tushman ML. Organizational environments and industry exit: the effects of uncertainty, munificence and complexity. *Ind Corp Change*. (2001) 10:675–711. doi: 10.1093/icc/10.3.675

26. Stacey RD. The science of complexity: an alternative perspective for strategic change processes. *Strateg Manag J*. (1995) 16:477–95. doi: 10.1016/0024-6301(95)99968-6

27. Long Q. Distributed supply chain network modelling and simulation: integration of agent-based distributed simulation and improved SCOR model. *Int J Prod Res*. (2014) 52:6899–917. doi: 10.1080/00207543.2014.910623

28. Alves H. Co-creation and innovation in public services. *Serv Ind J*. (2013) 33:671–82. doi: 10.1080/02642069.2013.740468

29. Inigo EA, Albareda L. Understanding sustainable innovation as a complex adaptive system: a systemic approach to the firm. *J Clean Prod*. (2016) 126:1–20. doi: 10.1016/j.jclepro.2016.03.036

30. Pathak SD, Day JM, Nair A, Sawaya WJ, Kristal MM. Complexity and Adaptivity in supply networks: building supply network theory using a complex adaptive systems perspective. *Decis Sci*. (2007) 38:547–80. doi: 10.1111/j.1540-5915.2007.00170.x

31. Merfji H, Miszalla T, Gilleron F. Strategic Management at the Point of inflation: systems complexity and competence theory. *Long Range Plan*. (1997) 30:939–46. doi: 10.1016/S0024-6301(97)00083-6

frontiers | Frontiers in Public Health

TYPE Systematic Review
PUBLISHED 28 September 2023
DOI 10.3389/fpubh.2023.1237066

OPEN ACCESS

EDITED BY
Shantanu Sur,
Clarkson University, United States

REVIEWED BY
Ameeta Kalokhe,
Emory University, United States
Zohar Lederman,
The University of Hong Kong,
Hong Kong SAR, China

*CORRESPONDENCE
Mark J. Lee
✉ mark.lee624@duke.edu

RECEIVED 15 June 2023
ACCEPTED 12 September 2023
PUBLISHED 28 September 2023

CITATION
Johannesson JM, Glover WA II, Petti CA, Veldman TH, Tsalik EL, Taylor DH, Hendren S, Neighbors CE, Tillekeratne LG, Kennedy SW, Harper B, Kibbe WA, Corbie G, Cohen-Wolkowiez M, Woods CW and Lee MJ (2023) Access to COVID-19 testing by individuals with housing insecurity during the early days of the COVID-19 pandemic in the United States: a scoping review. *Front. Public Health* 11:1237066. doi: 10.3389/fpubh.2023.1237066

Access to COVID-19 testing by individuals with housing insecurity during the early days of the COVID-19 pandemic in the United States: a scoping review

Jon M. Johannesson[1,2], William A. Glover II[3], Cathy A. Petti[1,4], Timothy H. Veldman[5,6], Ephraim L. Tsalik[1], Donald H. Taylor[7], Stephanie Hendren[8], Coralei E. Neighbors[6], L. Gayani Tillekeratne[1], Scott W. Kennedy[2], Barrie Harper[2], Warren A. Kibbe[9,10], Giselle Corbie[11,12,13,14], Michael Cohen-Wolkowiez[2,15], Christopher W. Woods[1,6] and Mark J. Lee[16]*

[1]Department of Medicine, Duke University School of Medicine, Durham, NC, United States, [2]Duke Clinical Research Institute, Duke University School of Medicine, Durham, NC, United States, [3]North Carolina State Laboratory of Public Health, North Carolina Department of Health and Human Services, Raleigh, NC, United States, [4]Healthspring Global Inc., Bradenton, FL, United States, [5]Duke Global Health Institute, Durham, NC, United States, [6]Hubert-Yeargan Center for Global Health, Duke University, Durham, NC, United States, [7]Sanford School of Public Policy, Duke University, Durham, NC, United States, [8]Duke University Medical Center Library, Duke University, Durham, NC, United States, [9]Department of Biostatistics and Bioinformatics, Duke University School of Medicine, Durham, NC, United States, [10]Duke Cancer Institute, Duke University School of Medicine, Durham, NC, United States, [11]Center for Health Equity Research, University of North Carolina, Chapel Hill, NC, United States, [12]Department of Social Medicine, University of North Carolina, Chapel Hill, NC, United States, [13]Department of Medicine, University of North Carolina, Chapel Hill, NC, United States, [14]Department of Internal Medicine, University of North Carolina, Chapel Hill, NC, United States, [15]Department of Pediatrics, Duke University School of Medicine, Durham, NC, United States, [16]Department of Pathology, Duke University School of Medicine, Durham, NC, United States

Introduction: The COVID-19 pandemic focused attention on healthcare disparities and inequities faced by individuals within marginalized and structurally disadvantaged groups in the United States. These individuals bore the heaviest burden across this pandemic as they faced increased risk of infection and difficulty in accessing testing and medical care. Individuals experiencing housing insecurity are a particularly vulnerable population given the additional barriers they face. In this scoping review, we identify some of the barriers this high-risk group experienced during the early days of the pandemic and assess novel solutions to overcome these barriers.

Methods: A scoping review was performed following PRISMA-Sc guidelines looking for studies focusing on COVID-19 testing among individuals experiencing housing insecurity. Barriers as well as solutions to barriers were identified as applicable and summarized using qualitative methods, highlighting particular ways that proved effective in facilitating access to testing access and delivery.

Results: Ultimately, 42 studies were included in the scoping review, with 143 barriers grouped into four categories: lack of cultural understanding, systemic racism, and stigma; medical care cost, insurance, and logistics; immigration policies, language, and fear of deportation; and other. Out of these 42 studies, 30 of these studies also suggested solutions to address them.

Conclusion: A paucity of studies have analyzed COVID-19 testing barriers among those experiencing housing insecurity, and this is even more pronounced in terms of solutions to address those barriers. Expanding resources and supporting investigators within this space is necessary to ensure equitable healthcare delivery.

KEYWORDS

pandemic, COVID-19, healthcare disparities, inequities, healthcare barriers, underserved

1. Introduction

Coronavirus disease 2019 (COVID-19) presented an unprecedented challenge across the United States and worldwide. Although the pandemic was a shared experience in the United States, COVID-19 has shined a spotlight on preexisting problems of healthcare inequity and disparities faced by individuals in structurally disadvantaged groups (1). COVID-19 disproportionately infected and affected individuals in marginalized communities, as indicated by the higher mortality and morbidity suffered by Black, Hispanic, and Native Americans compared with non-Hispanic White individuals, as well as by the economic struggles and food insecurities experienced by individuals living in poverty (1–3).

Individuals experiencing housing insecurity, many of whom already face structural disadvantages due to race/ethnicity or socioeconomic status, are at increased risk of exposure to COVID-19 and have less access to medical care (1, 4). Broadly, these are individuals experiencing homelessness, migrant workers for temporary or seasonal employment, individuals incarcerated in prison or jail, and immigrants temporarily detained at facilities. Individuals experiencing housing insecurity during a pandemic are faced with greater challenges in accessing information, getting tested, and receiving appropriate medical care. An estimated 6 million people in the United States experience housing insecurity annually. This sizable group consists of over 2 million incarcerated individuals (5), 30,000 refugees and asylum seekers (6), 3 million migrant and seasonal workers (7, 8), and half a million homeless individuals (9). Collectively, they add up to 6 million individuals, or almost 2% of the US population, and would rank in the top 20 most populous state based on the 2020–2022 US Census state ranking report (10).

In this article, we review publications regarding COVID-19 testing barriers experienced by these underserved groups and discuss efforts put forth by investigators to overcome some of these barriers. In our analysis, we included studies on the broader Latino migrant and immigrant community beyond those specifically focused on migrants in temporary housing and immigrants in detention facilities given the shared experiences within the broader community, and difficulties in teasing out subpopulations within these studies. Understanding these barriers will help not only to prepare for future pandemics but also to frame and address long-standing healthcare inequities and disparities in the United States.

2. Methods

2.1. Literature search methodology

To identify barriers in accessing COVID-19 testing experienced by individuals with housing insecurity, in collaboration with a medical librarian, we conducted an extensive publication search covering December 1, 2019, through April 4, 2022, on MEDLINE (PubMed), Embase (Elsevier), and CINAHL Complete (EBSCOhost) using a combination of keywords and database-specific subject headings for the following concepts: transient populations (migrants/immigrants, incarcerated, people experiencing housing instability), and non-traditional COVID-19 testing (defined as testing not conducted in a traditional healthcare setting) (Supplementary Table S1). No restrictions were placed on language. The search strategies were peer-reviewed by a second librarian with expertise in systematic review prior to the data/publication gathering. All citations from the search were uploaded to an EndNote 20 library before being uploaded to Covidence,[1] which was used to handle the citations during primary and secondary review. Additional references were identified, as applicable, by hand-searching bibliographies of included articles.

2.2. Protocol and registration

A scoping review protocol was made and shared openly on the Open Science Framework,[2] including the full search strategies.

2.3. Eligibility criteria

For primary review, all studies regardless of design or publication status, with full text in English directly or indirectly related to COVID-19 testing in individuals experiencing housing insecurity in the United States, were included. Populations considered for inclusion were (1) residents in prisons, jails, and detention centers; (2) people experiencing homelessness, including those in unstable housing (shelters and halfway homes); and (3) migrant/immigrant populations. To ensure inclusion of migrant/immigrant populations, studies were also included if they focused on rural populations, ethnic minorities, or those with potential language barriers. Search terms were also included that encompassed non-traditional COVID-19 diagnostic approaches; this included assays designed for supervised or unsupervised self-test or self-collection in any setting (e.g., home or clinic), or collection or test performed by a healthcare worker outside of a health system setting (e.g., community centers, mobile clinics, minute clinics). This was however not a factor in the inclusion or exclusion criteria. Study titles and abstracts were screened for eligibility in a primary review. If included, a study went to secondary

1 https://app.covidence.org/

2 https://osf.io/xe27b/

review. For secondary review, studies were read in their entirety. To be included, the study had to include or summarize explicit quantitative or qualitative data about COVID-19 testing in populations of interest as defined above, which also included testing barriers. Review articles were not included in secondary review. Reasons for excluding trials were recorded.

2.4. Review and data collection

For the primary review, two independent reviewers screened titles and abstracts of all studies yielded from the search after exclusion of duplicates. Studies were included for secondary review if the aforementioned inclusion criteria were fulfilled. The full text of all studies was obtained and further analyzed by the same two reviewers in the secondary review. In all cases, if there was a disagreement regarding the inclusion or exclusion of a study, this was resolved via discussion between the two reviewers.

Data were extracted using standardized forms within Covidence and further confirmed by a separate reviewer. Extracted data included study name, study authors, date of publication, publication status, study type (with further subclassification), population studied, time period of study, study location and setting, exact details of the study, primary outcome and secondary outcome information, study participants, age of study participants, and all relevant clinical outcomes. Data collection was stratified. Data were stored in Covidence and exported into Excel.

The eligibility criteria were not limited by study type except for review articles, which were excluded. The eligibility criteria included studies from December 1, 2019, through April 4, 2022. Studies were limited to the United States to maximize comparability and increase generalizability of results for policy making. Study setting was documented as it applied to each study, including home, health system (outpatient clinic or hospital), or community. Studies were considered for inclusion and analysis regardless of publication status.

2.5. Identification and categorization of barriers to COVID-19 testing

Publications that mentioned or described barriers to COVID-19 testing experienced by any individual within the population of interest were further analyzed. Specific barriers were identified, grouped, and tabulated with some publications having multiple barriers.

3. Results

The initial query identified 6,872 publications, with 63 additional publications identified manually with review of reference lists. After removal of duplicate publications, title and abstract reviews, and full-text reviews, only 42 publications reported or discussed barriers to COVID-19 testing in our target population (11–53) (Figure 1). These studies have a wide range of populations, geographic locations, and settings reflecting the breadth of individuals facing housing insecurity and the complexity they face (Supplementary Table S2). Barriers were identified from data gathered through surveys, analysis of interviews, synthesis of prior publications, and commentaries from key opinion leaders. Most publications reported or described multiple barriers. We identified a total of 143 specific barriers grouped into four categories: Cultural Barriers; Immigration and Language Barriers; Insurance, Cost, and Logistic Barriers; and Other. These were broken down into respective underserved populations: Homeless; Immigrant/Migrant; Incarcerated; and Detained (i.e., immigration) (Table 1).

3.1. Barriers to COVID-19 testing

3.1.1. Barrier: lack of cultural understanding, systemic racism, and stigma

Among the four categories, 17 publications identified cultural understanding, racism, stigma, and health literacy as significant barriers. While these are vastly different, many studies combined multiple constituent elements, collectively shedding light on these barriers. Even before the COVID-19 pandemic, marginalized groups were facing stigma, racism, mistrust, and lack of cultural understanding as significant barriers to accessing healthcare (11, 18, 21). The pandemic not only exacerbated these barriers but also brought to the forefront the pervasiveness of health inequity due to these barriers. One area of particular focus for improvement is effective messaging.

Culturally and racially sensitive messaging can become effective vehicles in delivering healthcare. Messengers can significantly contribute to effective messaging in these communities. In a commentary by Kanamori et al., the authors synthesized data collected in their previous studies from experts comprising migrant farmworkers, Latino community leaders, and mental health professionals (12). The authors point to the value of *personalismo*, which refers to the preference of friendship with individuals of similar sociodemographic background, and *collectivism*, which refers to a cultural orientation that values close, nurturing, and supportive interpersonal relationships over individualistic behaviors and attitudes, as important sources of information and trust that are largely left out of the general public health messaging strategy. Instead, misinformation and mistrust can permeate through these channels, more pronounced when combined with fear and lack of access to information. Authors state that COVID-19 is heavily stigmatized within the community, and the misinformation cycle perpetuates the stigma. While this study focused on farmworkers, other studies on homeless and incarcerated individuals point to similar barriers in information and communication within racial context (43, 49). This highlights the importance of controlling the delivery and flow of information.

However, even in a prison environment where the flow of information can be controlled, tailoring messages around cultural and linguistic needs is crucial for successful participation, according to a study that looked at mass COVID-19 testing in 16 prisons (13). Although the authors did not explicitly state the reason for this need, they found that in at least two prisons, over 15% of inmates refused testing; they attributed some portion of it to the lack of cultural and linguistic considerations in messaging. Overall, these studies suggest factors around racial and cultural stigma and misunderstanding can be significant barriers to accessing healthcare and that mitigation requires a multipronged approach.

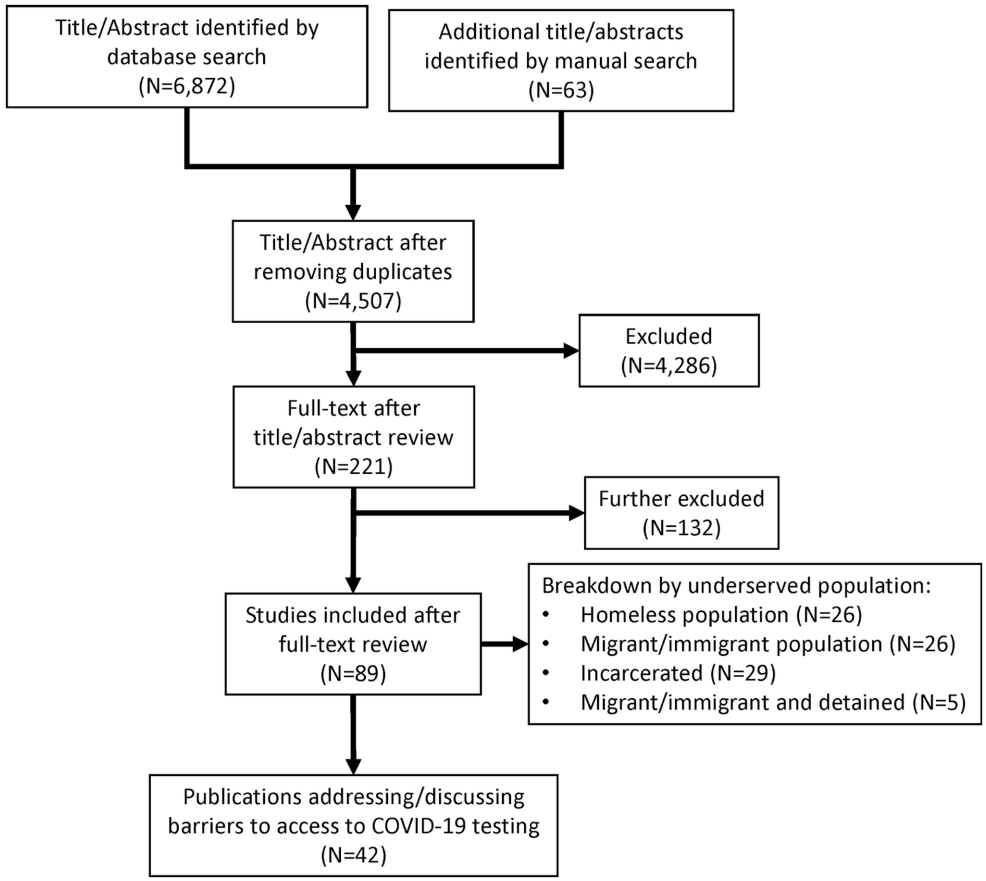


FIGURE 1
PRISMA flowchart. Literature search by database query (*N* = 6,872) and manual search (*N* = 63) covering December 1, 2019, through April 4, 2022, resulted in 42 publications of interest.

3.1.2. Barrier: medical care cost, insurance, and logistics

Our analysis revealed a significant number of barriers associated with medical costs and logistics of getting tested. Twenty-five publications identified one or more barriers within this category (Table 1). Individuals experiencing housing insecurity are especially vulnerable to these types of challenges. Having adequate healthcare coverage or access to a primary care provider is not common to individuals in this target population. Citing prior studies showing low primary care visitation rates in individuals experiencing homelessness, Knight et al. highlighted that barriers to healthcare contribute to decreased acceptance of COVID-19 testing in this group (11). The researchers also pointed out that limited access to the internet or telephones can lead to decreased knowledge about testing options, which can contribute to lower rates of testing. Likewise, in a perspective article, Behbahani et al. pointed out that while strategies like drive-thru testing have been largely successful in the general population, immigrants and people experiencing homelessness do not readily have access to motor vehicles to get to these sites (14).

Similarly, seasonal and migrant workers contracted to a particular farm or facility have limited access to primary care, and for most, health insurance is not provided by employers. Lauzardo et al. found that among the 100 migrant farmworkers in Florida involved in an outbreak, most reported having some COVID-19-related symptoms but could not seek medical care (53). Upon testing by the local public health department, 91 of the 100 workers tested positive for SARS-CoV-2. Based on the local health department investigation, the outbreak started with two workers who tested positive a week prior after presenting with symptoms.

Migrants and immigrants in the general community may also experience a similar lack of access to healthcare. During a free COVID-19 testing event in a predominantly Latino community in San Francisco, a survey was conducted to understand why participants did not seek testing prior to the free event (15). Some of the responses included not being able to get an appointment (25%), not knowing where or how to make an appointment (14%), not having insurance or a doctor (14%), and testing sites being too far away (3%). Many of these barriers are related to and affected by other barriers, such as linguistic challenges, access to transportation, and health literacy.

Collectively, these studies show how medical care cost, insurance, and logistics to access medical care present as barriers for individuals experiencing housing insecurity. Importantly, these studies also show that barriers do not exist in isolation but can be intertwined and codependent. Identifying and evaluating barriers, especially in these vulnerable populations, may be complex and necessitate complicated analysis in decoupling and understanding the association among and between barriers.

TABLE 1 List of barriers by groups.

Category	Barriers	Homeless	Immigrant/ Migrant	Incarcerated	Detained
Cultural barriers	Lack of culturally sensitive approaches	1	5		
	Lack of trust	1	7		1
	No access or perceived lack of access		2	4	1
	Poor health literacy	1	3		
	Stigma and racism in healthcare	1	2	1	
Immigration and language barriers	Undocumented status		2		
	Fears of deportation or other immigration ramifications		11		
	Fear of public charge rule		4		
	General anti-immigration policies		1		
	Lack of identification		2		
	Limited English proficiency		13		1
Insurance, cost, and logistic barriers	Closure of clinics		1		
	Distance to testing site	1	4		
	Fear of losing work	1	7		
	Fear of food insecurity	1	2		
	Fear of dying in hospital		1		
	Fear of quarantine or isolation	1	2	4	
	Fear of contact tracing	1			
	Fear of contracting COVID-19	1	1		
	Fear of losing personal privileges	3		1	
	Fear of law enforcement	1	1		
	Worries about safety			1	
	Institutional barriers to accessing healthcare				1
	Lack of appointment information	1	2		
	Lack of connection to healthcare	1	2		
	Lack of insurance		8		
	Medical care costs		5	2	
	Lack of information	1	4		1
	Lack of technology	3			
	Lag in or lack of result reporting		2		
	No appointments or need for appointment		3		
Other	Constant movement within facility			1	
	Drug abuse		1		
	Lack of time	1	2		
	Need to sign a form				1
	Not severe enough symptoms or limited to symptoms		2		

3.1.3. Barrier: immigration policies, language, and fear of deportation

Migrants and immigrants face an additional complexity in accessing COVID-19 testing. Fifteen publications addressed barriers experienced by migrants and immigrants, including undocumented status. Being undocumented, whether through lapse of legal status (e.g., expired work permit) or undocumented entry to the United States, is a major barrier to medical care. Even for those with legal status, the prospect of deportation or dealing with harsh immigration policies, like the *public charge rule*, present as

significant barriers (17). According to the public charge rule, a noncitizen who primarily depends on government assistance for subsistence, and thereby becomes a public charge, can be denied permanent residency (17). These challenges, combined with language and cultural barriers, place migrants and immigrants in a uniquely vulnerable position.

In one study, investigators found that the public charge rule is not only a significant concern but a major barrier to seeking medical care (18). Lechuga et al. conducted interviews through online surveys or by telephone, including with migrants and farmworkers. Among the participants, 76% reported not having health insurance, and 50.3% reported not seeking medical care in the United States in the preceding 12 months. Of the 49.3% who received medical care in the United States, 25.6% sought care at a hospital emergency room. When asked whether they would seek medical care if the clinic or doctor assured them that COVID-19-related care would not impact their immigration status or chances, 53.5% of participants were skeptical and would decline.

Cultural and linguistic barriers are additional challenges faced by migrant and immigrant populations. Davlantes et al. conducted a survey as well as interviews with key informants and several focus group sessions in Latino communities in the Prince William Health District in northern Virginia (20). When asked where they get their COVID-19 information, participants mentioned television (Spanish-language) and the Internet as primary sources, with clinics and hospitals being secondary. However, many participants indicated that health ministries from their countries of origin and prominent Hispanic or Latino business owners were also sources of information, underscoring the influence that "alternative" sources can have in this group. Participants consistently emphasized that most COVID-19 information was in English and was text-heavy, with less emphasis on videos, images, and graphics. Taken together, these studies underscore the unique situation that migrants and immigrants face in accessing medical care and emphasize how the pandemic should shift our focus on these barriers.

