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A sustainable trend in COVID-19 research: An environmental perspective

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Coronavirus disease 2019 (COVID-19) has spread across the globe producing hundreds of thousands of deaths, shutting down economies, closing borders and causing havoc on an unprecedented scale. Its potent effects have earned the attention of researchers in different fields worldwide. Among them, authors from different countries have published numerous research articles based on the environmental concepts of COVID-19. The environment is considered an essential receptor in the COVID-19 pandemic, and it is academically significant to look into publications to follow the pathway of hot topics of research and upcoming trends in studies. Reviewing the literature can therefore provide valuable information regarding the strengths and weaknesses in facing the COVID-19 pandemic, considering the environmental viewpoint. The present study categorizes the understanding caused by environmental and COVID-19-related published papers in the Scopus metadata from 2020 to 2021. VOSviewer is a promising bibliometric tool used to analyze the publications with keywords "COVID-19*" and "Environment." Then, a narrative evaluation is utilized to delineate the most interesting research topics. Co-occurrence analysis is applied in this research, which further characterizes different thematic clusters. The published literature mainly focused on four central cluster environmental concepts: air pollution, epidemiology and virus transmission, water and wastewater, and environmental policy. It also reveals that environmental policy has gained worldwide interest, with the main keyword "management" and includes keywords like waste management, sustainability, governance, ecosystem, and climate change. Although these keywords could also appear in other environmental policy-related research studies, the importance of the

COVID-19 pandemic requires such comprehensive research. The fourth cluster involves governance and management concerns encountered during the pandemic. Mapping the research topics in different clusters will pave the way for researchers to view future potential ideas and studies better. The scope for further research needs from the perspective of environmental concepts is reviewed and recommended, which can expand the vital role and value of environmental sciences in alerting, observing, and COVID-19 prediction for all four clusters. In other words, the research trend would shift from qualitative studies and perspectives to quantitative ones.

KEYWORDS

COVID-19 pandemic, SARS-CoV-2, environmental research trend, air quality, water and wastewater, epidemiology and virus transmission, environmental policy

1 Introduction

Millions of people died worldwide due to coronavirus disease 2019 (COVID-19) during recent years. Consequently, numerous studies in different areas have been inspired by the incredible social and economic effects of the pandemic and its unique features, specifically environmental science (Chakraborty et al., 2022a; b,c). As a major health crisis, the COVID-19 pandemic has pooled the attention of most researchers worldwide, leading to hundreds of publications in 2020 and 2021 mainly focusing on investigating and considering the environmental issues of COVID-19. The recent pandemic provided an exceptional opportunity to realize the possible effects of a pandemic on the environment, the actions required to minimize these impacts, and finally, how to enhance the environment's pandemic resilience. Many countries around the world are still struggling with the COVID-19 catastrophe; therefore, scientists are continually examining the pandemic's basic patterns and trying to make it more transparent in its unseen facets. New complicated mutations and various genetic variants of SARS-CoV-2 originated during the past 18 months (Sakib et al., 2021; Hossain et al., 2021). Evidently, numerous papers have been published in recent years to evaluate the impact of the COVID-19 pandemic on the environment.

In 2020, environmental science researchers focused significantly on specific issues such as the nature of the pandemic, virus transmission, and air pollution issues, while the key themes such as vulnerability assessment, environmental policy, and sustainable development management have been mostly neglected (Jakariya et al., 2021). The studies concerning the environmental impacts of COVID-19 have recurred in the literature. Organizing and systematizing the dataset and information already collected in this research is essential. Review papers are typically deemed promising tools to delineate the research direction and gaps and direct the researchers to future potential studies. Different perspectives were studied in recent review papers on COVID-19 related to the environment, like the optimistic viewpoint (Khan et al., 2021), pessimistic viewpoint (Sharma et al., 2021); socioeconomic (Bashir et al., 2020; Tepe, 2023); COVID-19 in the environment, humans, and animals (Swelum et al., 2020); air pollution (Liu et al., 2020; Sicard et al., 2020; Tang et al., 2020; Fareed et al., 2021; Srivastava, 2021; Jana et al., 2023), the pandemic's impact on pro-environmental product consumption (Kim and Lee, 2022); green gas emission; chemical materials; geographical variations on COVID-19 surveillance (Mohsin et al., 2021; Jakariya et al., 2022); the urban design's role on public health during the pandemic (Faedda et al., 2022); and future perspectives (Daughton, 2020).

In the present research, the Scopus database was used to identify the research trend direction. The bibliometric research method was used in this study for almost 3 years of publications, from January 2020 to December 2022. This method has been successfully applied in several studies, previously, such as environmental governance in rural areas, green energy (Tan et al., 2021; Russo et al., 2023), sustainable development goals (SDGs) in strategic planning (Petrushenko et al., 2020), and environmental management and social marketing (Letunovska et al., 2021). The environmental management and policy and interest in these research topics have been brought to the fore by the recent pandemic.

The present review is one of the first on environmental concepts to explain the hidden research trends during the COVID-19 pandemic. First, the study performs bibliometric and descriptive evaluations of the chosen papers related to COVID-19 and the environment. Second, a systematic literature review is used to categorize the existing literature, which assists in having a thorough understanding of COVID-19 and environmental issues. Lastly, as different driving forces, such as global warming and human violation of flora and fauna environments, may increase the occurrence of epidemics in the future, it is vital to have the required planning, reaction, and adaptation processes (Vadiati et al., 2010).

In order to emphasize current knowledge and gaps to delineate the hidden research trends during the epidemic, the existence of a literature review is vital. The main goals of the present study are the identification of the epidemic's effects on the environment besides focusing on the essential lessons which could be studied for post-COVID environment development. The remainder of the study is structured as follows. Section 2 describes the current research structure, including the advantages of bibliometric analysis, search strategies, and procedures, to describe and systemize the literature. The descriptive analysis of relevant papers is presented in Section 3. This section continues with potential research trends, suggestions for upcoming research topics, and machine learning (ML) applications. Finally, the conclusion and outlook are stated in Section 4. The flowchart of the present study is presented in Figure 1.

2 Materials and methods

Bibliometric analysis has scrutinized the bibliographic data obtained from previous research publications (Robertson et al.,