3.2. Potential solutions to overcome COVID-19 testing barriers

In addition to identifying barriers, 30 of the 42 publications we analyzed offered some potential solutions, and in a few studies, investigators implemented solutions aimed at overcoming certain barriers (16, 21, 22). Barriers to accessing medical care rooted in racism, mistrust, and lack of cultural understanding are systemic and difficult to overcome. Similarly, barriers based on fear of deportation or loss of privileges, financial burdens including lack of insurance or loss of employment, or logistical challenges such as transportation or telecommunication can be equally difficult to overcome. Many of these barriers are related to or dependent upon each other, making assessment and strategizing difficult. However, the strong public interest and motivation to curb the COVID-19 pandemic has presented us with unique opportunities to design and implement some innovative solutions. In our analysis, we identified three notable approaches, each uniquely targeted to a specific underserved population group (16, 21, 22). While we do not endorse a particular approach, these studies show that innovative approaches to overcome barriers can positively affect members of these underserved groups and the community at large.

3.2.1. Delivering integrated care where it is needed: the backpack medicine program approach

During the course of the pandemic, widespread use of drive-thru testing sites, mobile testing units, and walk-in clinics at local pharmacies and national chain stores addressed gaps in meeting the demand for COVID-19 testing. For the most part, these outside-the-box solutions to alleviate test volumes in clinics and hospitals met the needs of the general public. However, people experiencing homelessness still face barriers that limit their access to these solutions, such as not having a motor vehicle to get to drive-thru testing sites, proper identification when required, or a way of receiving test results, as well as not knowing these testing options exist (11, 14, 15, 19, 20). Thus, people experiencing homelessness may require further creative approaches.

In one study, a team of medical professionals at the Ventura County Medical Center in Ventura, CA, expanded on an existing outreach program called Backpack Medicine Program (BMP) to include COVID-19 testing (21). The program began in 2018 to provide free outreach by bringing medical care to individuals experiencing homelessness where they are located, including homeless encampments and shelters, parks, and under freeways. In some instances, the program also delivered care to local farm workers. The program provided basic primary care, wound care, behavioral health and addiction medicine, and housing and benefit assistance, taking an integrated care approach. In response to the pandemic, anyone suspected of COVID-19 was offered testing. While waiting for test results or if results were positive, individuals were offered to isolate at a sponsored hotel free of charge until eligible to stop isolation. If they declined relocation, they were asked to quarantine away from others in their respective encampments. In the first 4 weeks of the program, over 150 individuals were tested, identifying 24 positive cases.

Although this was a small study, it shows one approach to bridging the gaps in health inequalities and providing integrated care to individuals who might not otherwise receive proper care. This approach addresses many of the barriers that limit access to medical care for people experiencing homelessness. However, there are some limitations to this approach. First, while the authors do not mention the cost associated with running this program, funding for implementing and maintaining this type of program on a larger, national scale may be cost-prohibitive. Second, the authors mentioned that police presence is needed on occasion due to safety concerns of the BMP providers. Although the local police department provided support in this particular study, it cannot be assumed that all police departments would be able to provide support. Lastly, given the sensitivity around the presence of homeless people, potential backlash within the larger community cannot be ignored. Despite these caveats, this approach has been shown to work effectively in this population group. A targeted, well-supported rollout of similar programs in other jurisdictions could start to build confidence in their effectiveness and lead to wider implementation. Over time, delivery of integrated medical care to vulnerable populations could become a more routine practice.

3.2.2. Identifying cases in congregate settings before an outbreak: cohort-based testing approach

Individuals in congregate living situations, such as those incarcerated or detained in a facility, face similar challenges as those

who experience homelessness, but with added complexity due to their proximity and confined living situation, in which a single positive case can quickly lead to an outbreak. Promptly identifying cases and implementing isolation and quarantine measures while providing necessary support and assurance to the affected individuals is crucial to preventing outbreaks. Symptom-based identification of cases is one common approach, but given certain barriers around reporting symptoms, including fear of losing privileges and financial consequences, it may not be the most effective strategy. Also, presymptomatic or asymptomatic transmission of SARS-CoV-2 would not be identified in this approach. The constant emergence of variants and our changing understanding of transmission of this virus adds an additional layer of complexity.

To address these challenges, a group of investigators used a cohort-based testing approach to promptly identify presymptomatic and asymptomatic cases in a correctional facility in Chicago (16). Wadhwa et al. conducted COVID-19 testing and interviews of exposed contacts of laboratory-confirmed cases (16). Individuals with a laboratory-confirmed COVID-19 infection were moved from their unit into an isolation unit, while the remaining exposed contacts were quarantined together in their respective units. The investigators approached 224 exposed detainees assigned to two groups: serial testing vs. single test on day 14. Those in the serial testing group were tested on days 1, 3–5, and 14 from the time of the first laboratory-confirmed case. Those in the 14-day group were only tested on day 14 to leave quarantine. In the serial testing group, 16 out of 96 persons tested positive on day 1, and one person tested positive on day 3–5, for a total of 17 positive cases. No one in the serial group tested positive on day 14. In the single test group, 2 out of 82 persons tested positive on day 14. Of the 19 positive cases, 12 (63%) were asymptomatic, and 4 (21%) were presymptomatic. These findings suggest that symptom-based testing alone would have missed 84% of the cases and could have led to greater transmission. Thus, cohort-based testing by serial testing, especially soon after identification of a positive case, could help reduce transmission in congregate settings.

Cohort-based testing in correctional facilities poses various limitations in implementation. Wadhwa et al. observed high rates of refusal to participate in the study due to fear of losing privileges in the form of the commissary or phone calls. After all, if not for the testing, the 12 individuals with asymptomatic cases would not have been confined in isolation and presumably have enjoyed privileges sooner. Therefore, while cohort-based testing is an effective approach to identifying cases and potentially preventing or reducing outbreaks (particularly in settings such as nursing homes), other barriers in the incarcerated/detainee setting must be addressed to ensure noncoercive participation. This could include providing access to phone calls in isolation or delivery of commissary items to isolation cells or units.

3.2.3. Utilizing cultural and community centers as one-stop shops: community-adapted approach

Individuals within migrant and immigrant communities can face a wide range of challenges when attempting to access COVID-19 testing, from lack of access to a vehicle to fear of deportation. In this underserved population, an individual who is undocumented is liable to fear that contact tracing or any government involvement could lead to deportation. Engaging individuals within this group who are not only resource-limited but fear for their safety and liberty is a monumental task. However, as evidenced by the COVID-19 infection and mortality rates in this population, reaching members of underserved communities is critical.

One study took a community-adapted approach in addressing this need (22). The investigators partnered with the local health department and a community cultural center to develop a safe, culturally tailored space for COVID-19 testing designed to accommodate the specific needs of the local Latino community and other underserved populations, including sexual and gender minorities. The center is well known to the locals and is a gathering space for artist exhibitions, performances, religious services, and community gatherings. The program offers walk-in, drive-thru, and walk-up testing at no cost for those without insurance, regardless of symptom or in-state residency status. Additionally, there are onsite language services in English, Spanish, and Portuguese with additional languages via tele-interpretation.

To engage the community, the investigators worked with Latino community leaders and others to promote the program via social media, radio, churches, and other platforms. In the 2 months of the study, the program tested 498 participants, with 40% identifying as Latino, 32% as LGBTQIA+, and 52% as women. An important result of this study is that 90% of participants were asymptomatic. While the authors do not mention follow-up on these participants, one could assume that positive test results of these asymptomatic individuals may have reduced transmission in their respective communities or to their familial contacts. The investigators did not report on how the participants received the program. However, they mentioned that the program attracted individuals across the state, underscoring the success and need for this type of program.

Community-adapted testing programs using a well-known cultural center and engaging community leaders to provide testing services to marginalized groups that would otherwise remain disengaged can be an effective solution. This type of approach overcomes many barriers that other studies have identified. Although this framework can be useful, there are two caveats to this approach. First, implementation requires sustainable and consistent funding. Given that a testing site is required that needs to be staffed, along with substantial work in identifying and collaborating with local community leaders, the upfront investment may be substantial. In fact, the investigators noted that the human and financial resources needed to implement and maintain this type of testing site could limit the broader implementation of this type of program. Second, migrants and immigrants are not a monolithic group. Rather, they represent a spectrum of cultural backgrounds and experiences that cannot be fit into a single box of solutions. Therefore, this approach should be broadly defined, and the framework should be loosely structured, requiring adjustments and revisions at each specific implementation site. Nevertheless, this study shows that this approach can be successful and engage vulnerable populations.

4. Discussion and conclusion

The disproportionate impact of an infectious disease on morbidity and mortality in underserved populations is perhaps the ultimate proof of the impact of systemic or structural inequalities on human

health. The COVID-19 pandemic reaffirmed how interconnected and interdependent we are with each other, at all levels of the socioeconomic ladder, across racial and ethnic backgrounds, and at varying geographic locations.

Our scoping review revealed that there are many barriers faced by individuals with housing insecurity, including those in congregate living situations, temporary or transient living situations, other non-traditional settings, and individuals within other marginalized groups facing barriers in accessing COVID-19 testing. These individuals were not only left behind in major efforts to curb the virus, but also carried the heaviest burden of the pandemic. While individuals in congregate living situations are at risk of acquiring COVID-19 from others within the facilities, individuals in temporary or transient living situations and those living on streets, bridges, and other outdoor settings are not only exposed to acquiring COVID-19 as they move around, but also face challenges in accessing information, medical care, protective devices, and testing information that may be available in congregate facilities.

While there are many barriers, our scoping review also revealed that there are potential solutions. Several studies have implemented some of these solutions in small scale, while others have provided proposals and call-to-action solutions derived from various bodies of evidence. In our assessment, many of these solutions, especially those that include direct outreach and engagement with individuals in various levels and stages of housing insecurity, require tremendous investment. Creating community centers, empowering local/community leaders who can build trust and disseminate appropriate messaging, providing "house" calls for medical care, and building an overall infrastructure where everyone has equal access to testing require close coordination with insurance companies, healthcare organizations, government agencies, and strong political will.

Identifying barriers, determining root causes, and developing approaches to overcome these barriers are paramount in bridging healthcare inequity and disparity, for both future pandemics and overall delivery of medical care. Given the paucity of publications focusing on barriers faced by marginalized groups, there is a great need to expand resources and support investigators within this sphere. One national effort has recently come from the National Institutes of Health through the Rapid Acceleration of Diagnostics–Underserved Populations (RADx-UP) grant program, where studies (including this scoping review) are funded to expand COVID-19 testing and gather data that could inform potential barriers and solutions in marginalized communities.

Studies focused on distilling each of these barriers with study designs to understand the needs of those with housing insecurity are critically needed, especially studies that further focus on subpopulations including age (i.e., youth and older adult), gender, and wider ethnic groups. Studies with sufficient funding to carry out larger-scale and long-term implementation of solutions like delivery of medical care where the need is, or building community centers and infrastructure, are also needed. These studies are crucial in further assessing the issue and experimenting with different solutions. They are also needed to get wider commitment and buy-in from respective governmental entities (federal and local), healthcare facilities and payors, and community groups, and ultimately needed to provide realistic and sustaining solutions.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

JJ, WG, CP, TV, ET, CN, LT, SK, BH, CW, and ML: conceptualization. JJ, CP, TV, ET, CW, and ML: methodology and analysis. JJ and ML: original draft. JJ, SH, and ML: data search and extraction. JJ, WG, CP, TV, ET, DT, CN, LT, SK, BH, WK, GC, MC-W, CW, and ML: review and editing. MC-W and CW: supervision. All authors contributed to the article and approved the submitted version.

Funding

Research reported in this Rapid Acceleration of Diagnostics–Underserved Populations (RADx-UP) publication was supported by the National Institutes of Health (Award No. U24MD016258). The content was solely the responsibility of the authors and does not necessarily represent the official views of the National Institutes of Health.

Acknowledgments

Peter Hoffmann with Duke Clinical Research Institute provided editorial assistance with the manuscript.

Conflict of interest

CP was employed by the Healthspring Global Inc. CP reports receiving consulting fees from Abbott Molecular and Rapid Diagnostics. ET has been a consultant for Biomeme, Inc., has a patent pending for Methods to Diagnose and Treat Acute Respiratory Infections (US20180245154A1), and is currently employed by Danaher Corp. MC-W reports receiving support for research from the NIH (1U24-MD016258), National Institute of Allergy and Infectious Diseases (HHSN272201500006I, 1K24-AI143971), U.S. Food and Drug Administration (5U18-FD006298), and industry for drug development in adults and children. CW reports grants or contracts from DARPA, NIH-ARLG/NIAID/VTEU/NIMHO/NIGMS, Sanofi, Najit, CDC, Patient-Centered Outcomes Research Institute, USAMRAA, DOD, Abbott, and Pfizer; consulting fees from Arena Pharmaceuticals, BioFire, FHI Clinical, Giner, Karius, and SeLux Diagnostics; support for attending meetings and/or travel from American Society for Microbiology; patents planned, issued or pending for: biomarkers for the molecular classification of bacterial infection, methods to diagnose and treat acute respiratory infections, gene expression signatures useful to predict or diagnose sepsis and methods of using the same, host based molecular signatures of human infection with SARS-CoV-2 (COVID19), methods of identifying

infectious disease and assays for identifying infectious disease, and nasopharyngeal protein biomarkers of acute respiratory virus infection and methods of using same; participation on a Data Safety Monitoring Board or Advisory Board for IDbyDNA, Janssen, Regeneron, Roche Molecular Sciences; leadership or fiduciary role in other board, society, committee or advocacy group, paid or unpaid for American Society for Microbiology and American Society of Tropical Medicine and Hygiene; and other financial or non-financial interests with Biomeme and Predigen, Inc.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1237066/full#supplementary-material

References

1. Nana-Sinkam P, Kraschnewski J, Sacco R, Chavez J, Fouad M, Gal T, et al. Health disparities and equity in the era of COVID-19. *J Clin Transl Sci*. (2021) 5:e99. doi: 10.1017/cts.2021.23

2. Wasfy JH, Hidrue MK, Rockett H, Cafiero-Fonseca ET, Ferris TG, Del Carmen MG. Socioeconomic and demographic characteristics of both inpatients and outpatients with positive testing for SARS-CoV-2. *J Gen Internal Med*. (2021) 36:2522–4. doi: 10.1007/s11606-021-06919-x

3. Parolin Z, Lee EK. The role of poverty and racial discrimination in exacerbating the health consequences of COVID-19. *Lancet Reg Health Am*. (2022) 7:100178. doi: 10.1016/j.lana.2021.100178

4. Estrada LV, Levasseur JL, Maxim A, Benavidez GA, Pollack Porter KM. Structural racism, place, and COVID-19: a narrative review describing how we prepare for an endemic COVID-19 future. *Health Equity*. (2022) 6:356–66. doi: 10.1089/heq.2021.0190

5. Minton TD, Beatty LG, Zeng Z. *Correctional populations in the United States, 2019 – statistical tables* US Department of Justice, Bureau of Justice Statistics (2021) Available at: https://bjs.ojp.gov/library/publications/correctional-populations-united-states-2019-statistical-tables.

6. Baugh R. *Refugees and asylees: 2021*. Annual flow report US Dept of Homeland Security, Office of Immigration Statistics (2022) Available at: https://www.dhs.gov/sites/default/files/2022-10/2022_0920_plcy_refugees_and_asylees_fy2021.pdf.

7. *The National Agricultural Workers Survey (NAWS) tables for 2013-2014*. US Department of Labor. Available at: https://naws.jbsinternational.com/ (Accessed Jan 29, 2023).

8. *Foreign-Born workers: labor force characteristics—2021* US Department of Labor, Bureau of Labor Statistics. News Release (2022) Available at: https://www.bls.gov/news.release/archives/forbrn_05182022.htm.

9. Henry M, de Sousa T, Roddey C, Gayen S, Bednar TJ. The 2020 *Annual homeless assessment report (AHAR) to congress. Part 1: point-in-time estimates of homelessness*. US Department of Housing and Urban Development, Office of Community Planning and Development (2021). Available at: https://www.huduser.gov/portal/sites/default/files/pdf/2020-AHAR-Part-1.pdf.

10. *State Population totals and components of change: 2020-2022*. United States Census Bureau. Available at: https://www.census.gov/data/tables/time-series/demo/popest/2020s-state-total.html (Accessed August 25, 2023).

11. Knight KR, Duke MR, Carey CA, Pruss G, Garcia CM, Lightfoot M, et al. COVID-19 testing and vaccine acceptability among homeless-experienced adults: qualitative data from two samples. *J Gen Intern Med*. (2021) 37:823–9. doi: 10.1007/s11606-021-07161-1

12. Kanamori M, Castaneda D, Self KJ, Sanchez L, Rosas Y, Rodriguez E, et al. Why re-invent the wheel? Social network approaches can be used to mitigate SARS-CoV-2 related disparities in Latinx seasonal farmworkers. *Int J Environ Res Public Health*. (2021) 18:12709. doi: 10.3390/ijerph182312709

13. Hagan LM, Williams SP, Spaulding AC, Toblin RL, Figlenski J, Ocampo J, et al. Mass testing for SARS-CoV-2 in 16 prisons and jails—six jurisdictions, United States, April–May 2020. *MMWR Morb Mortal Wkly Rep*. (2020) 69:1139–43. doi: 10.15585/mmwr.mm6933a3

14. Behbahani S, Smith CA, Carvalho M, Warren CJ, Gregory M, Silva NA. Vulnerable immigrant populations in the New York metropolitan area and COVID-19: lessons learned in the epicenter of the crisis. *Acad Med*. (2020) 95:1827–30. doi: 10.1097/ACM.0000000000003518

15. Rubio LA, Peng J, Rojas S, Crawford E, Black D, Jacobo J, et al. The COVID-19 symptom to isolation cascade in a Latinx community: a call to action. *Open Forum Infect Dis*. (2021) 8. doi: 10.1093/ofid/ofab023

16. Wadhwa A, Fisher KA, Silver R, Koh M, Arons MM, Miller DA, et al. Identification of presymptomatic and asymptomatic cases using cohort-based testing approaches at a large correctional facility—Chicago, Illinois, USA, may 2020. *Clin Infect Dis*. (2021) 72:e128–35. doi: 10.1093/cid/ciaa1802

17. US Department of Homeland Security, Citizenship and Immigration Services. Available at: https://www.uscis.gov/green-card/green-card-processes-and-procedures/public-charge/public-charge-resources (Accessed January 29, 2023).

18. Lechuga J, Galletly CL, Glasman LR, Dickson-Gomez JB, McAuliffe TL. Latinx immigrants' legal concerns about SARS-CoV-2 testing and COVID-19 diagnosis and treatment. *J Immigr Minor Health*. (2022) 24:1–9. doi: 10.1007/s10903-021-01314-4

19. Gehlbach D, Vazquez E, Ortiz G, Li E, Sánchez CB, Rodríguez S, et al. Perceptions of the coronavirus and COVID-19 testing and vaccination in Latinx and indigenous mexican immigrant communities in the Eastern Coachella Valley. *BMC Public Health*. (2022) 22:1019. doi: 10.1186/s12889-022-13375-7

20. Davlantes E, Tippins A, Espinosa C, Lofgren H, Leonard S, Solis M, et al. Mitigating SARS-CoV-2 transmission in Hispanic and Latino communities—Prince William Health District, Virginia, June 2020. *J Racial Ethn Health Disparities*. (2022) 9:390–8. doi: 10.1007/s40615-021-00968-y

21. Alarcon J, Khan TV. Adapting backpack medicine in COVID-19 response for people experiencing homelessness in Southern California. *Am J Public Health*. (2021) 111:58–61. doi: 10.2105/AJPH.2020.305956

22. Murphy M, Dhrolia I, Zanowick-Marr A, Tao J, Coats CS, Napoleon S, et al. A community-adapted approach to SARS-CoV-2 testing for medically underserved populations, Rhode Island, USA. *Emerg Infect Dis*. (2021) 27:2445–9. doi: 10.3201/eid2709.204874

23. Aranda-Díaz A, Imbert E, Strieff S, Graham-Squire D, Evans JL, Moore J, et al. Implementation of rapid and frequent SARS-CoV2 antigen testing and response in congregate homeless shelters. *PLoS One*. (2022) 17:e0264929. doi: 10.1371/journal.pone.0264929

24. Barry K, McCarthy M, Melikian G, Almeida-Monroe V, Leonard M, De Groot AS. Responding to COVID-19 in an uninsured Hispanic/Latino community: testing, education and telehealth at a free clinic in Providence. *R I Med J*. (2020) 103:41–6.

25. Bigelow BF, Saxton RE, Flores-Miller A, Mostafa HH, Loss MJ, Phillips KH, et al. Community testing and SARS-CoV-2 rates for Latinxs in Baltimore. *Am J Prev Med*. (2021) 60:e281–6. doi: 10.1016/j.amepre.2021.01.005

26. Chan J, Burke K, Bedard R, Grigg J, Winters J, Vessell C, et al. COVID-19 in the new York City jail system: epidemiology and health care response, march-April 2020. *Public Health Rep*. (2021) 136:375–83. doi: 10.1177/0033354921999385

27. Chidavaenzi NZ, Agathis N, Lees Y, Stevens H, Clark J, Reede D, et al. Implementation of a COVID-19 screening testing program in a rural, tribal nation: experience of the San Carlos Apache tribe, January-February 2021. *Public Health Rep*. (2022) 137:220–5. doi: 10.1177/00333549211061770

28. Corwin C, Sinnwell E, Culp K. A mobile primary care clinic mitigates an early COVID-19 outbreak among migrant farmworkers in Iowa. *J Agromed*. (2021) 26:346–51. doi: 10.1080/1059924X.2021.1913272

29. Dunne EM, Morgan E, Wells-Moore B, Pierson S, Zakroff S, Haskell L, et al. COVID-19 outbreaks in correctional facilities with work-release programs - Idaho, July-November 2020. *MMWR Morb Mortal Wkly Rep*. (2021) 70:589–94. doi: 10.15585/mmwr.mm7016a3

30. Eliaz A, Blair AH, Chen YH, Fernandez A, Ernst A, Mirjahangir J, et al. Evaluating the impact of language concordance on coronavirus disease 2019 contact tracing outcomes among Spanish-speaking adults in San Francisco between June and November 2020. *Open Forum Infect Dis*. (2022) 9:ofab612. doi: 10.1093/ofid/ofab612

31. Galletly CL, Lechuga J, Dickson-Gomez JB, Glasman LR, McAuliffe TL, Espinoza-Madrigal I. Assessment of COVID-19-related immigration concerns among Latinx immigrants in the US. *JAMA Netw Open*. (2021) 4:e2117049. doi: 10.1001/jamanetworkopen.2021.17049

32. Ghinai I, Davis ES, Mayer S, Toews KA, Huggett TD, Snow-Hill N, et al. Risk factors for severe acute respiratory syndrome coronavirus 2 infection in homeless shelters in Chicago, Illinois-March-May, 2020. *Open Forum Infect Dis*. (2020) 7. doi: 10.1093/ofid/ofaa477

33. Gibson B. NCCHC survey yields insights into COVID-19 in U.S. correctional facilities. *J Correct Health Care*. (2020) 26:204–6. doi: 10.1177/1078345820947694

34. Hershow RB, Segaloff HE, Shockey AC, Florek KR, Murphy SK, DuBose W, et al. Rapid spread of SARS-CoV-2 in a state prison after introduction by newly transferred incarcerated persons - Wisconsin, august 14-October 22, 2020. *MMWR Morb Mortal Wkly Rep*. (2021) 70:478–82. doi: 10.15585/mmwr.mm7013a4

35. Imbert E, Kinley PM, Scarborough A, Cawley C, Sankaran M, Cox SN, et al. Coronavirus disease 2019 (COVID-19) outbreak in a San Francisco homeless shelter. *Clin Infect Dis*. (2020) 73:324–7. doi: 10.1093/cid/ciaa1071

36. Kerkhoff AD, Sachdev D, Mizany S, Rojas S, Gandhi M, Peng J, et al. Evaluation of a novel community-based COVID-19 'Test-to-Care' model for low-income populations. *PLoS One*. (2020) 15:e0239400. doi: 10.1371/journal.pone.0239400

37. Matthew OO, Monahan PF, Luque JS. The novel coronavirus and undocumented farmworkers in the United States. *New Solut*. (2021) 31:9–15. doi: 10.1177/1048291121989000

38. Molyneux K, Kaur K, Kona N, Santos Malave G, Baranowski KA, Singer EK, et al. 95 experiences of detained asylum seekers during the COVID-19 pandemic. *Ann Emerg Med*. (2021) 78:S44. doi: 10.1016/j.annemergmed.2021.07.097

39. Natoli LJ, Vu KL, Sukhija-Cohen AC, Engeran-Cordova W, Maldonado G, Galvin S, et al. Incarceration and COVID-19: recommendations to curb COVID-19 disease transmission in prison facilities and surrounding communities. *Int J Environ Res Public Health*. (2021) 18:9790. doi: 10.3390/ijerph18189790

40. Nelson B, Kaminsky DB. A COVID-19 crisis in US jails and prisons. *Cancer Cytopathol*. (2020) 128:513–4. doi: 10.1002/cncy.22335

41. Pirraglia PA, Torres CH, Collins J, Garb J, Kent M, McAdoo SP, et al. COVID-19 mitigation for high-risk populations in Springfield Massachusetts USA: a health systems approach. *Int J Equity Health*. (2021) 20:230. doi: 10.1186/s12939-021-01567-3

42. Rocha LP, Rose R, Hoch A, Soares C, Fernandes A, Galvão H, et al. The impact of the COVID-19 pandemic on the Brazilian immigrant community in the U.S: results from a qualitative study. *Int J Environ Res Public Health*. (2021) 18. doi: 10.3390/ijerph18073355

43. Qureshi N, Cardenas C, Tran ND, Henderson SO. Implementation of a COVID-19 infection control plan in a large urban jail system. *Public Health Rep*. (2022) 137:442–8. doi: 10.1177/00333549221076551

44. Rogers JH, Link AC, McCulloch D, Brandstetter E, Newman KL, Jackson ML, et al. Characteristics of COVID-19 in homeless shelters: a community-based surveillance study. *Ann Intern Med*. (2021) 174:42–9. doi: 10.7326/M20-3799

45. Singer EK, Molyneux K, Kaur K, Kona N, Malave GS, Baranowski KA. The impact of immigration detention on the health of asylum seekers during the COVID-19 pandemic. *SSM Qual Res Health*. (2022) 2:100072. doi: 10.1016/j.ssmqr.2022.100072

46. Stadnick NA, Cain KL, Oswald W, Watson P, Ibarra M, Lagoc R, et al. Co-creating a theory of change to advance COVID-19 testing and vaccine uptake in underserved communities. *Health Serv Res*. (2022) 57:149–57. doi: 10.1111/1475-6773.13910

47. Marcom RT, Lambar EF, Rodman B, Thomas G, Watson A, Parrish B, et al. Working along the continuum: North Carolina's collaborative response to COVID-19 for migrant & seasonal farmworkers. *J Agromedicine*. (2020) 25:409–12. doi: 10.1080/1059924X.2020.1815621

48. Wallace M, James AE, Silver R, Koh M, Tobolowsky FA, Simonson S, et al. Rapid transmission of severe acute respiratory syndrome coronavirus 2 in detention facility, Louisiana, USA, may-June, 2020. *Emerg Infect Dis*. (2021) 27:421–9. doi: 10.3201/eid2702.204158

49. Winterbauer E, Levy PD, Calhoun D, Elwell T, Fishbein E, Donohue S, et al. Qualitative review of promising practices for testing vulnerable populations at off-site COVID-19 testing centers. *Healthc*. (2021) 9:100519. doi: 10.1016/j.hjdsi.2021

50. Tosh SR, Berg UD, Leon KS. Migrant detention and COVID-19: pandemic responses in four New Jersey detention centers. *J Migrat Hum Secur*. (2021) 9:44–62. doi: 10.1177/23315024211003855

51. Towns R, Corbie-Smith G, Richmond A, Gwynne M, Fiscus L. Rapid deployment of a community-centered mobile Covid 19 testing unit to improve health equity. *NEJM Catal Innov Care Deliv*. (2020). doi: 10.1056/CAT.20.0522

52. Wilkins CH, Friedman EC, Churchwell AL, Slayton JM, Jones P, Pulley JM, et al. A systems approach to addressing Covid-19 health inequities. *NEJM Catal Innov Care Deliv*. (2021) 2:1. doi: 10.1056/CAT.20.0374

53. Lauzardo M, Kovacevich N, Dennis A, Myers P, Flocks J, Morris JG Jr. An outbreak of COVID-19 among H-2A temporary agricultural workers. *Am J Public Health*. (2021) 111:571–3. doi: 10.2105/AJPH.2020.306082

frontiers | Frontiers in Public Health

TYPE Perspective
PUBLISHED 29 September 2023
DOI 10.3389/fpubh.2023.1208615

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Margaret Haworth-Brockman,
University of Manitoba, Canada
W. K. Chow,
Hong Kong Polytechnic University, Hong Kong SAR, China

*CORRESPONDENCE
Chao Wang
✉ chaowang@um.edu.mo

RECEIVED 19 April 2023
ACCEPTED 04 September 2023
PUBLISHED 29 September 2023

CITATION
Shen T and Wang C (2023) Regulating China's health code system to prepare for future pandemics. *Front. Public Health* 11:1208615. doi: 10.3389/fpubh.2023.1208615

Regulating China's health code system to prepare for future pandemics

Taixia Shen[1] and Chao Wang[2]*

[1]Law School & Intellectual Property School, Jinan University, Guangzhou, China, [2]Faculty of Law, University of Macau, Taipa, Macau, China

This study investigates the challenges that China's health code system presents to individuals' lives and social development, using normative analysis and a case study. It looks for effective strategies to reform and regulate this system to prepare for future pandemics. Health code apps and mini programs have been widely deployed as effective tools for COVID-19 containment in China. However, their widespread and improper use has created risks due to the lack of both a systematic design and a basic supervision mechanism. The health code system risks infringing on individual privacy during data collection and storage. During the pandemic, the right to liberty and the right to treatment of Chinese citizens who lacked an appropriate health code were severely compromised. In some instances, the health code system was used as a stability maintenance tool by the authorities through arbitrary health code conversions. This article argues that China's health code systems should be reformed and regulated in preparation for future pandemics and that a new act regulating its management and use should be launched at the national level. Data collection, retention, and processing should be limited to the minimum amount of data needed to achieve the objective of protecting public health. The health code conversion power wielded by the authorities should be defined and regulated, the rules and procedures of code conversion should be transparent, arbitrary health code conversion behaviors should be prevented and punished, and persons whose rights have been violated by wrongful code conversion should have access to legal remedies.

KEYWORDS

China's health code system, future pandemics, rule of law, human rights, algorithmic governance, public health

1. Introduction

During the novel coronavirus pneumonia (COVID-19) pandemic, various levels of the Chinese government collaborated with high-tech companies to implement a health code system that would control the spread of the virus. This data-powered system controls and traces people's contacts by utilizing mobile phone positioning data to generate a quick medical response code that indicates an individual's health status. Health codes are dynamic codes accessed via mobile phone apps or mini-programs. They are automatically generated and checked by local government systems using both information from users' self-declarations and disease control-related big data. To obtain a code, applicants are required to visit the sign-up page of a relevant app or mini-program and provide personal information such as their name, national identity or passport number, and phone number. They are also

required to report their travel history and any possible contact with confirmed or suspected COVID-19 patients within the past 14 days, as well as symptoms such as fever, fatigue, a dry cough, a stuffy nose, or a sore throat. Once the authorities verify this information, each user is assigned a quick-response code indicating their health status: red (high risk), amber (potentially infectious), or green (low risk) (1). This system gradually became one of the most useful and powerful digital tools available for epidemic prevention and control. In addition, China's everyday use of the health code system connected app users to data systems that synthesized social information from the authorities responsible for public health, public transportation, border control, and community governance, ultimately facilitating the nationwide restoration of economic and social order (2). However, the implementation of China's health code system had a profound impact on individuals' rights and lives. Everyone had to show their codes at shops, stations, parks, airports, libraries, and other public places. The movements of individuals without a green health code were restricted. The color of a person's health code could even determine their living situation. For instance, individuals assigned a red code were required to promptly arrange for transfer to an isolation hotel or to self-isolate at home for 14 days under China's COVID-19 prevention and control measures. Due to the widespread and improper use of this health code system, individual privacy and personal rights were greatly compromised.

At the end of November 2022, China's central government finally relented and began shifting away from its almost 3-year-long hyper-restrictive "zero-COVID-19" strategy. The release of 10 new measures to optimize China's COVID-19 response sharply decreased the number of situations in which the health codes were used. For instance, a green health code was no longer needed to enter shops, use public transportation, or travel to another city within China (3). With China's adjustments to its COVID-19 measures, the issue of whether the widely used health codes should be eliminated altogether has caused heated debate. Given the precedent that the system created for abuse and the risks it posed to personal rights, some experts have argued that the health code system should be abandoned. For instance, Wang (4) argued that the health code system should be completely withdrawn following the cessation of pandemic controls. However, other experts have suggested that the health code system should be transformed from a management tool into a service utility. For example, the system could be used as an identification credential for medical services such as appointments, registration, prescriptions, and payment (5).

This article explores the main challenges that China's health code system poses to personal rights and interests and examines whether this system should be withdrawn completely or reformed and regulated to prepare for future epidemics. The remainder of the paper is organized as follows. Section 2 examines how the health code system challenged individuals' fundamental rights and interests during the COVID-19 pandemic. Section 3 discusses whether the system should be abandoned completely. Section 4 argues that the health code system should be regulated and normalized to prepare for future pandemics, and Section 5 draws conclusions based on the study's findings.

2. Challenges posed by China's health code system to individuals' rights and interests

2.1. Privacy issues in China's health code system

The health code system's challenges related to data security and personal information have been recognized by the central government. The Data Security Law (DSL) of the People's Republic of China (PRC) and the Personal Information Protection Law (PIPL) of the PRC were passed in 2021 to regulate the processes of collecting and using personal data and to protect personal privacy. These laws imposed stricter requirements for the protection of personal information during health code use than in the past.

Before the DSL and the PIPL, the Cyber Security Law (CSL) of the PRC, which was passed in December 2016, set rules for information collection and management. Article 5 of the PIPL establishes the principles of information use whereby the handling of personal information shall follow the principles of lawfulness, fairness, necessity, and good faith. Article 6 reaffirms that the collection of personal information shall be kept to a minimum scope and that the information shall be used for processing purposes; excessively collecting personal information shall not be allowed. However, there is no definition of the minimum scope of collecting personal information. In response to the outbreak of COVID-19, the government launched a health code system requiring users to provide their name, gender, mobile phone number, ID number, and other information. This system posed a great threat to personal privacy and information. Its main problems are highlighted in the following paragraphs.

First, consent is greatly devalued when personal information is collected to generate health codes. When registering with the system, users must click to agree to the system's user service agreement and privacy policy, which seems to indicate recognition of the principle of informed consent. In reality, however, the principle of informed consent is not upheld, as individuals cannot obtain a health code without consenting to the collection of personal information, causing them great inconvenience during travel.

Second, there is no effective safety management mechanism related to the system's control and storage of information. When information is disseminated through platforms such as WeChat and QQ, it is stored by commercial companies rather than in government databases, greatly compromising confidentiality and security. In such circumstances, information can flow rapidly, and when there are no identity-related safeguards pertaining to users viewing that information and no restrictions on the transfer of files between users, the information is more likely to leak than it would be otherwise (6). Reports have indicated that epidemic prevention and control departments at all levels in China unintentionally leaked and spread statistical personal privacy information during the COVID-19 pandemic (7). For example, there was an incident in which numerous celebrities' photos and ID information kept by the Beijing health code system were leaked and sold online (8).

In addition, personal location information is collected and provided to epidemic prevention and control departments,

transportation providers, shopping malls, parks, schools, restaurants, and other public institutions. This means that the personal whereabouts of individuals are collected and recorded by the site code (which is one branch of the health code). The reason given for the collection of this information is that the health code system also incorporates civil aviation, railway, bus, and other traffic data; telecommunications operator data; and financial institution and payment data. Through data analysis, citizens' travel patterns can be determined and high-risk groups can be identified (9). As a result, the health code system became a powerful tool for tracking COVID-19 in China. Although this system improved administrative efficiency, its information collection and application processes create major risks (10).

Overall, there are many hidden privacy hazards in China's health code system due to its lack of institutional construction and its collection, storage, and disposal of massive amounts of basic and sensitive personal information.

2.2. The health code system and the right to liberty

Initially, the health code system was launched to facilitate citizens' rapid and safe movement during an emergent and abnormal period. In reality, the right to free movement greatly depends on the color of a person's health code. Different colors indicate different degrees of the right to liberty. People with green health codes enjoy a complete right to liberty, whereas people with red codes are required to immediately quarantine for 14 days, and their right to liberty is greatly restricted. People with yellow health codes cannot enter public places until their code color changes to green. Under the health code system, people without a green code are not allowed to enter public places, including parks, nor are they permitted to go to other countries, cities, or towns. Consequently, individuals' right to liberty is severely restricted by the health code system.

The sacrifice of some people's right to liberty in the interest of public health is somewhat acceptable to most Chinese people. However, both the absence of transparency in the coding rules and inaccurate coding violate individuals' right to liberty, along with other related rights and interests (11). Crucially, the right to liberty is the basis of other rights.

An extreme case of a rights violation that aroused public outrage was the "red code incident" in June 2022. Depositors of rural banks in Henan province, along with depositors in other provinces, such as Shandong, were assigned red health codes that prevented them from withdrawing their funds from Henan banks (12). According to statistics provided by the Zhengzhou Discipline Inspection Commission, 1,317 village and town bank depositors were assigned red codes in this incident. Of those depositors, 446 were assigned red codes when they entered Zhengzhou, and 871 who remained outside Zhengzhou were assigned red codes when they scanned a site code that others had sent to them (13).

2.3. The health code system and the right to treatment

The right to treatment is also closely connected with China's health code system. Theoretically, ordinary patients who were not infected with the SAR-CoV-2 virus should have enjoyed the right to timely and effective diagnosis, treatment, and rehabilitation during the epidemic prevention period. During the period of COVID-19 prevention and control, appropriate basic medical and health services should have been available and accessible. However, the ordinary patient's right to treatment was denied or interfered with if they did not have a green health code and had not received a negative nucleic acid certificate in the previous 24 or 48 hours. In one case, a woman in Xi'an had a miscarriage after being refused timely admission to Xi'an Gaoxin Hospital because her nucleic acid test results had expired (14).

Article 30 of the Regulation on the Administration of Medical Institutions of the PRC and Article 27 of the Law on Doctors of the PRC indicate that medical institutions must provide immediate treatment to critically ill patients. However, the Joint Prevention and Control Mechanism of the State Council released a notice on the technical guidelines for the prevention and control of novel coronavirus infection in medical institutions (third edition) on September 8, 2021. This notice claimed that medical institutions must make nucleic acid testing compulsory among key groups of newly hospitalized patients, accompanying persons, and staff (15). Based on this notice, local hospitals could only admit patients who had obtained a certificate of a negative result from the new coronavirus nucleic acid test no more than 24 or 48 hours prior to admission. As a result, the health code system restricted the right to treatment during the pandemic.

3. Should the health code system be abandoned?

Although it is obvious that the health code system has facilitated pandemic control and economic recovery in China, it has limitations. First, there have been problems involving the collection of huge amounts of personal data, including sensitive and basic private information. Second, the system has restricted individuals' right to liberty, right to treatment, and related rights and interests. In this context, the development of digital technologies may have strengthened authoritarian control by facilitating a wide range of human rights abuses (16). However, proposals to abolish the health code system across China are overly simplistic.

This article argues that China's health code system should be regulated and reformed rather than simply abolished. The primary bases for this argument are as follows.

First, the abolition of the health code system across China could cause wasted spending for local governments, at least to a degree. Local governments have spent a substantial amount of money on the establishment and normal running of the health code system. If China were to abolish the health code system, the need to establish new health codes in the event of future pandemics would incur further unnecessary costs for local governments.

FIGURE 1
(A) Yuesheng Shi mini-program. **(B)** Zhejiang health code mini-program.

Second, the abolition of health codes across China could have negative effects on other government services and functions. All of the data related to the codes must be deleted or destroyed if the health code system is abandoned, according to the PIPL. However, different provinces use different platforms for the health code systems. In some provinces and cities, health code apps/mini-programs are embedded in apps/mini-programs used for other services, such as the Yuekang code (the health code of Guangdong province), which is embedded in in the Yuesheng Shi mini-program. Other provinces' health codes are separate mini-programs, such as the Zhejiang health code. Data stored on the first type of health code platform may be more difficult to delete than data stored on the second type of platform, as deleting health-code-related data in that situation may affect the operation of other government functions (17). Figure 1 shows the differences between the Yuekang code embedded in the Yuesheng Shi mini-program and the Zhejiang health code's mini-programs on WeChat.

Third, it would be counterproductive to abolish the health code system, as it has completed a transformative upgrade in some cities and provinces. Some areas have added functions related to fever clinic inquiries, medical appointments, medication services, and transportation services to their original platforms, thus transforming the health code into a government service code. For instance, on December 19, 2022, Beijing launched its trial operation of the Jingtong mini-program, which integrated the "Beijing Pass" (a mini-program providing public services such as housing, accumulation funds, social security, and cards to enter Beijing) and the Beijing health code (Figure 2A). Citizens can choose whether to voluntarily extend the personal identity verification information they have provided under the Beijing health code to the Jingtong page. Figure 2B illustrates the integration of the Beijing Pass and the Beijing health code in the Jingtong mini-program. In addition, the Hainan provincial health code not only provides "one-code access" to Haikou Bus services but also connects users with a number of duty-free shops (18).

4. Can China's health code system be reformed to prepare for future pandemics?

During the COVID-19 pandemic, China's health code system has sacrificed some fundamental rights, such as the right to privacy, the right to liberty, and the right to treatment, on the grounds of protecting the public interest. The system's legal offenses and rights violations should be rectified, and the system should be regulated.

FIGURE 2
(A) Beijing health code. **(B)** Jingtong mini-program.

4.1. Legally upgrading the health code system for future pandemics

The travel history code was simultaneously removed from all platforms on December 13, 2022, and all traffic history and related data were also deleted (19). Several Yuekang code services, such as service portals for the older adult and young children, health declarations, and pandemic prevention workstations, recently closed, and all of the data collected for these services were taken offline and slated for destruction to protect individuals' personal information. However, the Yuekang code system remains operational (20). This is a good example of how to adjust the health code system consistent with the PIPL and national epidemic policy.

It is worth noting that in some provinces and cities, such as Hainan, Gansu and Beijing, local authorities have expanded the health code's functionality beyond pandemic control. The health code now encompasses scanning health codes, nucleic acid testing, and vaccination and governmental services, extending its functions to areas such as health care, transportation, and tourism. In a survey of adult health code app users aged 18 and above in the two major Chinese cities of Wuhan and Hangzhou, almost four out of 10 users supported the extensive use of health code apps, while the voices calling for restrictions or abolition were minimal (21). However, the issues of whether and how to upgrade or transform the health code system remain contentious in academic circles. Some scholars have argued that the health code system, as a special tool created in response to the unique needs and conditions of COVID-19 control, should be terminated. However, others have argued that the health code offers an important opportunity to upgrade both governance and public services in a post-pandemic society (22). One viewpoint suggests that the health code could be expanded by incorporating additional features such as online consultations, medical appointments and other public services. Another has proposed transforming the health code into a separate health care service code or public service code, thereby eliminating the original system (23). This article argues that any upgrade to the health code system should undergo scrutiny to ensure its compliance with the law. First, basic personal information such as names, IDs, and telephone numbers should be retained and protected by the health code system. However, information obtained from health declarations and COVID-19 prevention workstations should be deleted pursuant to the PIPL and related legislation on the information and data management field. Second, the algorithms and criteria used to determine an individual's health

code should be legally and transparently established, as they greatly impact personal liberties and rights, such as the right to personal information, the right to privacy, and the right to know (24). Third, effective and accessible mechanisms should be implemented to allow individuals to appeal decisions and rectify errors or unfair assessments. These features would enhance the system's fairness, effectiveness, credibility, and respect for human rights and the rule of law.

Overall, the health code should be upgraded to a comprehensive code based on essential personal information, encompassing both the existing health code system and other public services like transportation, housing, and social security. However, personal information such as users' gender and age that will not be necessary for future pandemic control should be removed. If local governments decide to retain or update the health code system, it will be crucial to ensure their compliance with the relevant laws. Additionally, the new comprehensive code built upon the health code should not be mandatory, and thus individuals would have the freedom to choose whether to use it. In the event of future pandemics, it will be simple and convenient to widely utilize the upgraded health code.

4.2. Regulating the health code system at the national level

While retaining the health code system is a good way to prepare for a possible recurrence of the pandemic, considering the level of chaos during the process of creating local regulations on health codes, this article argues that the health code system should be regulated at a national level in future pandemics. The main reasons are set forth below.

First, current national laws regulating data and information use are still too vague to deal with the challenges posed by the health code system to personal privacy and other fundamental rights. Some Chinese laws, such as the CSL, the DSL, and the PIPL, have established principles of information use such as lawfulness, fairness, necessity, and good faith. Article 6 of the PIPL affirms that the collection of personal information shall be limited to the minimum scope necessary for processing and that the excessive collection of personal information shall not be allowed. However, it does not clearly define these terms or provide specific guidelines for defining the minimum necessary scope of collection or excessive collection. Article 19 of the PIPL stipulates that the retention period for personal information shall be the shortest time necessary to achieve the processing purpose, except as otherwise provided by any law or administrative regulation. However, it does not define or explain the shortest time necessary to achieve the processing purpose (25).

Furthermore, according to Article 8 (5) of the Legislation Law of the PRC, the health code system, which is intrinsically related to citizens' fundamental rights and freedoms, should be regulated by national laws. Nevertheless, the interim measures for the management of the health codes launched by central and local governments create the risk of excessive authority. In addition, the Interim Measures for the Management and Services of Health Codes for the Prevention and Control of the New Coronavirus Pneumonia Epidemic passed in January 2021, and local measures regulating the health code system suggested principled requirements for coding rules and data protection (26). However, there are no specific provisions addressing the rights and responsibilities related to health code management.

4.3. The main content of the health code system act for future pandemics

This article admits that the content and specific provisions of the health code bill or act of the PRC require clear and rigorous elucidation. They must at least address the following main points.

The PLPL provides no clear definition of either the minimum necessary scope or excessive collection related to the process of personal information collection. Thus, providing a clear scope of personal information collection for the upgraded health code system is a top priority.

Increasing the transparency of health code use and management rules is also vital. The vast majority of Chinese citizens have no idea where their health code-related information is stored or whether it is secure, and they do not know the details of the code conversion rules. Therefore, the law should regulate the operation and management of health codes, and the code conversion rules should be made transparent.

In addition, the laws should establish a relief system entitling the public to seek redressal from the relevant departments or judicial bodies if their rights have been violated through the misuse or misapplication of health codes.

5. Conclusions

Although China's health code system has aided the containment of COVID-19, it has also presented considerable challenges to the personal privacy, right to liberty, and right to treatment of its citizens due to the excessive collection, mishandling, and misuse of their personal data (24). In the long run, regulating China's health code system at the national level will help the nation to prepare for future pandemics. The process of health code application, information and data collection and storage rules, code conversion rules, and a relief system should be the main provisions of such legislation. Like all kinds of technologies, digital health codes systems have advantages and disadvantages and must be regulated. Humans and human rights should be placed at the center of pandemic prevention and control, and protecting and respecting those rights should be considered of primary importance.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

TS and CW contributed to the conception of the study and the writing, reviewing, and editing of the paper. All authors contributed to the manuscript revision and they read and approved the submitted version.

Funding

This paper was the result of the research project On the legal protection mechanism of the free movement of persons in the Guangdong–Hong Kong–Macao Greater Bay Area, which was funded by the National Social Science Fund of China Project (grant number: 22FFXB052).

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

References

1. Shen T, Wang C. Big data technology applications and the right to health in China during the COVID-19 pandemic. *Int J Environ Res Public Health*. (2021) 18:7325. doi: 10.3390/ijerph18147325

2. Huang G, Hu A, Chen W. Privacy at risk? Understanding the perceived privacy protection of health code apps in China. *Big Data Soc*. (2022) 9. doi: 10.1177/20539517221135132

3. The State Council Information Office of China. *COVID-19 Response Further Optimized with 10 New Measures*. (2022). Available online at: http://english.scio.gov.cn/pressroom/2022-12/08/content_78556582.htm (accessed February 1, 2023).

4. Wang X. *Health Code Must be Completely Withdrawn*. Shanghai Fazhi Bao (December 23, 2022). Available online at: http://www.shfzb.com.cn/html/2022-12/23/node_3407.html (accessed January 9, 2023).

5. Wu X. *Opinion: Why China's COVID Health Codes should be Abandoned*. (2022). Available online at: https://www.caixinglobal.com/2022-12-23/opinion-why-chinas-covid-health-codes-should-be-abandoned-101981373.html (accessed January 9, 2023).

6. Liu C, Graham R. Making sense of algorithms: relational perception of contact tracing and risk assessment during COVID-19. *Big Data Soc*. (2021) 8:1–13. doi: 10.1177/2053951721995218

7. Gao Y. To prevent and control the epidemic, it is more important to protect personal information. *Huanqiu net*. (2020). Available online at: https://opinion.huanqiu.com/article/9CaKrnKqYGM (accessed October 17, 2021).

8. Hongxin News. *Celebrities' Photos of Jian Kang Bao were Leaked, 70 Photos were Packaged for 2 Yuan, and 1000 Artist ID Numbers were Bought for 1 Yuan*. (2020). Available online at: http://news.chengdu.cn/2020/1228/2173698.shtml (accessed December 12, 2020).

9. Yang F, Heemsbergen L, Fordyce R. Comparative analysis of China's health code, Australia's COVID Safe and New Zealand's COVID tracer surveillance apps: a new corona of public health governmentality? *Media Int Aust*. (2021) 178:183–97. doi: 10.1177/1329878X20968277

10. Ao S, Wang T. Research progress of the health code in China in the post-COVID-19 era. *J Emerg Manag Disaster Commun*. (2022) 3:41–56. doi: 10.1142/S2689980922310017

11. Fang X, Yan F. *Research on the Challenges of Digital Social Governance behind Health Codes*. People's Forum: Academic Frontiers. (2020) 16:78–91. doi: 10.16619/j.cnki.rmltxsqy.2020.30.026

12. Xu W, Costaglione F. Health codes of depositors at Henan's rural banks mysteriously turn red again. *Yicai Global*. (2022). Available online at: https://www.yicaiglobal.com/news/health-codes-of-depositors-at-henan-rural-banks-mysteriously-turn-red-again (accessed March 4, 2023).

13. Shi Q, Zhang Y. Henan health code discoloration warning. *China Economic Weekly*. (2022) 12:52–5. Available online at: http://www.ceweekly.cn/2022/0630/388493.shtml (accessed January 24, 2023).

14. Zhang X. Xi'an punishes personnel responsible for accidental miscarriage during COVID lockdown. *China Daily*. (2022). Available online at: https://www.chinadaily.com.cn/a/202201/06/WS61d69134a310cdd39bc7f82b.html (accessed January 22, 2022).

15. The Joint Prevention and Control Mechanism of the State Council of China. *Notice on the Technical Guidelines for the Prevention and Control of Novel Coronavirus Infection in Medical Institutions*, 3rd ed. China's State Council. (2021). Available online at: http://www.gov.cn/xinwen/2021-09/14/content_5637141.htm (accessed February 1, 2023).

16. Dragu T, Lupu Y. Digital authoritarianism and the future of human rights. *Int. Organ*. (2021) 75: 991–1017. doi: 10.1017/S0020818320000624

17. Yao J, Guo L. Will the offline part of the "Yuekang Code" be the precursor of the offline of health codes in other cities? *Caijing Magazine*. (2023). Available online at: http://yuanchuang.caijing.com.cn/2023/0214/4917680.shtml (accessed March 4, 2023).

18. Wang H. The epidemic ends basically, are the health codes completely deleted or upgraded? *Yixue Jie net*. (2022). Available online at: https://www.yxj.org.cn/detailPage?articleId=365969 (accessed February 2, 2022).

19. China to end use of digital travel code starting Tuesday. *Xinhua net*. (2022). Available online at: https://english.news.cn/20221212/0925bd8836f7437c8aee7ce4db505e06/c.html (accessed March 4, 2023).

20. Hamer LJ. *Guangdong Health Code Officially goes Offline, JY International Cultural Communications Group Magazines*. (2023). Available online at: https://www.thatsmags.com/china/post/35668/guangdong-health-code-officially-goes-offline (accessed January 2, 2023).

21. Chen W, Huang G, Hu A. Red, yellow, green or golden: the post-pandemic future of China's health code apps. *Inf Commun Soc*. (2022) 25:1–16. doi: 10.1080/1369118X.2022.2027502

22. Cong W. From pandemic control to data-driven governance: the case of China's health code. *Front Polit Sci*. (2021) 3:627959. doi: 10.3389/fpos.2021.627959

23. Huang H, Wang Z, Wu Y. Deletion, destroy or transformation, what will be the health codes? *Southern Metropolis Daily* (March 18, 2023). Available online at: https://epaper.oeeee.com/epaper/A/html/2023-03/18/content_5181.htm#article (accessed July 6, 2023).

24. Zhang X. Decoding China's COVID-19 health code apps: the legal challenges. *Healthcare*. (2022) 10:1479. doi: 10.3390/healthcare10081479

25. Wang C, Shen T. China's new legislation on personal information protection in light of the COVID-19 pandemic. *JI CL*. (2022) 9:109–24.

26. Guan B. Research on the administrative law status of carry-on code in big data intelligence era. *Trib Polit Sci Law*. (2022) 40:14–27.

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 12 October 2023
DOI 10.3389/fpubh.2023.1212825

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Sally Moyce,
Montana State University, United States
Ana F. Abraido-Lanza,
Columbia University, United States

*CORRESPONDENCE
Brendon Bhagwandeen
✉ b.bhagwandeen@hw.ac.uk

RECEIVED 27 April 2023
ACCEPTED 29 September 2023
PUBLISHED 12 October 2023

CITATION
Lyons N and Bhagwandeen B (2023) Examining healthcare needs and decisions to seek health services among Venezuelan migrants living in Trinidad and Tobago using Andersen's Behavioral Model.
Front. Public Health 11:1212825.
doi: 10.3389/fpubh.2023.1212825

Examining healthcare needs and decisions to seek health services among Venezuelan migrants living in Trinidad and Tobago using Andersen's Behavioral Model

Nyla Lyons[1] and Brendon Bhagwandeen[2]*

[1]Medical Research Foundation of Trinidad and Tobago, Port of Spain, Trinidad and Tobago, [2]School of Mathematical and Computer Sciences, Heriot-Watt University Malaysia, Putrajaya, Malaysia

Introduction: Beginning in 2016, Trinidad and Tobago experienced increasing flows of migrants and refugees from Venezuela. Through a Government Registration Exercise in 2019, followed by a Re-registration Exercise in 2020, migrants and refugees benefitted from access to publicly available primary care and emergency medical services. By applying Andersen's Behavioral Model for Health Service Use, our study examined the non-communicable disease care needs of migrants, and factors influencing their decision to seek public and private health services.

Method: Between September and December 2020, a health questionnaire was administered via telephone to $n = 250$ migrants from Venezuela. Descriptive statistics summarized the constructs of Andersen's Behavioral Model. The model comprised of predisposing factors including migrants' social characteristics; enabling factors namely monthly earnings, education level and most trusted source of information on medical needs; need for care factors such as migrants self-reported health status, presence of non-communicable health conditions and having visited a doctor in the past 12 months; and the outcome variables which were migrants' decisions to seek public and private health services. Pearson χ^2 tests, odds ratios and multivariable logistic regression with backward elimination examined the factors influencing a migrant's decision to seek health services.

Results: Overall, 66.8% of migrants reported they would seek public health services, while 22.4% indicated they would seek private health services. Predisposing factors namely length of time residing in Trinidad and Tobago ($p = 0.031$) and living with family/friends ($p = 0.049$); the enabling factor of receiving information from publicly available sources ($p = 0.037$); and the need for care factor of visiting a doctor for a physical health problem ($p = 0.010$) were significant correlates of their decision to seek care in the public sector. Predisposing factors namely living with family/friends ($p = 0.020$) and the enabling factor of having difficulty accessing healthcare services ($p = 0.045$) were significant correlates of their decision to seek care from private providers.

Discussion: Our findings demonstrated the positive association between social networks and a migrant's decision to use public and private health services, thus underscoring the importance of family and friends in facilitating health service use, promoting proper health practices and preventing diseases. Overall, the use of Andersen's Behavioral Model aided in identifying the factors associated with the use of health services by Venezuelan migrants in Trinidad and Tobago. However, further studies are needed to better understand their need for ongoing care, to inform policy, and to plan targeted health interventions for addressing the gaps in health service access, barriers and use.

KEYWORDS

health service use, migrants, Trinidad and Tobago, Venezuelan, Andersen's Behavioral Model

1. Introduction

As of August 2020, the United Nations High Commissioner for Refugees (UNHCR) estimated that 5.4 million Venezuelan refugees and migrants fled their country in search of food, shelter, and healthcare because of ongoing political and economic instability in Venezuela. Up to 85% of Venezuelan refugees and migrants resided in Latin American countries such as Colombia (1.7 million), followed by Peru (870,000), Ecuador (385,000), and Chile (371,000). Many were also seeking safety in the Caribbean, including the countries of Aruba, Curacao, the Dominican Republic, Guyana, and Trinidad and Tobago (1).

Beginning in 2016, Trinidad and Tobago experienced increasing flows of refugees and migrants from Venezuela. By the end of 2017, the UNHCR reported a total of 2,700 refugees seeking asylum and by April 2018, the number of reported refugees increased to over 5,300. By the end of 2019, the UNHCR estimated just over 21,000 refugees and migrants from Venezuela residing in Trinidad and Tobago. This number was expected to increase to 33,400 by the end of 2020 (2). A report by Refugees International in 2019 put the number of Venezuelans on the islands of Trinidad and Tobago at 40,000, giving the highest *per capita* Venezuelan population in the English-speaking Caribbean (2).

Non-communicable diseases (NCDs) represent a significant share of mortality and morbidity among persons residing in Venezuela. In 2021, it was estimated that 18.8 million Venezuelans worldwide lacked access to health services, including 10.4 million who were diagnosed with chronic diseases (3). Conditions surrounding the migration process may increase exposure and vulnerability to NCD risk factors. Upon arrival in host countries, it has been shown that migrants were further exposed to lifestyle risk factors and behavioral changes which increased their risk and vulnerability. Therefore, these circumstances left migrants at a higher risk of developing or worsening existing health conditions (3). Migrants' health might be further compromised because of their healthcare experiences such as language and/or cultural differences, cost of medications, discrimination, xenophobia, and lack of information on where to access health services, thus affecting the continuity of treatment which is critical for many NCDs.

In Trinidad and Tobago, persons in need of international protection remained subject to the provisions of the 1976 Immigration Act. The Government acceded to the 1951 Geneva Convention on the Status of Refugees, and its 1967 Protocol in 2014 (4). In 2020, a draft policy was developed to address the provision of public healthcare services to non-nationals (5), and as of 2023, it is yet to be officially implemented. This intensified challenges for migrants and refugees who already faced barriers getting the care they needed. As a result of public health measures, including the closure of non-essential services and businesses during the most recent pandemic, this was exacerbated and it was reported that Venezuelan refugees and migrants in Trinidad and Tobago were greatly impacted by a loss of income (6), further compromising their access to health services. Currently, there has been no national policy in Trinidad and Tobago consistent with international law and standards governing migrants' access to ongoing healthcare services. In June 2019, in response to the increasing number of refugees and migrants from Venezuela, the Government of the Republic of Trinidad and Tobago conducted a Registration Exercise whereby all refugees and migrants (including those residing illegally) were given an opportunity to obtain "one-year legal status" in the country. Successful registrants were granted one-year work permits and benefitted from access to publicly available emergency medical and primary care services. However, access to secondary and tertiary healthcare remained limited. This was documented in 2020 in the policy for treating with non-nationals for the provision of public health services. Access to ongoing medical care and specialized health services such as the treatment of cancer and for surgeries were not covered in the policy. It was further advised that migrants seeking ongoing medical services and specialized care may do so at their own expense. In March 2020, a Re-registration Exercise was conducted for migrants previously registered in 2019, providing them with a six-month extension (5).

The burden of non-communicable diseases among migrants in Trinidad and Tobago is unclear and moreover, their health needs relating to NCDs are not well understood. The lack of legal documents can prove to be a major barrier to accessing care at public facilities as patients are asked to produce these documents at the registration counter. Workers at the healthcare facilities are required to inform the authorities of undocumented migrants. Despite this, many healthcare workers in public health centers still provided the required care to migrants. On the other hand, private facilities would generally treat patients regardless of their immigration status. However, in both the public and private setting, language and communication were major barriers faced. Therefore, by applying Andersen's Behavioral Model for Health Service Use, this study examined the medical needs of Venezuelan migrants residing in Trinidad and Tobago and the associations between predisposing, enabling and needs factors with their decisions to seek public and private health services. With the advent of public health emergencies such as in the case of the COVID-19 pandemic, health inequalities were exacerbated for refugees and asylum seekers because economic and social hardships left them at risk of worsening health conditions. In addition, the capacities of health systems may be stretched, further compounding issues related to access and use of public health services for refugees and migrant subpopulations. Therefore, this study also had implications for development of a comprehensive national policy prioritizing refuges and integrating the health of refugees and migrants as part of the national response during public health emergencies.

2. Materials and methods

2.1. Analytical framework

Andersen's Behavioral Model for Health Service Use has been applied in several studies in a variety of settings and across populations to assess health seeking behaviors. The model is a well-validated theoretical framework aimed at understanding determinants of health service utilization, taking into account both individual and social determinants (7). The model asserts that access to and use of health services are influenced by three main categories of factors: (1) predisposing factors (social characteristics), (2) enabling factors (resource availability), and (3) need factors (quest for solutions to illness) (8) (Figure 1).

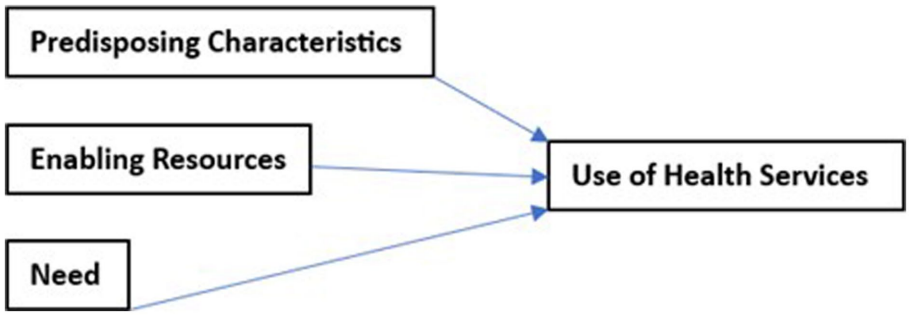


FIGURE 1
General Framework of Andersen's Behavioral Model.

2.2. Study context

The Medical Research Foundation of Trinidad and Tobago (MRFTT) was established in March 1997 as a non-governmental organization (NGO) to investigate the epidemiology of HIV and HTLV-1. It is the largest HIV Treatment and Care Centre in Trinidad and Tobago. In 2002, with the increasing prevalence of HIV/AIDS, the Government of the Republic of Trinidad and Tobago commissioned the MRFTT to deliver prevention programs and treatment to persons diagnosed with HIV. Beginning in 2018, the MRFTT expanded the programs to target migrant subpopulations with non-communicable disease-risk prevention, treatment and management through health outreach activities. Given the inflows of Venezuelan migrants, it was important to examine the health needs and use of health services by this minority subpopulation and understand the extent of diseases and uptake of health services which could assist in reducing new and/or worsening health conditions.

2.3. Study design and participants

This cross-sectional study was carried out from September to December 2020 among Venezuelan migrants residing in Trinidad and Tobago via telephone interviews using a structured questionnaire due to the COVID-19 pandemic restrictions. Each interview was done by one of two trained bilingual nurses. The study was facilitated by the MRFTT.

The study used two sampling strategies since the subpopulation of Venezuelan migrants in Trinidad and Tobago was largely hidden. A convenience sample of migrants was reached from persons responding to flyers with information about the study, that were distributed to a large community-based organization providing refugee support services to Venezuelan migrants. These migrants would then share details of the study for snowball sampling to be used in recruiting further participants. Responses came from a sample of $n = 250$ Venezuelan migrants residing in Trinidad and Tobago. Persons were given the incentive of free health check-ups for participating.

The eligibility criteria included persons of Venezuelan nationality living in Trinidad and Tobago between 3 months and 5 years. Persons meeting the criteria were briefed about the study protocol and were asked to provide their consent to participate. Interviews were conducted in Spanish by the nurses, responses were translated and then recorded in English to a Microsoft Excel spreadsheet stored on a password protected computer. Only members of the research team had access to the data file.

2.4. Study questionnaire and data collection

Guided by Andersen's Behavioral Model for Health Service Use, predisposing factors in our study were social characteristics including age, gender, time since arrival in Trinidad and Tobago, main reason for migration, living alone or with family/friends and having arrived in Trinidad and Tobago alone or with family/friends. Enabling factors explained barriers and facilitators to health service use such as education level, income earned, self-rated English fluency, knowledge of where to access healthcare, having difficulties accessing care and most trusted source of information about medical needs. Need factors were overall self-rated health status, worrying about a diagnosed non-communicable health condition (mental or physical) and having visited a doctor in the past 12 months for a diagnosed non-communicable health condition (mental or physical) as shown in Figure 2. A questionnaire using these factors was developed and translated into Spanish for interviews.

The outcome variables in this study were migrants' decisions to seek public health services and private health services. Public health services included public hospitals, community health centers and emergency medical services. Private health services included private doctors, private hospitals, and pharmacists.

The questionnaire was pre-tested using a convenience sample of migrants selected from persons with similar characteristics to those that were intended to participate in the study. This helped in identifying potential problems in the language, structure and design of the questionnaire. Some minor adjustments were subsequently made to better facilitate the flow of the interview process. Each interview took between 10 and 15 min to complete.

2.5. Statistical analysis

Descriptive statistics for categorical variables were presented as frequencies with percentages and were used to characterize baseline distributions of study variables. Univariate associations between predisposing, enabling and need factors with a migrant's decision to use public and private health services were observed using Pearson χ^2

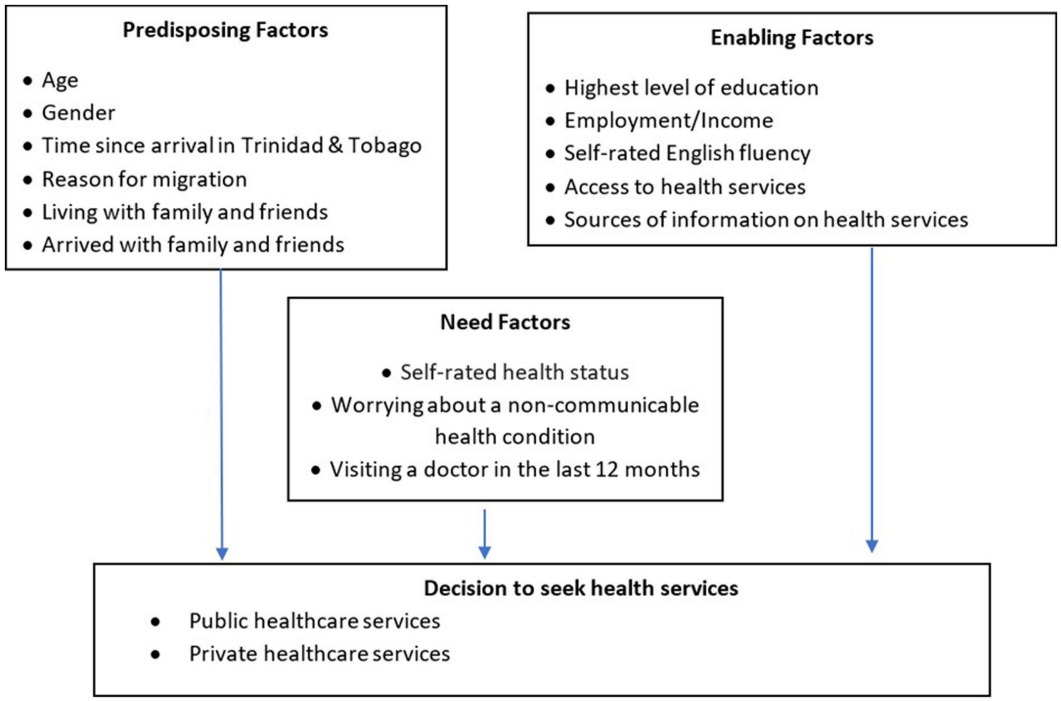


FIGURE 2
Andersen's Behavioral Model for Health Service Use in this study.

tests or Fisher's exact tests where appropriate and unadjusted odds ratios (OR) with 95% confidence intervals (CI). Baseline differences were also compared using Pearson χ^2 tests or Fisher's exact tests. Predisposing, enabling and need factors based on Andersen's Behavioral Model were used in multivariable logistic regression analyses to observe significant correlates and adjusted odds ratios (AOR) for migrants deciding to seek public and private health services in Trinidad and Tobago. Backward elimination was used to select the correlates which best explained their decisions. Statistical significance was set at $p < 0.05$.

2.6. Ethical approval

Permission to conduct this study was granted by the University of the West Indies (UWI) Institutional Review Board (IRB) in September 2020.

3. Results

3.1. Social characteristics and health needs of migrants

Table 1 summarized the social characteristics of the migrants in this study. A total of $n = 250$ Venezuelan migrants residing in Trinidad and Tobago were recruited. Most participants were under 40 years of age ($n = 165$, 66%), female ($n = 149$, 59.6%) and have been residing in Trinidad and Tobago for at least 12 months ($n = 213$, 85.2%). Approximately 90% of the migrants in this study left Venezuela because of economic or political reasons and now live in Trinidad and Tobago with either family or friends. Most of the participants completed formal schooling ($n = 221$, 88.4%), were earning under $1,000 TT each month ($n = 145$, 58%) and self-reported low levels of English fluency ($n = 157$, 62.8%). Chaguanas/Couva ($n = 39$, 15.6%), San Fernando ($n = 47$, 18.8%) and Point Fortin ($n = 33$, 13.2%) were the common areas of residence for these migrants.

Table 2 summarized the health status and health needs of these migrants. Most of the participants believed that they were in "good health" ($n = 152$, 60.8%). Approximately 30% of the participants reported diagnosed mental and physical non-communicable health problems which worried them, with 53 (21.2%) believing that they needed to visit a doctor for their mental health problems, while 113 (45.2%) believed that they needed to visit a physician or health center for their physical health problems. Twenty-nine of the participants in this study (11.6%) had some knowledge of where to access healthcare in Trinidad and Tobago upon arrival, with 78 (31.2%) experiencing difficulties in accessing healthcare since residing in the country. Approximately two-thirds of the migrants ($n = 167$, 66.8%) reported that official healthcare providers were their most trusted sources for information regarding their medical needs. Overall, 167 migrants (66.8%) indicated that they would seek public health services, while 56 (22.4%) would seek private healthcare in Trinidad and Tobago.

3.2. Differences in migrants' decisions to seek public and private health services according to social characteristics

Table 3 summarized the differences in migrants' decisions to seek public and private health services according to their social characteristics.

Significant differences in a migrant's decision to seek public health services were observed when the length of time they resided in

TABLE 1 Social characteristics of migrants.

Variable	*n*	%
Age		
20–29 years	72	28.8
30–39 years	93	37.2
40–49 years	59	23.6
≥50 years	26	10.4
Total	250	100.0
Gender		
Male	101	40.4
Female	149	59.6
Total	250	100.0
Time since migrating to Trinidad and Tobago		
<12 months	37	14.8
≥12 months	213	85.2
Total	250	100.0
Main reason for migration		
Economical/Political	227	90.8
Asylum seeker/Escape violence	11	4.4
Family reunification	12	4.8
Total	250	100.0
Household dynamic		
Lives alone	22	8.8
Lives with family/friends	228	91.2
Total	250	100.0
Education level		
No formal education	29	11.6
Elementary schooling	94	37.6
High school	120	48.0
College/University schooling	7	2.8
Total	250	100.0
Monthly earnings		
<$1,000 TT	145	58.0
$1,000–$3,000 TT	70	28.0
>$3,000 TT	35	14.0
Total	250	100.0
English fluency		
Low	157	62.8
Moderate	81	32.4
High	12	4.8
Total	250	100.0
Approximate area of residence in Trinidad and Tobago		
Arima/Tunapuna/Piarco	15	6.0
Chaguanas/Couva	39	15.6
Mayaro/Rio Claro	23	9.2
Penal/Debe/Siparia	18	7.2
Point Fortin	33	13.2
Port of Spain/San Juan/Laventille	14	5.6
Princess Town	16	6.4
San Fernando	47	18.8
Other	45	18.0
Total	250	100.0

TABLE 2 Health status and health needs of migrants.

Variable	*n*	%
View of health (self-rated)		
Poor health	24	9.6
Fair health	74	29.6
Good health	152	60.8
Total	250	100.0
Diagnosed mental health problem		
No	171	68.4
Yes	79	31.6
Total	250	100.0
Diagnosed physical health problem		
No	180	72.0
Yes	70	28.0
Total	250	100.0
Needed to visit doctor for mental health problem		
No	197	78.8
Yes	53	21.2
Total	250	100.0
Needed to visit doctor for physical health problem		
No	137	54.8
Yes	113	45.2
Total	250	100.0
Knowledge of where to access healthcare in Trinidad and Tobago upon arrival		
No	221	88.4
Yes	29	11.6
Total	250	100.0
Had difficulties accessing healthcare since in Trinidad and Tobago		
No	172	68.8
Yes	78	31.2
Total	250	100.0
Most trusted source of information on medical needs		
Official healthcare providers	167	66.8
Social networks	20	8.0
Internet	49	19.6
Other	14	5.6
Total	250	100.0
Decision to seek public health services		
No	83	33.2
Yes	167	66.8
Total	250	100.0
Decision to seek private health services		
No	194	77.6
Yes	56	22.4
Total	250	100.0
Decision to seek health services		
No	48	19.2
Yes	202	80.8
Total	250	100.0

TABLE 3 Differences in migrants' decision to seek public and private health services according to social characteristics, row %.

Variable	Decision to seek public healthcare			Decision to seek private healthcare		
	No	Yes	*p*-value	No	Yes	*p*-value
Age			0.604			0.902
20–29 years	27 (37.5)	45 (62.5)		56 (77.8)	16 (22.2)	
30–39 years	30 (32.3)	63 (67.7)		74 (79.6)	19 (20.4)	
40–49 years	20 (33.9)	39 (66.1)		45 (76.3)	14 (23.7)	
≥50 years	6 (23.1)	20 (76.9)		19 (73.1)	7 (26.9)	
Gender			0.688			0.297
Male	35 (34.7)	66 (65.3)		75 (74.3)	26 (25.7)	
Female	48 (32.2)	101 (67.8)		119 (79.9)	30 (20.1)	
Time since migrating to Trinidad and Tobago			0.031			0.247
<12 months	18 (48.6)	19 (51.4)		26 (70.3)	11 (29.7)	
≥12 months	65 (30.5)	148 (69.5)		168 (78.9)	45 (21.1)	
Main reason for migration			0.007			0.570
Economical/Political	77 (33.9)	150 (66.1)		174 (76.7)	53 (23.3)	
Asylum seeker/Escape violence	6 (54.5)	5 (45.5)		9 (81.8)	2 (18.2)	
Family reunification	–	12 (100.0)		11 (91.7)	1 (8.3)	
Household dynamic			0.007			0.029
Lives alone	13 (59.1)	9 (40.9)		13 (59.1)	9 (40.9)	
Lives with family/friends	70 (30.7)	158 (69.3)		181 (79.4)	47 (20.6)	
Education level			0.194			0.266
No formal education	13 (44.8)	16 (55.2)		24 (82.8)	5 (17.2)	
Elementary schooling	35 (37.2)	59 (62.8)		78 (83.0)	16 (17.0)	
High school	34 (28.3)	86 (71.7)		87 (72.5)	33 (27.5)	
College/University schooling	1 (14.3)	6 (85.7)		5 (71.4)	2 (28.6)	
Monthly earnings			0.032			0.311
<$1,000 TT	57 (39.3)	88 (60.7)		117 (80.7)	28 (19.3)	
$1,000–$3,000 TT	15 (21.4)	55 (78.6)		50 (71.4)	20 (28.6)	
>$3,000 TT	11 (31.4)	24 (68.6)		27 (77.1)	8 (22.9)	
English fluency			0.737			0.770
Low	53 (33.8)	104 (66.2)		123 (78.3)	34 (21.7)	
Moderate	25 (30.9)	56 (69.1)		61 (75.3)	20 (24.7)	
High	5 (41.7)	7 (58.3)		10 (83.3)	2 (16.7)	
Approximate area of residence in Trinidad and Tobago			0.885			0.597
Arima/Tunapuna/Piarco	6 (40.0)	9 (60.0)		12 (80.0)	3 (20.0)	
Chaguanas/Couva	11 (28.2)	28 (71.8)		26 (66.7)	13 (33.3)	
Mayaro/Rio Claro	9 (39.1)	14 (60.9)		17 (73.9)	6 (26.1)	
Penal/Debe/Siparia	4 (22.2)	14 (77.8)		13 (72.2)	5 (27.8)	
Point Fortin	13 (39.4)	20 (60.6)		25 (75.8)	8 (24.2)	
Port of Spain/San Juan/Laventille	6 (42.9)	8 (57.1)		12 (85.7)	2 (14.3)	
Princess Town	5 (31.3)	11 (68.8)		13 (81.3)	3 (18.8)	
San Fernando	16 (34.0)	31 (66.0)		41 (87.2)	6 (12.8)	
Other	13 (28.9)	32 (71.1)		35 (77.8)	10 (22.2)	

Trinidad and Tobago ($p = 0.031$), primary reason for migrating ($p = 0.007$), household dynamic ($p = 0.007$), and monthly earnings ($p = 0.032$) were considered. There was a significantly higher proportion of migrants residing in Trinidad and Tobago for at least 12 months (69.5%) who would seek public health services compared to those living in Trinidad and Tobago for less than 12 months (51.4%). All persons who migrated to reunite with their family would seek public health services; this was followed by persons who migrated for economic or political reasons (66.1%) and asylum seekers (45.5%). There was a significantly higher proportion of migrants living with family or friends (69.3%) who would seek public health services compared to those who lived alone (40.9%). Migrants earning $1,000–$3,000 TT each month (78.6%) had the highest proportion of persons who would seek public health services, followed by those who earned more than $3,000 TT (68.6%) and then less than $1,000 TT each month (60.7%). However, significant differences in migrant's decision to seek public health services were not observed when age ($p = 0.604$), gender ($p = 0.688$), highest level of education obtained ($p = 0.194$), English fluency ($p = 0.737$) and approximate area of residence in Trinidad and Tobago ($p = 0.885$) were considered.

A significant difference in migrants' decisions to seek private health services was observed when their household dynamic ($p = 0.029$) was considered. There was a significantly lower proportion of migrants living with family or friends (20.6%) who would seek private health services compared to those who lived alone (40.9%). Significant differences in a migrant's decision to seek private health services were not observed when categories of age ($p = 0.902$), gender ($p = 0.297$), length of time residing in Trinidad and Tobago ($p = 0.247$), primary reason for migrating ($p = 0.570$), highest level of education obtained ($p = 0.266$), monthly earnings ($p = 0.311$), English fluency ($p = 0.770$), and approximate area of residence in Trinidad and Tobago ($p = 0.597$) were considered.

3.3. Associations between migrants' decisions to seek public and private health services with social characteristics

Table 4 provided the univariate associations and unadjusted odds ratios with 95% confidence intervals of a migrant's decision to seek public and private health services with their social characteristics.

The length of time migrants resided in Trinidad and Tobago was significantly associated with their decision to seek public health services in the country ($p = 0.033$). The odds of migrants living in Trinidad and Tobago for more than 12 months seeking public health services were over twice the odds of migrants residing in the country for less than 12 months (OR 2.157, 95% CI 1.063–4.377). The household dynamic of participants in this study was another independent factor that was significantly associated with their decision to seek public health services in Trinidad and Tobago ($p = 0.010$). The odds of persons living with family or friends seeking public health services were over three times the odds of persons living alone (OR 3.260, 95% CI 1.332–7.981). Monthly earnings were also significantly associated with a migrant's decision to seek public health services ($p = 0.035$). Persons earning between $1,000–$3,000 TT each month had greater odds of seeking public health services relative to migrants earning less than $1,000 TT per month (OR 2.375, 95% CI 1.226–4.600). Migrants' age, gender, primary reason for migrating, highest level of education obtained, English fluency and approximate area of residence were not observed to be statistically significantly associated with their decision to seek public health services in Trinidad and Tobago ($p > 0.05$).

The household dynamic of migrants was an independent factor that was significantly associated with their decision to seek private health services in Trinidad and Tobago ($p = 0.034$). The odds of persons living with family or friends seeking private health services were lower than the odds of persons living alone (OR 0.375, 95% CI 0.151–0.930). Other social characteristics of migrants were not statistically significantly associated with their decisions to seek private health services in Trinidad and Tobago ($p > 0.05$).

3.4. Differences in migrants' decisions to seek public and private health services according to health status and health needs

Table 5 summarized the differences in migrants' decisions to seek public and private health services according to their health status and health needs.

Significant differences in a migrant's decision to seek public health services were observed when their need to visit a doctor for a physical health problem ($p = 0.005$) and their main source of information relating to medical needs ($p = 0.012$) were considered. A significantly higher proportion of migrants who needed to visit a doctor for a physical health problem (76.1%) would seek public health services compared to persons who did not need to visit a doctor for a physical health problem (59.1%). The proportion of migrants who trusted official healthcare providers for information concerning their medical needs (73.7%) who would seek public health services was significantly higher than persons who trusted social networks (55%), internet sources (51%) or an alternative source (57.1%). Significant differences in a migrant's decision to seek public health services were not observed when their self-rated health status ($p = 0.558$), having a diagnosed mental health problem ($p = 0.824$), having a diagnosed physical health problem ($p = 0.943$), needing to visit a doctor for a mental health problem ($p = 0.645$), knowing where to access healthcare in Trinidad and Tobago upon arrival ($p = 0.792$) and having difficulties accessing healthcare since residing in Trinidad and Tobago ($p = 0.259$) were considered.

Significant differences in a migrant's decision to seek private health services were observed when their need to visit a doctor for a physical health problem ($p = 0.008$) and having difficulties accessing healthcare since residing in Trinidad and Tobago ($p = 0.034$) were considered. A significantly higher proportion of migrants who needed to visit a doctor for a physical health problem (30.1%) would seek private health services compared to persons who did not need to visit a doctor for a physical health problem (16.1%), while a significantly lower proportion of migrants who experienced difficulties accessing healthcare since residing in Trinidad and Tobago (14.1%) would seek private health services compared to persons who did not experience any difficulties accessing health services (26.2%). Significant differences in a migrant's decision to seek private health services were not observed when their self-rated health status ($p = 0.458$), having a diagnosed mental health problem ($p = 0.921$), having a diagnosed physical health problem ($p = 0.818$), needing to visit a doctor for a

TABLE 4 Univariate associations and unadjusted odds ratios (with 95% CI) of migrants' decisions to seek public and private health services with social characteristics.

Variable	Decision to seek public healthcare (Ref: Decided not to seek public healthcare)			Decision to seek private healthcare (Ref: Decided not to seek private healthcare)		
	Unadjusted OR	95% CI	*p*-value	Unadjusted OR	95% CI	*p*-value
Age			0.610			0.903
20–29 years	Ref	Ref	–	Ref	Ref	–
30–39 years	1.260	0.661–2.403	0.483	0.899	0.424–1.903	0.899
40–49 years	1.170	0.570–2.403	0.669	1.089	0.481–2.466	0.838
≥50 years	2.000	0.714–5.600	0.187	1.289	0.461–3.610	0.628
Gender			0.688			0.298
Male	Ref	Ref	–	Ref	Ref	–
Female	1.116	0.654–1.905	0.688	0.727	0.399–1.324	0.298
Time since migrating to Trinidad and Tobago			0.033			0.249
<12 months	Ref	Ref	–	Ref	Ref	–
≥12 months	2.157	1.063–4.377	0.033	0.633	0.291–1.378	0.249
Main reason for migration			0.393			0.486
Economical/Political	Ref	Ref	–	Ref	Ref	–
Asylum seeker/Escape violence	0.428	0.127–1.446	0.172	0.730	0.153–3.481	0.692
Family reunification	–	–	–	0.298	0.038–2.365	0.252
Household dynamic			0.010			0.034
Lives alone	Ref	Ref	–	Ref	Ref	–
Lives with family/friends	3.260	1.332–7.981	0.010	0.375	0.151–0.930	0.034
Education level			0.195			0.273
No formal education	Ref	Ref	–	Ref	Ref	–
Elementary schooling	1.370	0.590–3.182	0.465	0.985	0.327–2.968	0.978
High school	2.055	0.894–4.725	0.090	1.821	0.641–5.169	0.260
College/University schooling	4.875	0.519–45.789	0.166	1.920	0.287–12.862	0.501
Monthly earnings			0.035			0.315
<$1,000 TT	Ref	Ref	–	Ref	Ref	–
$1,000–$3,000 TT	2.375	1.226–4.600	0.010	1.671	0.862–3.242	0.129
>$3,000 TT	1.413	0.643–3.106	0.389	1.238	0.508–3.016	0.638
English fluency			0.739			0.772
Low	Ref	Ref	–	Ref	Ref	–
Moderate	1.142	0.642	2.031	1.186	0.631–2.231	0.597
High	0.713	0.216–2.355	0.580	0.724	0.151–3.460	0.685
Approximate area of residence in Trinidad and Tobago			0.890			0.627
Arima/Tunapuna/Piarco	Ref	Ref	–	Ref	Ref	–
Chaguanas/Couva	1.697	0.488–5.902	0.406	2.000	0.479–8.354	0.342
Mayaro/Rio Claro	1.037	0.274–3.920	0.957	1.412	0.294–6.790	0.667
Penal/Debe/Siparia	2.333	0.512–10.638	0.274	1.538	0.301–7.870	0.605
Point Fortin	1.026	0.295–3.569	0.968	1.280	0.287–5.707	0.746
Port of Spain/San Juan/Laventille	0.899	0.203–3.901	0.876	0.667	0.094–4.733	0.685
Princess Town	1.467	0.335–6.430	0.612	0.923	0.155–5.486	0.930
San Fernando	1.292	0.390–4.273	0.675	0.585	0.127–2.698	0.492
Other	1.641	0.486–5.545	0.425	1.143	0.269–4.859	0.856

Ref, Reference category.

TABLE 5 Differences in migrants' decision to access public and private health services according to health status and health needs, row %.

Variable	Decision to seek public healthcare			Decision to seek private healthcare		
	No	Yes	*p*-value	No	Yes	*p*-value
View of health (self-rated)			0.558			0.458
Poor health	9 (37.5)	15 (62.5)		20 (83.3)	4 (16.7)	
Fair health	21 (28.4)	53 (71.6)		60 (81.1)	14 (18.9)	
Good health	53 (34.9)	99 (65.1)		114 (75.0)	38 (25.0)	
Diagnosed mental health problem			0.824			0.921
No	56 (32.7)	115 (67.3)		133 (77.8)	38 (22.2)	
Yes	27 (34.2)	52 (65.8)		61 (77.2)	18 (22.8)	
Diagnosed physical health problem			0.943			0.818
No	60 (33.3)	120 (66.7)		139 (77.2)	41 (22.8)	
Yes	23 (32.9)	47 (67.1)		55 (78.6)	15 (21.4)	
Needed to visit doctor for mental health problem			0.645			0.286
No	64 (32.5)	133 (67.5)		150 (76.1)	47 (23.9)	
Yes	19 (35.8)	34 (64.2)		44 (83.0)	9 (17.0)	
Needed to visit doctor for physical health problem			0.005			0.008
No	56 (40.9)	81 (59.1)		115 (83.9)	22 (16.1)	
Yes	27 (23.9)	86 (76.1)		79 (69.9)	34 (30.1)	
Knowledge of where to access healthcare in Trinidad and Tobago upon arrival			0.792			0.814
No	74 (33.5)	147 (66.5)		171 (77.4)	50 (22.6)	
Yes	9 (31.0)	20 (69.0)		23 (79.3)	6 (20.7)	
Had difficulties accessing healthcare since in Trinidad and Tobago			0.259			0.034
No	61 (35.5)	111 (64.5)		127 (73.8)	45 (26.2)	
Yes	22 (28.2)	56 (71.8)		67 (85.9)	11 (14.1)	
Most trusted source of information on medical needs			0.012			0.129
Official healthcare providers	44 (26.3)	123 (73.7)		125 (74.9)	42 (25.1)	
Social networks	9 (45.0)	11 (55.0)		17 (85.0)	3 (15.0)	
Internet	24 (49.0)	25 (51.0)		38 (77.6)	11 (22.4)	
Other	6 (42.9)	8 (57.1)		14 (100.0)	–	

mental health problem ($p = 0.286$), knowing where to access healthcare in Trinidad and Tobago upon arrival ($p = 0.814$) and their most trusted source of information relating to medical needs ($p = 0.129$) were considered.

3.5. Associations between migrants' decisions to seek public and private health services with health status and health needs

Table 6 provided the univariate associations and unadjusted odds ratios with 95% confidence intervals of migrants' decisions to seek public and private health services with their health status and health needs.

Migrants' belief that they needed to visit a doctor for their physical health problems was significantly associated with their decision to seek public health services in Trinidad and Tobago ($p = 0.005$). The odds of migrants who believed that they needed to visit a doctor for their physical health problems seeking public health services were over twice the odds of migrants who did not have this perception (OR 2.202, 95% CI 1.270–3.818). The main source of information relating to medical needs was significantly associated with a migrant's decision to seek public health services ($p = 0.014$). Migrants trusting the internet for information relating to their medical needs had lower odds of deciding to seek public health services relative to persons who trusted official healthcare providers (OR 0.373, 95% CI 0.193–0.719). Other variables relating to the health status and health needs of migrants were not found to be statistically significantly associated with their decision to seek public health services ($p > 0.05$).

Migrants' belief that they needed to visit a doctor for their physical health problems was also found to be significantly associated with their decision to seek private health services ($p = 0.009$). The odds of migrants believing that they needed to visit a doctor for their physical health

TABLE 6 Univariate associations and unadjusted odds ratios (with 95% CI) of migrants' decision to access healthcare services with health status/needs.

Variable	Decision to seek public healthcare (Ref: Decided not to seek public healthcare)			Decision to seek private healthcare (Ref: Decided not to seek private healthcare)		
	Unadjusted OR	95% CI	*p*-value	Unadjusted OR	95% CI	*p*-value
View of health (self-rated)			0.559			0.461
Poor health	Ref	Ref	–	Ref	Ref	–
Fair health	1.514	0.575–3.989	0.401	1.167	0.344–3.956	0.805
Good health	1.121	0.460–2.732	0.802	1.667	0.536–5.183	0.378
Diagnosed mental health problem			0.824			0.921
No	Ref	Ref	–	Ref	Ref	–
Yes	0.938	0.534–1.649	0.824	1.033	0.546–1.954	0.921
Diagnosed physical health problem			0.943			0.818
No	Ref	Ref	–	Ref	Ref	–
Yes	1.022	0.568–1.838	0.943	0.925	0.474–1.805	0.818
Needed to visit doctor for mental health problem			0.645			0.289
No	Ref	Ref	–	Ref	Ref	–
Yes	0.861	0.456–1.626	0.645	0.653	0.297–1.436	0.289
Needed to visit doctor for physical health problem			0.005			0.009
No	Ref	Ref	–	Ref	Ref	–
Yes	2.202	1.270–3.818	0.005	2.250	1.225–4.132	0.009
Knowledge of where to access healthcare in Trinidad and Tobago upon arrival			0.792			0.814
No	Ref	Ref	–	Ref	Ref	–
Yes	1.119	0.485–2.578		0.892	0.344–2.312	0.814
Had difficulties accessing healthcare since in Trinidad and Tobago			0.260			0.037
No	Ref	Ref	–	Ref	Ref	–
Yes	1.399	0.780–2.508	0.260	0.463	0.225–0.954	0.037
Most trusted source of information on medical needs			0.014			0.790
Official healthcare providers	Ref	Ref	–	Ref	Ref	–
Social networks	0.437	0.170–1.126	0.086	0.525	0.147–1.882	0.323
Internet	0.373	0.193–0.719	0.003	0.862	0.404–1.836	0.699
Other	0.477	0.157–1.452	0.192	–	–	–

problems seeking private health services were over twice the odds of migrants who did not have this perception (OR 2.250, 95% CI 1.225–4.132). Having difficulties accessing healthcare since migrating to Trinidad and Tobago was another independent factor significantly associated with a migrant's decision to seek private health services in the country ($p=0.037$). Migrants who experienced difficulties accessing healthcare had lower odds of deciding to seek private health services (OR 0.463, 95% CI 0.225–0.954) relative to persons who did not have difficulties. A migrant's self-rated health status, having diagnosed mental and physical health problems, needing to visit a doctor for their mental health problem and most trusted source of information for their medical needs were not found to be statistically significantly associated with their decision to seek private health services in Trinidad and Tobago ($p>0.05$).

3.6. Andersen's Behavioral Model for Health Service Use

Table 7 provided the results of our multivariable analyses of migrants' decisions to seek public and private health services with variables selected from Andersen's Behavioral Model for Health Service Use using backward elimination.

TABLE 7 Adjusted odds ratios (with 95% CI) of migrant's decision to seek public and private health services using selected variables from Andersen's Behavioral Model.

Variable	Decision to seek public healthcare (Ref: Decided not to seek public healthcare)			Decision to seek private healthcare (Ref: Decided not to seek private healthcare)		
	Adjusted OR	95% CI	*p*-value	Adjusted OR	95% CI	*p*-value
Time since migrating to Trinidad and Tobago			0.031	–	–	–
<12 months	Ref	Ref	–	–	–	–
≥12 months	2.336	1.083–5.039	0.031	–	–	–
Main reason for migration			0.489	–	–	–
Economical/Political	Ref	Ref	–	–	–	–
Asylum seeker/Escape violence	0.451	0.122–1.665	0.232	–	–	–
Family reunification	–	–	–	–	–	–
Household dynamic			0.049			0.020
Lives alone	Ref	Ref	–	Ref	Ref	–
Lives with family/friends	2.595	1.005–6.696	0.049	0.312	0.117–0.830	0.020
Visited doctor for physical health problem			0.010			0.012
No	Ref	Ref	–	Ref	Ref	–
Yes	2.170	1.203–3.913	0.010	2.263	1.199–4.272	0.012
Had difficulties accessing healthcare since in Trinidad and Tobago	–	–	–			0.045
No	–	–	–	Ref	Ref	–
Yes	–	–	–	0.466	0.221–0.983	0.045
Most trusted source of information on medical needs			0.037			0.714
Official healthcare providers	Ref	Ref	–	Ref	Ref	–
Social networks	0.450	0.162–1.252	0.126	0.472	0.125–1.785	0.268
Internet	0.409	0.205–0.816	0.011	0.809	0.365–1.794	0.602
Other	0.412	0.118–1.435	0.164	–	–	–

The predisposing, enabling and need factors of Anderson's Behavioral Model based on the variables in our study were initially included in a multivariable binary logistic regression model to determine the odds of migrants deciding to seek public and private health services in Trinidad and Tobago. Backward elimination was employed to select the factors which best explained their decision to access these health services.

The predisposing factors relating to the length of time migrants resided in Trinidad and Tobago ($p = 0.031$), household dynamic ($p = 0.049$); the enabling factor relating to a migrant's main source of information for medical needs ($p = 0.037$); and the need factor relating to visiting a doctor for physical health problems ($p = 0.010$) were observed to be significant correlates of a migrant's decision to seek public health services in Trinidad and Tobago.

While adjusting for their reasons for migration, the odds of migrants living in Trinidad and Tobago for more than 12 months seeking public health services remained over twice the odds of migrants residing in the country for less than 12 months (AOR 2.336, 95% CI 1.083–5.039). The odds of persons living with family or friends seeking public health services were now over two times the odds of persons living alone (AOR 2.595, 95% CI 1.005–6.696). The odds of migrants who believed that they needed to visit a doctor for their physical health problems seeking public health services remained over twice the odds of migrants who did not have this belief (AOR 2.170, 95% CI 1.203–3.913). Migrants who trusted the internet for information on their medical needs seeking public health services continued to have lower odds of deciding to seek public health services relative to persons who trusted official healthcare providers (AOR 0.409, 95% CI 0.205–0.816).

The predisposing factor of a migrant's household dynamic ($p = 0.020$) and the enabling factor of having difficulties accessing healthcare ($p = 0.045$) were observed to be significant correlates of a migrant's decision to seek private health services in Trinidad and Tobago.

While adjusting for their sources of information for medical needs, the odds of migrants living with family or friends and seeking private health services remained lower than the odds of migrants living alone (AOR 0.312, 95% CI 0.117–0.830). Similarly, the odds of migrants who experienced difficulties accessing healthcare while in Trinidad and Tobago then deciding to seek private health services

remained lower than the odds of persons who did not have difficulties (AOR 0.466, 95% CI 0.221–0.983).

4. Discussion

It has been emphasized that migrants face multiple barriers to care and health services throughout their migration journey and in their country of destination (9, 10). Using constructs of Andersen's Behavioral Model for Health Service Use, this study aimed to examine the medical needs and associations between predisposing, enabling and need factors on decisions to seek public and private health services among a sample of Venezuelan migrants residing in Trinidad and Tobago.

With the inflows of Venezuelan refugees and migrants to Trinidad and Tobago, there has been increasing demands on the use of health services in the public sector. The health sector of Trinidad and Tobago is comprised of public and private care systems and all nationals may access care through the public system at no cost. At the primary level, healthcare is offered through district health centers, with some providing 24-h access to services. Additional primary care and treatment services for selected conditions are offered through non-governmental organizations which are supported by the Government. Secondary care services are provided by public hospitals and through inpatient and outpatient clinical services. General hospitals are often the first point of offering immediate/emergency care for physical injuries, inpatient and outpatient medical and surgical services, psychiatric inpatient and outpatient services and linkages to specialist referrals. Specialist hospitals offer a range of services including psychiatric, women's and maternity care. A selected range of tertiary care services is also offered at specific hospitals. Some tertiary level services such as cardiac surgery and magnetic resonance imaging (MRI) scans have been offered to the public. The private health sector is smaller and includes a variety of healthcare providers such as physicians, dentists, pharmacists, opticians, along with private healthcare facilities including private hospitals and nursing homes, clinical laboratories, and diagnostic testing facilities. Most tertiary care services are accessed privately or abroad and paid for either out of pocket or through private insurance.

The Government of the Republic of Trinidad and Tobago developed a draft policy for treating with non-nationals with respect to providing public healthcare services. The policy indicated that registered Venezuelan migrants were to be granted access to free emergency medical services, primary healthcare, and immunization services available in the public sector. Apart from this, Venezuelan migrants and non-nationals benefitted from the Government's "Treat All Policy" with respect to non-communicable diseases. Given increasing constraints on the public health system, the policy further advised that Venezuelan migrants, refugees, and other non-nationals seeking ongoing medical care and/or specialized health services may do so at their own costs. In this regard, migrants and refugees would resort to paying for private health care services to address their unmet medical needs.

Participation in our study was not linked to the Government Registration Exercises and, therefore, the study did not ascertain how many migrants in our sample were part of these undertakings. Overall, over two thirds of migrants in our study reported that they used public health services, while around one-quarter indicated they used private health services. As it pertained to their medical needs, 30% of migrants reported being worried about diagnosed mental and physical health problems. Additionally, 21.2% of the migrants reported needing to visit a doctor for a mental health problem and 45.2% for a physical health problem since residing in Trinidad and Tobago. When asked to rate their health, 10% of participants rated themselves as "not healthy," with 30% rating themselves as being in "fair health." Our findings suggested that almost half of our study population reported experiencing health challenges which required medical attention. This may be reflective of their unmet health needs. Many refugees and migrants with medical conditions experienced interruptions in access to healthcare because of their migration journey. Refugees and migrants may also experience new health problems because of the social and economic hardships experienced in the host countries, leaving them potentially at a greater risk for contracting infectious diseases due to their exposure to infections and lack of health resources (9–11).

The results of our univariate analyses showed significant associations between a migrant's decision to seek public health services with the length of time residing in Trinidad and Tobago, living with family/friends, monthly earnings, visiting a doctor for a physical health problem and their most trusted source of information on their medical needs. A migrant's decision to seek private health services was significantly associated with living with family and friends, visiting a doctor for a physical health problem and having difficulties accessing healthcare in Trinidad and Tobago.

In the context of Trinidad and Tobago, recently arrived migrants received information on services available to them at the time of pre-registration by the UNHCR and local implementing partners. These services included legal assistance, cash-based assistance, refugee status determination services, case management, psychosocial support, linkage to assistance for medical services including survivors of gender-based violence (GBV), sexual and reproductive health services, employment skills training and English language training. These services also covered information about the availability of medical services offered in the public system and through UNHCR supported NGO networks. Persons arriving with and living with families were provided with information on the availability of healthcare services in the public health system. In addition, just over half of the migrants enrolled in our study reported having an income of $1,000 TT or less which may explain the association between monthly earnings and their decisions to access healthcare in the public system versus the private system. Having visited a medical doctor in the past 12 months suggested an indication of their medical needs which was further associated with the decisions to use of both public and private health care systems.

Our study results also highlighted the importance of social networks in decisions to use private health services by migrants, further underscoring the value of family and friends in helping to steer individuals to seek healthcare. The use of the private healthcare services was also associated with migrants who experienced difficulties accessing healthcare services in general, suggesting challenges related to accessing the health system due to barriers based on registration status and/or medical needs due to the limitations imposed by the Government Policy which did not facilitate the provision of ongoing medical and/or specialized care to Venezuelan refugees and migrants and other non-nationals in the public setting.

These findings were further supported in studies which presented that migrants and refugees' decisions to seek healthcare could be compromised because of social characteristics when interacting with the health system in host countries. Factors such as employment, level of earnings, educational background, language barriers and information on where to access health services upon arrival in countries have impacted migrants' use of health services (12, 13).

Andersen's Behavioral Model and its expanded versions have been widely used across various health service settings and across several populations both in clinical and non-clinical settings to understand the factors associated with health service use. The findings of existing studies showed mixed results, each underscoring the relative contributions and significance of the model's theoretical constructs, i.e., predisposing, enabling and need factors, in explaining disparities in the uptake and use of mental health services, antenatal care, long-term care and the overall health seeking behaviors among various populations (14–23). In our study, the theoretical constructs of Andersen's Behavioral Model namely the predisposing factors of length of time residing in Trinidad and Tobago and living with family/friends; the enabling factor of receiving information from public healthcare providers; and the need factor of visiting a doctor for a physical health problem were significant correlates of migrants' decisions to seek public health services. This study also found that predisposing factors such as living with family/friends and the enabling factor of having difficulty accessing healthcare services were significant determinants of their decision to seek services from private health care providers.

Our findings reinforced literature which employed Andersen's theoretical constructs to examine the health seeking behaviors among migrant subpopulation groups. Studies supported that the model's constructs namely predisposing factors and need factors were consistently and significantly associated with migrants' use of health services. One study using a cross-sectional sample among migrant workers in Malaysia examined the influence of sociodemographic factors on the use of health services. Guided by Andersen's Behavioral Model, the results showed that predisposing factors namely marital status and education, and need factors namely self-rated health status, sickness, and chronic illnesses in the previous year were significant determinants of health service use among the study participants (20). In another study based on a stratified sample of migrants in Beijing, Andersen's Behavioral Model was also used to demonstrate the effects of migrants' predisposing, enabling and need characteristics on their use of health services. The results of their binary logistic regression showed that the predisposing variable of ethnicity and need variable defined by "degree of symptom" were significant correlates of health service use and consistently predicted the uptake of health services among migrants (22). In our application of Andersen's Model, the predisposing factor of living with family/friends and the enabling factor of having difficulty accessing health services were significant correlates influencing migrants' decisions to seek private health services. The results underscored the importance of migrants' social networks, i.e., family and friends, in the designing and planning of interventions to increase service uptake and reducing barriers to health service use. Therefore, to increase access to and the uptake of health services, it may be helpful to reach migrants through targeted communication campaigns with their social networks and wider community.

Other studies have highlighted the importance of need factors in predicting migrants' use of health services. In one study among African immigrants living in the United States, Andersen's Behavioral Model was used to explore factors associated with the use of and barriers to the uptake of mental health services. The results of their analysis showed that need and enabling factors such as age, religion, acculturative stress and neighborhood risk factors were most common in predicting mental health service use, while hope of self-healing and financial factors were reported as the most common barriers to the uptake of mental health services (23). In a more recent study, Andersen's Behavioral Model was also used to explain the utilization of health services and examine gender and ethnic differences in service uptake among Middle Eastern, Hispanic/Latino and Asian immigrants in the United States. Overall, the study found that Andersen's constructs namely the need factor of the likelihood of seeing a doctor in the past 12 months significantly predicted health service use among Middle Eastern immigrants. All immigrant women, regardless of ethnicity, were more likely than men to report seeking medical services and the effect of predisposing, need and enabling characteristics for Hispanic and Asian immigrants were significantly different to Middle Eastern immigrants (15). Therefore, our findings corroborated with the existing literature that predisposing, enabling and need factors were vital in examining migrants' decisions to use health services in host countries.

The influence of these social characteristics, resource availability and quests for solutions to illnesses on the uptake of health services by migrants has been supported in studies of undocumented migrants as well (24, 25). Our study showed that there was a greater tendency for migrants to use public health services, i.e., hospital and emergency rooms when they had a physical health problem that required medical attention. This finding also suggested that migrants were treating physical non-communicable health problems more seriously (by visiting a doctor). Studies have emphasized the increased need for culturally appropriate health services for refugees and migrants assisting to reduce the risk of both mental and physical illness and increase service uptake by those who needed it (26, 27).

Our study was conducted in 2020, i.e., one year after the Government Registration Exercise granting access to free primary health care and emergency medical services for Venezuelan migrants and families who were successfully registered. This may help explain why migrants living with family or friends displayed higher odds of seeking public health care relative to those living alone. It is possible that family and friends benefitted from the Government Registration exercise granting access to free publicly available health care. Alternatively, our results also showed that the odds of using private health care were lower among migrants living with family and friends than persons living alone suggesting that the use private healthcare was a deterrent for migrants living with other persons given the associated costs.

To the best of our knowledge, this was the first study aimed at examining the decision to seek public and private health services by the Venezuelan migrant subpopulation in the English-speaking Caribbean. Our study provided vital insights into the health needs of these migrants while applying Andersen's Behavioral Model to this vulnerable subpopulation. However, further studies are needed to

understand specific barriers influencing migrants' decisions to seek health services, identify their needs for ongoing care and to inform evidence-based targeted interventions and programs addressing their health needs.

4.1. Study limitations

One of the limitations of this study was the sample size of $n = 250$ participants. There are thousands of undocumented migrants from Venezuela in Trinidad and Tobago as in the case of the Government Registration Exercise in which over 16,000 migrants participated. Therefore, the sample is not generalizable to the larger population of Venezuelans living in Trinidad and Tobago. Another, limitation was that some of these findings may be biased in part due to the selection of study participants. Some the migrants elicited for this study were selected from persons who previously accessed outreach health services and who were seeking refugee status documentation.

However, despite these limitations our study was vital as it examined the medical needs and factors associated with the uptake of health services among a highly vulnerable subpopulation. This has not been previously explored in Trinidad and Tobago and the wider English-speaking Caribbean. All migrants who were approached participated in the study and we are confident that it yielded value as migrants are regarded as a hidden population given levels of stigma and many of whom did not want to access public health services because of their legal status. Our study did not consider whether migrants had health insurance, nor did we assess the role of stigma, but these migrants may have also experienced difficulties while using public health services due to societal and/or internalized stigma.

5. Conclusion

The findings from our study were comparable to results of the IOM Displacement Tracking Matrix Survey showing that of the migrants who accessed health services, 53% reported going to public hospitals and 39% reported going to public health centers (28). A total of 1,323 Venezuelan nationals living in Trinidad and Tobago were surveyed between November and December 2022. The available data showed a large proportion of Venezuelans using publicly available health services and by extension suggested an increasing demand on the public health sector to provide these services. Given the high demand for the use of public healthcare services, our study aided in understanding the scope of their medical needs and the factors associated with their decision to use these public and private sources of healthcare services.

Overall, our findings contributed to the existing body of literature underscoring the value of Andersen's Behavioral Model for Health Service Use. In addition to migrants' predisposing, need and enabling characteristics, factors related to the macro environment such as Government Policies, may additionally account for variations in health service use (29). In the context of our study, Venezuelan migrants benefitted from Government Policies which facilitated their access to primary care and emergency health services in the public sector and relied on public information about the availability of health services for their medical needs. Additionally, during the time of public health emergencies such as in the case of the COVID-19 pandemic, refugees and migrants faced worsening health conditions and increasing risks because of their access to and availability of public healthcare services. Therefore, without adequate policies, migrants and refugees find themselves in a "tolerated" situation with limited access and information on the availability of health care services leaving them with fewer resources to maintain their health and reduce the burden of non-communicable diseases.

Data availability statement

The data analyzed in this study is subject to the following licenses/restrictions: The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation. Requests to access these datasets should be directed to b.bhagwandeen@hw.ac.uk.

Ethics statement

The studies involving humans were approved by University of the West Indies (UWI) Institutional Review Board (IRB). The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

NL conceived and designed the study, collected, and discussed the data, wrote, discussed, and reviewed the manuscript. BB conducted the analysis and interpreted data, discussed, wrote, and reviewed the manuscript. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

1. Latin America and the Caribbean Migration Portal. Available at: https://www.migrationportal.org/country/trinidad-tobago.

2. United Nations Higher Commissioner for Refugees (UNHCR). UNHCR Trinidad and Tobago fact sheet. (2021). Available at: https://data2.unhcr.org/en/documents/details/86320.

3. The United Nations International Children's Emergency Fund (UNICEF). *The impact of COVID-19 on migrant children in Trinidad and Tobago*. UNICEF (2020).

4. United Nations (UN). Convention relating to the status of refugees. Available at: http://www.refworld.org/docid/3be01b964.html.

5. Office of the Prime Minister of the Republic of Trinidad and Tobago. Venezuelan registration policy gets green light. (2019). Available at: https://www.opm.gov.tt/venezuelan-registration-policy-gets-green-light.

6. Catholic Relief Services (CRS). *The Venezuelan regional humanitarian crisis and COVID-19*. CRS (2020).

7. Anderson JG. Health services utilization: framework and review. *Health Serv Res*. (1973) 8:184–99.

8. Andersen RM. National health surveys and the behavioral model of health services use. *Med Care*. (2008) 46:647–53. doi: 10.1097/MLR.0b013e31817a835d

9. Wang L, Kwak M-J. Immigration, barriers to healthcare and transnational ties: a case study of South Korean immigrants in Toronto, Canada. *Soc Sci Med*. (2015) 133:340–8. doi: 10.1016/j.socscimed.2014.11.039

10. Lessard-Phillips L, Fu L, Lindenmeyer A, Phillimore J. *Migration and vulnerability during the pandemic: barriers to wellbeing*. Doctors of the World UK (2021).

11. De Vito E, De Waure C, Specchia ML, Ricciardi W. *Public health aspects of migrant health: a review of the evidence on health status for undocumented migrants in the European Region*. Copenhagen: WHO Regional Office for Europe (2015).

12. Rechel B, Mladovsky P, Ingleby D, Mackenbach JP, McKee M. Migration and health in an increasingly diverse Europe. *Lancet*. (2013) 381:1235–45. doi: 10.1016/S0140-6736(12)62086-8

13. Tormo M-J, Salmerón D, Colorado-Yohar S, Ballesta M, Dios S, Martínez-Fernández C, et al. Results of two surveys of immigrants and natives in Southeast Spain: health, use of services, and need for medical assistance. *Salud Publica Mex*. (2015) 57:38–49. doi: 10.21149/spm.v57i1.7401

14. Kim H-K, Lee M. Factors associated with health services utilization between the years 2010 and 2012 in Korea: using Andersen's behavioral model. *Osong Public Health Res Perspect*. (2016) 7:18–25. doi: 10.1016/j.phrp.2015.11.007

15. Shafeek Amin N, Driver N. Health care utilization among Middle Eastern, Hispanic/Latino, and Asian immigrants in the United States: an application of Andersen's behavioral model. *Ethn Health*. (2022) 27:858–76. doi: 10.1080/13557858.2020.1830034

16. Dang Y, Zou G, Peng B, Ling L. Health service seeking behavior among migrant workers in small and medium-sized enterprises in Guangdong, China: does family migration matter? *Biomed Res Int*. (2018) 2018:1–10. doi: 10.1155/2018/3620436

17. Yang PQ, Hwang SH. Explaining immigrant health service utilization: a theoretical framework. *SAGE Open*. (2016) 6:2158244016648137. doi: 10.1177/2158244016648137

18. Lederle M, Tempes J, Bitzer EM. Application of Andersen's behavioural model of health services use: a scoping review with a focus on qualitative health services research. *BMJ Open*. (2021) 11:e045018. doi: 10.1136/bmjopen-2020-045018

19. Tolera H, Gebre-Egziabher T, Kloos H. Using Andersen's behavioral model of health care utilization in a decentralized program to examine the use of antenatal care in rural western Ethiopia. *PLoS One*. (2020) 15:e0228282. doi: 10.1371/journal.pone.0228282

20. Uddin MS, Akhtar R, Masud MM, Hye QMA. Utilization of health care services among migrant workers in Malaysia. *Human Soc Sci Lett*. (2020) 8:481–92. doi: 10.18488/journal.73.2020.84.481.492

21. Travers JL, Hirschman KB, Naylor MD. Adapting Andersen's expanded behavioral model of health services use to include older adults receiving long-term services and supports. *BMC Geriatr*. (2020) 20:1–16. doi: 10.1186/s12877-019-1405-7

22. Shao S, Wang M, Jin G, Zhao Y, Lu X, Du J. Analysis of health service utilization of migrants in Beijing using Anderson health service utilization model. *BMC Health Serv Res*. (2018) 18:1–11. doi: 10.1186/s12913-018-3271-y

23. Saasa SK, Rai A, Malazarte N, Yirenya-Tawiah AE. Mental health service utilization among African immigrants in the United States. *J Community Psychol*. (2021) 49:2144–61. doi: 10.1002/jcop.22602

24. Devillanova C. Social networks, information and health care utilization: evidence from undocumented immigrants in Milan. *J Health Econ*. (2008) 27:265–86. doi: 10.1016/j.jhealeco.2007.08.006

25. Gea-Sánchez M, Alconada-Romero Á, Briones-Vozmediano E, Pastells R, Gastaldo D, Molina F. Undocumented immigrant women in Spain: a scoping review on access to and utilization of health and social services. *J Immigr Minor Health*. (2017) 19:194–204. doi: 10.1007/s10903-016-0356-8

26. Mahmoud I, Hou X-y. Immigrants and the utilization of hospital emergency departments. *World J Emerg Med*. (2012) 3:245. doi: 10.5847/wjem.j.issn.1920-8642.2012.04.001

27. Shawyer F, Enticott JC, Block AA, Cheng I-H, Meadows GN. The mental health status of refugees and asylum seekers attending a refugee health clinic including comparisons with a matched sample of Australian-born residents. *BMC Psychiatry*. (2017) 17:76. doi: 10.1186/s12888-017-1239-9

28. International Organization for Migration (IOM). *Displacement Tracking Matrix (DTM) Trinidad and Tobago – monitoring Venezuelan citizens presence, round 4*. Trinidad and Tobago: IOM (2022).

29. Derose KP, Gresenz CR, Ringel JS. Understanding disparities in health care access—and reducing them—through a focus on public health. *Health Aff*. (2011) 30:1844–51. doi: 10.1377/hlthaff.2011.0644

frontiers | Frontiers in Public Health

TYPE Original Research
PUBLISHED 12 October 2023
DOI 10.3389/fpubh.2023.1253123

OPEN ACCESS

EDITED BY
Carla Sofia e Sá Farinha,
New University of Lisbon, Portugal

REVIEWED BY
Arkalgud Ramaprasad,
University of Illinois Chicago, United States
Arnaud Fernandez,
Center Hospitalier Universitaire de Nice, France
Luca Bussotti,
Technical University of Mozambique, Mozambique

*CORRESPONDENCE
Aly Savadogo
✉ alysavadogo@gmail.com

RECEIVED 04 July 2023
ACCEPTED 27 September 2023
PUBLISHED 12 October 2023

CITATION
Ouedraogo M, Sanou D, Kere IWZ, Sankara S, Thiombiano-Coulibaly N, Ouedraogo O, Zoungrana B, Hama-Ba F and Savadogo A (2023) Sahel terrorist crisis and development priorities: case of financial allocations for the control of non-communicable diseases in Burkina Faso. *Front. Public Health* 11:1253123. doi: 10.3389/fpubh.2023.1253123

Sahel terrorist crisis and development priorities: case of financial allocations for the control of non-communicable diseases in Burkina Faso

Moussa Ouedraogo[1,2], Dia Sanou[3], Ines Wendlassida Zaheira Kere[1], Souleymane Sankara[1], Nana Thiombiano-Coulibaly[2], Ousmane Ouedraogo[4], Bassibila Zoungrana[1], Fatoumata Hama-Ba[5] and Aly Savadogo[1]*

[1]Doctoral School of Sciences and Technology, Laboratory of Applied Biochemistry and Immunology (LABIA), Joseph Ki-ZERBO University, Ouagadougou, Burkina Faso, [2]Nutrition Directorate, Ministry of Health, Ouagadougou, Burkina Faso, [3]FAO, Subregional Office, Eastern Africa, Addis Ababa, Ethiopia, [4]United Nations Children's Fund (UNICEF), Ouagadougou, Burkina Faso, [5]Food Technology Department, Institute for Research in Applied Sciences and Technologies, National Center for Scientific and Technological Research, Ouagadougou, Burkina Faso

In Africa, nearly 46% of all mortality will be attributed to non-communicable diseases (NCDs) by 2030. While the cost of inaction far exceeds the cost of action against NCDs, global funding for the prevention and control of NCDs is minimal. The objective of this was to explore the Ministry of Health budget allocations for NCDs from 2010 to 2020 as well as the effect of the terrorism crisis on these allocations. The methodology was based on the budget tracking tool developed by the Scaling Up Nutrition Movement. Twenty-nine budget lines related to the prevention and/or control of NCDs have been identified. About 29.9 million USD were allocated to the fight against NCDs with an absorption rate of more than 98%.There is an upward trend of allocated budget characterized by an exponential increase from the development of the national integrated strategic plan for the fight against NCDs (2016–2020). In 2017, an increase of 184% compared to 2016 was observed. However, the efforts were challenged by the emergence of the terrorist threat which triggered in January 2016, leading to a drastic reduction in allocations for NCDs in favor likely of defense and security priorities as well as addressing the needs of internally displaced persons. A trend analysis suggests that the NCDs budget significantly decrease as the country global terrorist index increase. Further analysis is needed to better understand the implication on NCD incidence, and identify advocacy opportunities for mitigating the negative impact of the terrorist treat on NCDs and other development issues.

KEYWORDS

terrorism, financing, budget allocation, NCDs, Burkina Faso

1. Introduction

Non-communicable diseases (NCDs) are a major cause of poverty and thus a serious threat to the achievement of the Sustainable Development Goals (SDGs) (1). They are biggest silent killer, causing 9 million deaths each year among people under 60 years in low- and middle-income countries. That represents a slow-motion development emergency (2). In sub-Saharan

Africa, NCDs are expected to be the leading cause of death by 2030 (3). For all countries, the cost of inaction far exceeds the cost of action against noncommunicable diseases (4). It is encouraging to see that NCDs are now gaining momentum in the global development agenda. In September 2011, world leaders agreed on a roadmap with concrete commitments, to tackle the global burden of NCDs (5). While much efforts has been made globally, significant progress in the fight against NCDs has been observed only in high-income countries (6). This is mainly due to the fact that funding from the global community for the prevention and control of NCDs in developing countries remains insufficient – overshadowed by donor support for communicable diseases, maternal and child health and other traditional health issues (7, 8). The total cost of implementing a combination of individual and population-wide interventions, in terms of health expenditure, amounts to 4% of GDP in low-income countries, and less than 1% in upper-income countries (4). Ouedraogo et al. reported that many concerns around the governance of NCDs, including issues of funding remain unanswered in most ECOWAS countries (9). There is a consensus that adequate financing is a powerful catalyst for Scaling Up the fight against NCDs. Overall, there has been a downward trend in the Official development assistance (ODA) to address NCDs over the past decade (10). In addition, there is a significant mismatch between international resources and the real needs of recipient countries. Some authors argue that the NCD target (Target 3.4) of the Sustainable Development Goals (SDGs) cannot be achieved if funding does not increase (11). With the high likelihood that the burden of NCDs will likely increase in coming years, countries should prioritize funding for their prevention and control.

In 2015, Burkina Faso adopted an Integrated Strategic Plan for the Fight against Non-Communicable Diseases 2016–2020 with a total implementation cost of $9 million. However, this plan has not been evaluated to appraise the effectiveness of the implementation of the planned interventions.

Furthermore, the challenging security situation that the country is experiencing since 2016 could have a considerable impact on the budget allocations for NCDs (12). While this could negatively affect investment priorities, little is known about the implications for social sectors such as prevention and control of NCDs. Most of the available data focus on the number of incidents and the immediate effects on lives lost, the economy and different socio-economic indicators such as health and nutrition, access to water and health services, education. The objective of this study is to examine the budget allocations of the Ministry of Health of Burkina Faso for the fight against NCDs between 2010 and 2020 and to assess the effects of the security crisis related to terrorist threat on these allocations.

2. Methodology

The methodological approach is based on the methods developed by the Scaling Up Nutrition Movement (13) to track budget allocations and expenditures for nutrition, adapted by UNICEF and Action Against Hunger (14). This approach has been developed for tracking nutrition investments by identifying budget lines and subsequent allocations related to nutrition specific and nutrition-sensitive interventions. The method comprises 4 fundamental steps: planning, data collection, validation, and data analysis. Although the tool makes it possible to monitor both funding from technical and financial partners (external funding) and the government budget (internal funding), only state allocations were analyzed in this study due to the difficulty in obtaining exact data on funding from technical and financial partners. The budget lines considered in this analysis are those related to the prevention and control of non-communicable diseases (NCDs) as indicated by the Ministry of Health. While NCDs should be addressed by multiple sectors to facilitate the sharing of the financial burden to promote joint accountability for achieving specific NCD-related targets, the exploratory study focus on allocations from the health sector. The lack of a common multi-sectoral results framework listing consensual interventions for the fight against NCDs in Burkina Faso makes financial monitoring difficult in the other contributing sectors.

2.1. Data source

The analysis focused on the allocations and final expenditure of the Ministry of Health of Burkina Faso during the period 2010 to 2020. This data was retrieved from the Expenditures Integrated Circuit (CID – circuit intégré de la dépense) platform of the Ministry of Economy, Finance and Development (MINEFID). The platform includes all operations containing allocations and expenditures as well as transfers made by the government to local authorities and other public institutions. At the request of the research team, an annual database (2010 to 2020) was extracted from the CID by a MINEFID agent, containing the allocations and expenditures and then made available to authors for the various analyses. The authors then carried out a meticulous examination of the budget of the Ministry of Health to extract the budget lines relating to NCDs.

Information on the terrorism index was obtained from the various annual reports on the Global Terrorism Index of the Institute for Economics and Peace (15).

2.2. Data collection and processing (extraction of budget lines)

Data from the CID platform were scrutinized to extract all budget lines relating to NCDs. Certain budget lines were not taken into account in accordance with the SUN approach used. Indeed, the methodology suggests that budget lines should not be included in the analysis when they are related to:

- the payment of the salaries of public officials;
- the operation of the general and technical departments; hospitals, health districts, and training institutions, etc.;
- the organizations of exams and competitions;
- operating and project expenses.

2.3. Validation of budget lines

The authors analyzed the budget lines selected during the data collection phase in order to carry out the categorization and

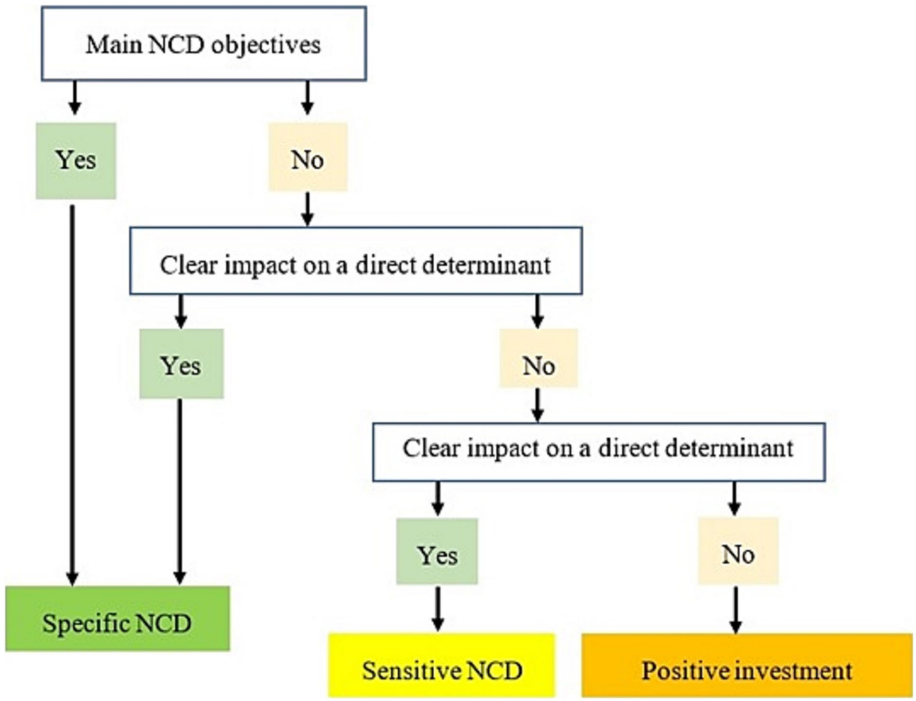


FIGURE 1
Conceptual framework for categorizing pro-NCD budget lines adapted from the conceptual framework for categorizing pro-nutrition budget lines (14).

weighting. The categorization made it possible to classify the budget lines selected into 3 categories namely specific, sensitive, and positive (Figure 1). Then, the validated budget lines were weighted. This involved assigning a rate to each line according to its estimated level of contribution to the prevention and fight against NCDs in the country. This rate was determined by the authors based on available scientific evidence, the current status of the intervention implemented in the country, the context of NCDs at the national and international level, and finally on the basis of the interventions proposed in the Action Plan prevention and control of non-communicable diseases 2013–2020 (4, 16). Budget lines considered specific to NCD were given a weighting of 100%. As for those classified as sensitive to NCDs, three levels of weighting were applied according to the estimated degree of sensitivity of the investments, i.e., 10, 25 and 50% for investments with low, medium and high sensitivity, respectively. Favorable investments were not taken into account in total NCDs expenditures. As a result, a zero rate was applied to these lines.

2.4. Data processing and analysis

The database obtained was processed with the Stata 12 software. Data were summarized using descriptive analyses and frequency calculation for budget allocations. Trends of budgetary allocations was explored throughout the years and according to the overall index of terrorism in Burkina Faso from 2015 to 2020. The Pearson correlation coefficient was used to assess the correlation between the proportions of allocations and the overall terrorism index. The selected budget lines were categorized according to the objectives of the WHO global action plan for the fight against NCDs 2013–2020. The differences observed were evaluated using the student test (*T*-Test) with a significance level of 5% and a confidence interval of 95%.

3. Results

3.1. Budget lines

Overall, twenty-nine (29) budget lines related to the prevention and/or management of NCDs in Burkina Faso were identified. Following the categorization and weighting, three (3) budget lines were considered "specific" to NCDs, eighteen (18) were "sensitive" and eight (8) were considered to be "positive investments" (Table 1).

3.2. Budget allocations and expenditures

Over the 11 years period considered (2010 to 2020) i.e., the Ministry of Health of Burkina Faso has allocated nearly 17.33 billion FCFA (29.9 million US dollars) representing an average of 2.72 million dollars per year in the fight against NCDs. This allocation represents about 1.55% of the total budget of the Ministry of Health during the same period. The budget absorption rate,

TABLE 1 Selected budget lines.

N°	Budget lines	Allocation type	Categorization
1	Childbirth & Emergency Obstetric Care / Subsidies to other beneficiary categories	Current transfer	Positive investment
2	Acquire contraceptive products	Investment	Positive investment
3	Acquire vaccines and consumables	Investment	Sensitive
4	Acquire micronutrients	Investment	Positive investment
5	Acquisition of Hospital Equipment / STATE / CHR / Technical equipment-tools	Investment	Positive investment
6	Support Dialysis Units/Subsidies to other categories of beneficiaries	Investment	Specific
7	Ensure the construction and equipment of the Infrastructures of the Bobo-Dioulasso hemodialysis project	Investment	Sensitive
8	Ensure coverage of community-based health workers/Subsidies to other categories of beneficiaries	Current transfer	Sensitive
9	Ensure Burkina's commitments to Global Fund financing for the management of certain diseases/Subsidies to other categories of beneficiaries	Current transfer	Sensitive
10	Ensure the medical examination of workers	Current transfer	Sensitive
11	National Center for Apparatus and Orthopedics/ Subsidies to other beneficiary categories	Current transfer	Positive investment
12	National Center for the Fight against Blindness/ Subsidies to other beneficiary categories	Current transfer	Sensible
13	Build and equip a cancer center in Ouagadougou/Research and development costs	Investment	Sensible
14	Female cancer screening	Current transfer	Specific
15	Availability of maternal health services / STATE / Eta tranche / Other purchases of goods & services	Investment	Sensible
16	Students in 6th year of Pharmacy / Current transfers to households	Current transfer	Sensible
17	End of medical cycle students	Current transfer	Sensible
18	Free preventive care/Subsidies to other beneficiary categories	Current transfer	Positive investment
19	Hospital interns/Routine transfers to households	Current transfer	Sensible
20	National Vaccination Days/ Subsidy to public establishments	Current transfer	Sensible
21	Tobacco control/Transfers to supranational organizations & government contribution	Current transfer	Specific
22	Doctors in specialization/Routine transfers to households	Current transfer	Sensible
23	Standardization of health facilities / STATE / Standardization	Investment	Positive investment
24	Workers' Health Office/subsidies to other beneficiary categories	Current transfer	Sensible
25	Pay Burkina's contribution to the World Health Organization	Current transfer	Sensible
26	Pay Burkina's contribution to the West African Health Organization/Transfers to supranational authorities and contributions to international organizations	Current transfer	Sensible
27	Support the construction of the Tengandogo radiotherapy center	Investment	Sensible
28	Social programs/STATE/Dialysis unit/Other purchases of goods & services	Investment	Sensible
29	Care for children aged 0 to 5/Subsidies to other beneficiary categories	Current transfer	Positive investment

TABLE 2 Budget allocations and expenditure related to NCDs of the Ministry in charge of Health from 2010–2020.

Year (2010–2020)	Total	Yearly average
Total budget allocations for NCDs (FCFA)	29885033.32[a] $	2716821 $
Total expenses for NCDs (FCFA)	29459619.47 $	2678147.22 $
Absorption rate (expenses / allocations in %)	98.58%	98.58%

[a]1 dollar US = 580 FCFA.

which was defined as the percentage of allocated budget effectively used was more than 98% (Table 2). With this high absorption rate, we carried out the analyses with only budget allocations.

3.3. Allocation by intervention type

Of this budget of 17.33 billion de FCFA (29.8 million $), 6.64 billion representing 38.4% were allocated to "NCDs specific" interventions, while 10.68 billion, i.e., 61.6% were allocated to "sensitive" interventions (Figure 2).

3.4. Budget allocation by objectives of the global action plan

The analysis of the budget according to the objectives of the WHO global action plan for the fight against NCDs 2013–2020 suggests that only interventions aimed at achieving 3 out of the 6 WHO objectives, namely objectives 3, 4 and 5 received budget allocation (Figure 3). Objective 4, which aims to strengthen and guide health systems, received most of the allocation, i.e., 13.6 billion, i.e., 78.48% of total funding. Objective 5 which aims to promote and strengthen the national capacity to carry out actions to prevent and fight against NCDs was the second most funded with 2.08 billion, approximately 12% and finally Objective 3 which aims to reduce the exposure to modifiable risk factors received 1.64 billion, i.e., 9.5%.

The action plan Objectives which did not receive any budgetary allocation include Objective 1 "Give higher priority to the fight against noncommunicable diseases in the global, regional and national agendas and in the development goals agreed at the at the international level, by strengthening international cooperation and awareness," Objective 2 "Strengthen national capacities, leadership, governance, multisectoral action, and partnerships to accelerate the fight against noncommunicable diseases in the countries "and the Objective 6 "Monitor trends and determinants of noncommunicable diseases and assess progress in prevention and control."

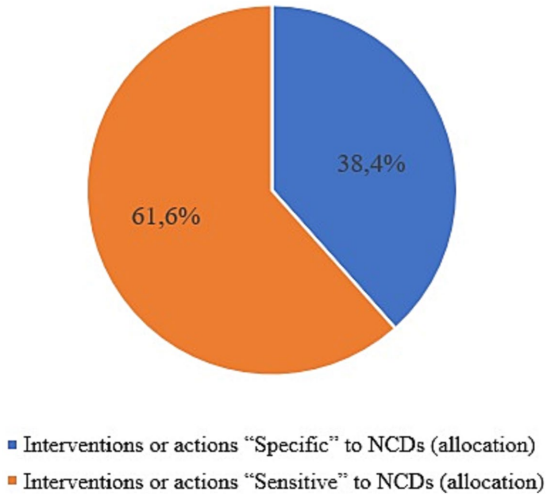


FIGURE 2
Allocation by intervention type.

3.5. Evolution of budget allocations from 2010 to 2020

The trend analysis of allocations shows an upward trend in annual allocations from 365 million in 2010 to more than 5 billion in 2017, with a serrated evolution between 2010 and 2013 (Figure 4).

The allocations then experienced a drastic reduction of more than 62%, down from 5.019 billion in 2017 to 1.877 billion in 2020, i.e., almost its 2016 value.

3.6. Allocations before and after the development of the integrated strategic plan for the fight against NCDs 2016–2020

In 2015, the Ministry of Health developed an integrated national strategic plan to fight against NCDs 2016–2020. Immediately after the

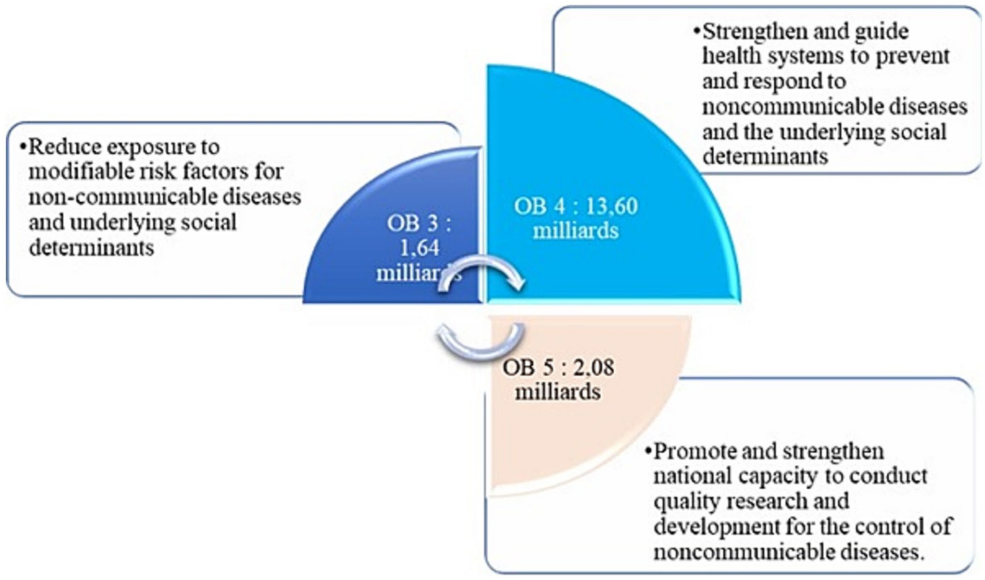


FIGURE 3
Allocations by objectives of the global NCD action plan.

10.3389/fpubh.2023.1253123

adoption of this Integrated Strategic Plan, the annual budget for NCDs more than doubled from 807 million CFA francs in 2015 to 1.87 billion CFA francs in 2020 (Figure 4). There is a funding peak to 5.019 billion in 2017, which represents an increase of 522% compared to 2015, the year preceding the entry into force of the National Strategic Plan 2016–2020.

The comparison of the average annual budget allocations before (2010–2015) and after (2016–2020) the development of the strategic plan (Figure 5) shows that overall, the budget allocations improved after the development of the strategic plan. Indeed, the average annual allocation increased significantly ($p = 0.02$) from about 467.4 million before the adoption of the Strategic Plan to more than 2.9 billion FCFA afterwards.

3.7. Effect of terrorism on budget allocations

On January 15, 2016, a double terrorist attack was perpetrated by al-Qaeda in the Islamic Maghreb, killing in total 30 person including 20 expatriates. Since that year the security situation has continued to deteriorate with government losing control of over 40% of the territory resulting in thousands of people internally displaced and many health facilities closed or operating at a minimum.

Figure 5 shows that the proportion of the budget directed to NCDs increased until 2017, when terrorist attacks began to intensify with an overall terrorism index of 6.2. From 2017, there was a gradual reduction in Ministry of Health allocations for NCDs as the number of terrorist incidents increased and became widespread across the country (Figure 6). Thus, we observe a significant negative correlation between the global terrorism index and the Ministry of Health allocations for NCDs ($r^2 = -0.32$, $p = 0.008$).

4. Discussion

This study contributed to documenting one of the most important evidence gaps related to governance of NCDs in low-income countries, i.e., level of investments for the prevention and control of NCDs. Findings show that over the period 2010–2020, the Burkina Faso Ministry of Health allocated nearly 1.5% of its sectoral budget for the control of NCDs. The financial allocation increased by more than 119% in 2016 compared to 2015, the year before the adoption of the integrated national plan (2016–2020) with a record increase of more than 522% in 2017 compared to 2015. Unfortunately, the emergence and expansion of the terrorism threat in the region reversed the government efforts, and the financial allocation for NCD keep decreasing as the terrorism index increased.

Five years after the endorsement of the Global action plan for the prevention and control of noncommunicable diseases 2013–2030 which committed Heads of State to commit to establishing and strengthening multisectoral national policies and plans for the prevention and control of NCDs, the government of Burkina Faso developed an integrated strategic plan for the fight against NCDs 2016–2020 (5). This is an indication that Burkina leaders acknowledged the devastating impact of noncommunicable diseases in the national agenda and committed to implement WHO recommendations to reduce the NCDs burden. It is well recognized that strong political leadership and commitment at the highest national level is the first key action to furthering a development issue on government agendas and galvanize actions. A policy framework is a tool to translate commitment into action through a set of feasible actions and interventions for which specific and timed targets and indicators can be developed, and progress measured. While the development of a reference document is not enough to address NCDs, the important increase in budgetary allocations for NCDs suggest that

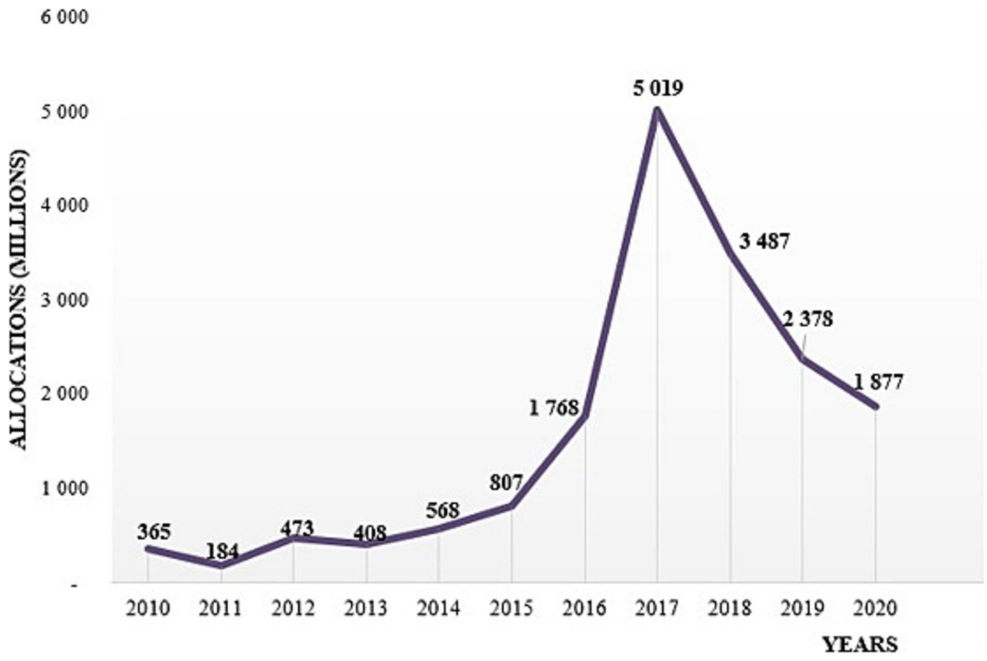


FIGURE 4
Evolution of budget allocations from 2010 to 2020.

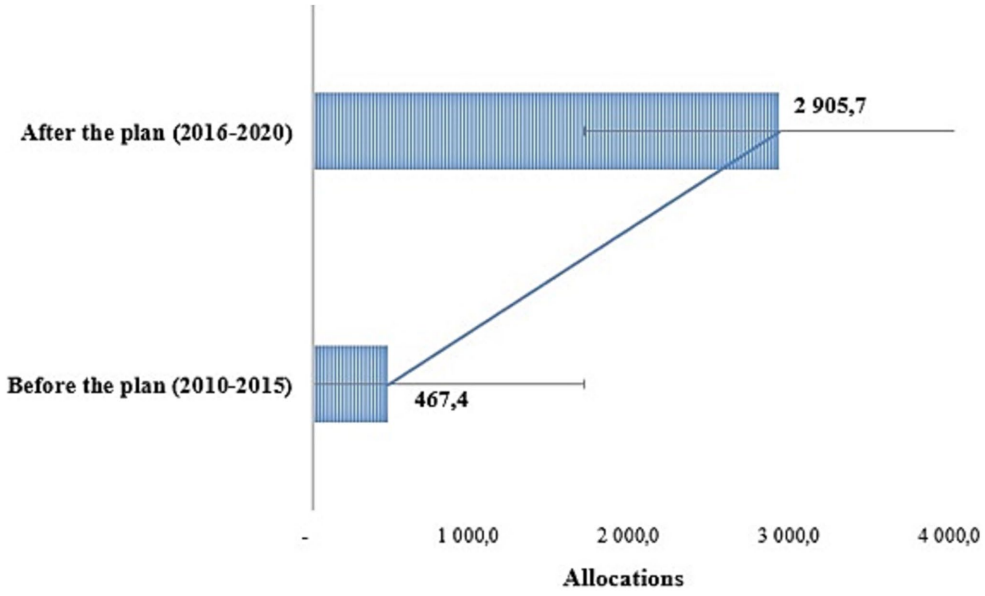


FIGURE 5
Comparison of average allocations before and after the strategic plan.

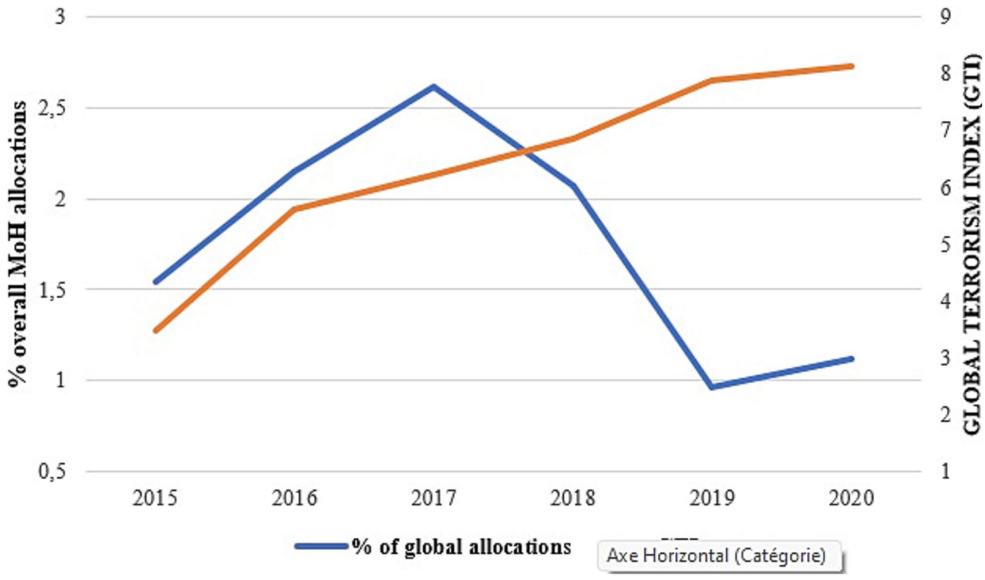


FIGURE 6
Comparative trends between MoH allocation for NCDs and global terrorist index.

policy adoption can accelerate the scale-up of proven effective actions for the prevention and control of NCDs (17). Although we are unable to clearly establish the impact of the strategic plan on the increase in allocations, the process of developing the national strategic framework has help better understood the problem, well-structured and cost the response, and therefore clarify investment opportunities (17–19). The plan highlight the importance of "screening for female cancer" which is considered one of the most cost-effective interventions in the fight against NCDs with a cost-effectiveness ratio ≤ 1 $ according to WHO (16). The cost of this intervention alone was estimated to 1.5 billion, and thus significantly increasing the national allocation.

The budget allocation was not equitably distributed across the 6 objectives of the WHO action plan, with interventions aimed at achieving objectives 1, 2, and 6. The objective non prioritized are mostly related to enabling environment including agenda setting and governance (Objective 1), capacity strengthening (Objective 2) and monitoring, evaluation and learning (Objective 6). However, while health systems strengthening and the reduction of modifiable risk

factors for noncommunicable diseases and underlying social determinants are critical, the impact on the nine NCD targets will be stronger if all six objectives of the global plan are funded (16). The lack of internal resources for evaluations, in particular the carrying out of STEPS surveys, does not make it possible to monitor progress in the prevention and fight against NCDs on the one hand and on the other hand to inform decision-makers with conclusive data. and updated in a timely manner. For example, over the analysis period (2010 to 2020), Burkina Faso carried out a STEPS survey in 2013 thanks to the resources of technical and financial partners compared to 11 nutritional surveys with the SMART methodology.

Findings suggest that after continuous increase over the past year, the annual financial allocation of the Ministry of Health for NCDs reverted in 2017, one year after Burkina Faso experienced its first terrorist attack. Further, after 2017, the allocations for NCDs decreased continuously as the number of terrorist attacks became widespread across the country. There was a strong negative correlation between the global terrorist index and the annual financial allocation for NCDs. It is to be noted that the impact of terrorism on budget allocation was observed in the 2018 budget likely because it was considered minor treat in the first year and the government spending in the response took effect only in the financial planning of 2018. Since then, the security situation continued to deteriorate, and terrorist related insecurity expanded across the country with many implications.

First the government has to increase the financial allocations for defense and security priorities. This has likely resulted in a shift towards reduction in the budgetary allocations of certain ministerial departments and development priorities.

Second not only does the insecurity inflict significant human and material losses, but it can generate innumerable humanitarian disasters (massive displacement of populations, food insecurity and malnutrition, ill health, economic, and social insecurity). Indeed, the increasing insecurity in some part of Burkina Faso led to population displacement towards less risky areas, causing enormous pressure on social infrastructure and financial demand to address the immediate basic social needs (clothing, housing, water, food, and health). The permanent secretariat of the National Council for Emergency Relief and Rehabilitation (SP/CONASUR) estimated that more than 2 million people in Burkina Faso were internally displaced (IDPs) in march 2023 (20). According to the results of CH, close to 2.2 million people need immediate assistance (population in phase 3 to 5) in March 2023 in Burkina Faso (21).

Thirdly, terrorist related insecurity can also yield negative consequences on the economies, including loss of national income, slower economic growth, lower foreign direct investment (FDI) and disparate effects on international trade. The terrorist attacks are said to have reduced net foreign direct investment in Spain by 13.5% and in Greece by 11.9% from the mid-1970s to 1991 (12). These economic losses could negatively affect investment priorities in the social sectors such as health. Terrorist incidents can also reduce investor confidence which leads to a reduction in foreign direct investment in the national economy (22, 23). The Institute for Economics and Peace (IEP), for example, estimated that between 2007 and 2016, foreign direct investment in target countries fell by 43%, from US$4.84 billion in 2007 to $2.74 billion in 2016 and the contribution of foreign direct investment to GDP fell from an average of 3.2% in 2007 to 2.5% in 2016 (23).

The impact of these terrorist attacks on the burden of NCDs is not well documented, yet there is likelihood that NCDs situation may worsen. Druetz et al. (24) have reported that the terrorist crisis lead to a deterioration of indicators of access to maternal health services in Burkina Faso. In Nigeria, other authors observed negative effects of Boko Haram attacks on the likelihood of any antenatal care visit, delivery at a health facility, and delivery attended by a skilled health professional (25). In the current study, we could not obtain reliable quality data on the prevalence of NCDs in Burkina Faso that are regularly collected to assess the impact of both the financial resource allocations and absorption and the negative impact of terrorism attacks on the occurrence of NCDs. The most reliable information on NCD in Burkina Faso was the STEP survey conducted in 2010. The second STEPs was completed in 2022 after we completed our data collection. We considered DHIS2, a web-based platform used as a health management information system worldwide; unfortunately, these data contain a lot of gaps to be used in this type of analysis. As a result, we decided to focus the current analyses on budget allocations, while exploring other opportunities to deepen the analysis to include NCD outcomes.

Beyond this study, lack of or poor data quality is generally one key gap for accountability in health programming as for many development issues where there is consistent budget allocation and absorption without measurement of outcome. Planning and budget allocation for development should therefore account not only for financial resource for the collection of outcome data, but also using the outcome data information for feedback and learning to identify key bottlenecks and gaps and make necessary corrective measures. There is a need to build a comprehensive health information management system, which includes outcome data to foster accountability.

In addition to the challenge of fighting insecurity, many efforts are still needed to improve budget allocations for the fight against NCDs when we know the financial burden of NCDs on households in low-and middle-income countries like Burkina Faso. If the downward trends continue, it may worsen the growing burden of non-communicable diseases, and therefore put a great strain on health systems and the country will not be able to meet the WHO/SDG targets for NCDs.

5. Conclusion

This study shows that the government of Burkina Faso through its Ministry of health allocates less than 2% of the health budget for the prevention and control of NCDs even if these diseases are considered a priority health problem and a leading cause of death globally. However, a significant increase in budget allocations has been observed since the endorsement of the WHO Global NCD Action Plan 2013–2020. The domestication of this plan in the national policy landscape through the adoption of an Integrated Strategic Plan for the fight against NCDs (2016–2020) has strengthened the political commitment as evidence by the important increased in the financial allocations for NCDs. Unfortunately, the efforts were reversed by the emergence of terrorist related insecurity triggered by the attacks of 2016 with an exponential reduction in allocations from 2017. To our knowledge, this is the first study in ECOWAS region to that attempts to assess the financial allocation for SDGs. It represents important baseline information to track funding allocations for the control of NCDs over years.

However, the study has some the limitations that may affect the interpretation of findings and are therefore worth highlighting. In this

study, due to methodological constraints such as lack of a consensual list of interventions for the fight against NCDs and data availability in other sectors, we limit the budget appraisal to the Ministry of Health. Further study that will include budget allocations from other sectors are needed. In addition, the classification and weighting methodology used to estimate the contribution rate for the different budget lines is derived from the one used for nutrition.

Finally, while there is evidence of negative impact of the terrorist related insecurity on financial allocations for NCDs, it is not clear how this will translate in terms of NCD indicator. Further analysis is needed to better understand the implication on NCD incidence and identify advocacy opportunities for mitigating the negative impact of the terrorist threat on NCDs and other development issues, which might be killing equally or even more than the terrorist crisis.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary material, further inquiries can be directed to the corresponding author.

Author contributions

MO, DS, AS, and NT-C collaborated for the conception and design of the study. MO led data collection in collaboration with IK and SS. MO and IK organized the database. MO carried out the statistical analysis. MO, DS, and OO interpreted the data. MO wrote the first draft of the manuscript under the guidance of DS and AS. All authors contributed to the article and approved the submitted version.

Acknowledgments

We would like to thank Adam Aho, Urbain Zongo, and Wendpouiré M. Ouedraogo for their useful comments and suggestions on the earlier version of this paper. Our sincere acknowledgements to Estelle A. Bambara, Souleymane Tirogo, and all the colleagues from the Nutrition Directorate, Ministry of Health Burkina Faso for their encouragements.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

All claims expressed in this article are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers. Any product that may be evaluated in this article, or claim that may be made by its manufacturer, is not guaranteed or endorsed by the publisher.

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1253123/full#supplementary-material

References

1. Mbanya JC, Squire S, Cazap E, Puska P. Mobilising the world for chronic NCDs. *Lancet*. (2010) 377:536–7. doi: 10.1016/S0140-6736(10)61891-0

2. Dain K. Challenges facing Global Health networks: the NCD Alliance experience: comment on "four challenges that Global Health networks face". *Int J Health Policy Manag*. (2018) 7:282–5. doi: 10.15171/ijhpm.2017.93

3. Curbing N. *Noncommunicable diseases in Africa: youth are key to curbing the epidemic and achieving sustainable development*. Washington: Population Reference Bureau (2015).

4. Chestnov O. *World Health Organization global action plan for the prevention and control of noncommunicable diseases*. Switzerland: Geneva (2013).

5. Nations Unies O. *Déclaration politique de la Réunion de haut niveau de l'Assemblée générale sur la prévention et la maîtrise des maladies non transmissibles*. New York. (2011). Available at: http://www.un.org/ga/search/view_doc. asp.

6. Alwan A. *Global status report on noncommunicable diseases 2010*. World Health Organization. (2011).

7. Nugent R. A chronology of global assistance funding for NCD. *Glob Heart*. (2016) 11:371–4. doi: 10.1016/j.gheart.2016.10.027

8. Gupta I, Ranjan A. Public expenditure on non-communicable diseases & injuries in India: a budget-based analysis. *PLoS One*. (2019) 14:e0222086. doi: 10.1371/journal.pone.0222086

9. Ouedraogo M, Sanou D, Ouedraogo O, Zongo U, Hama-Ba F, Savadogo A. An overview of governance of noncommunicable diseases (NCDs) in West African countries. *Pan Afr Med J*. (2023) 44:203. doi: 10.11604/pamj.2023.44.203.36175

10. Global Burden of Disease Cancer CollaborationFitzmaurice C, Akinyemiju TF, al Lami FH, Alam T, Alizadeh-Navaei R, et al. Global, regional, and national cancer incidence, mortality, years of life lost, years lived with disability, and disability-adjusted life-years for 29 cancer groups, 1990 to 2016: a systematic analysis for the global burden of disease study. *JAMA Oncol*. (2018) 4:1553–68. doi: 10.1001/jamaoncol.2018.2706

11. Nugent R, Brouwer E. Economic benefit-cost analysis of select secondary prevention interventions in LMIC. *Glob Heart*. (2015) 10:319–21. doi: 10.1016/j.gheart.2015.09.002

12. Subhayu B, Javed Y. The toll of terrorism. *Finance Dev*. (2015) 52:26–8.

13. Nutrition SU. (2021). *Investigating nutrition in national budgets: budget analysis for nutrition by the SUN movement, for the SUN movemen*. 2015.

14. Aho AKJ, Siri A, Tou Nana A, Gueye IN, Ndiaye S, Nébié G, et al. (2018). *Consultation ouest africaine sur la méthodologie de suivi du financement de la nutrition. Bureau régional de l'UNICEF pour l'Afrique de l'Ouest et du Centre, Bureau régional de Action Contre la Faim pour l'Afrique de l'Ouest; 2018*. Available at: https://www.actioncontrelafaim.org/wp-content/uploads/2018/04/Consultation-ouest-africaine_Design_v5_Final.pdf

15. Alfaro E. Understanding the global terrorism index. In: *Modern indices for international economic diplomacy*. Cham: Springer International Publishing (2022). p. 271–294.

16. Mondiale de la Santé O. *Combattre les MNT:«meilleurs choix» et autres interventions recommandées pour lutter contre les maladies non transmissibles (No. WHO/NMH/NVI/17.9)*. Organisation mondiale de la Santé. (2017).

17. Shilton T, Robertson G. (2018). *Battre les maladies non transmissibles de manière équitable–soyons sérieux*. SAGE Publications Sage UK: London, England. p. 78–80.

18. World Health Organization. *Global action plan for the prevention and control of noncommunicable diseases 2013-2020*. World Health Organization. (2013).

19. World Health Organization & Public Health Agency of Canada. *Preventing chronic diseases: a vital investment*. World Health Organization. (2005).

20. SP/CONASUR. Situation des PDI au 28 Février 2023. In: *Informing humanitarians worldwide, UN Office for the Coordination of Humanitarian Affairs*. (2023). Available at: https://reliefweb.int/report/burkina-faso/burkina-faso-apercu-des-personnes-deplacees-internes-28-fevrier-2023

21. MAAH. Fiche de communication du cadre harmonisé de mars 2023. In: Agriculture, editor. *Food security cluster* (2023). Available at: https://fscluster.org/burkina-faso/document/fiche-de-communication-du-cadre-0

22. Omenma TJ, Nwaogaidu JC, Okwueze FO. Terrorism trends in Africa. *Afr Insight*. (2020) 50:164–80.

23. UNDP. *Measuring the economic impact of violent extremism leading to terrorism in_Africa*. United Nations Development Programme_Empowered lives, Resilient nations. (2019). Available at https://www.undp.org/africa/publications/measuring-economic-impact-violent-extremism-leading-terrorism-africa

24. Druetz T, Browne L, Bicaba F, Mitchell MI, Bicaba A. Effects of terrorist attacks on access to maternal healthcare services: a national longitudinal study in Burkina Faso. *BMJ Glob Health*. (2020) 5:e002879. doi: 10.1136/bmjgh-2020-002879

25. Chukwuma A, Ekhator-Mobayode UE. Armed conflict and maternal health care utilization: evidence from the Boko Haram insurgency in Nigeria. *Soc Sci Med*. (2019) 226:104–12. doi: 10.1016/j.socscimed.2019.02.055

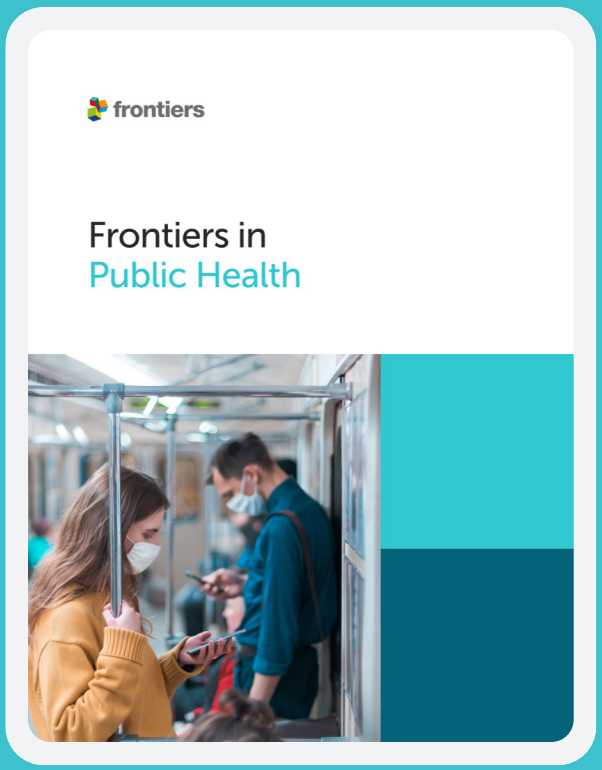
Frontiers in Public Health

Explores and addresses today's fast-moving healthcare challenges

One of the most cited journals in its field, which promotes discussion around inter-sectoral public health challenges spanning health promotion to climate change, transportation, environmental change and even species diversity.

Discover the latest Research Topics

See more →



Frontiers

Avenue du Tribunal-Fédéral 34
1005 Lausanne, Switzerland
frontiersin.org

Contact us

+41 (0)21 510 17 00
frontiersin.org/about/contact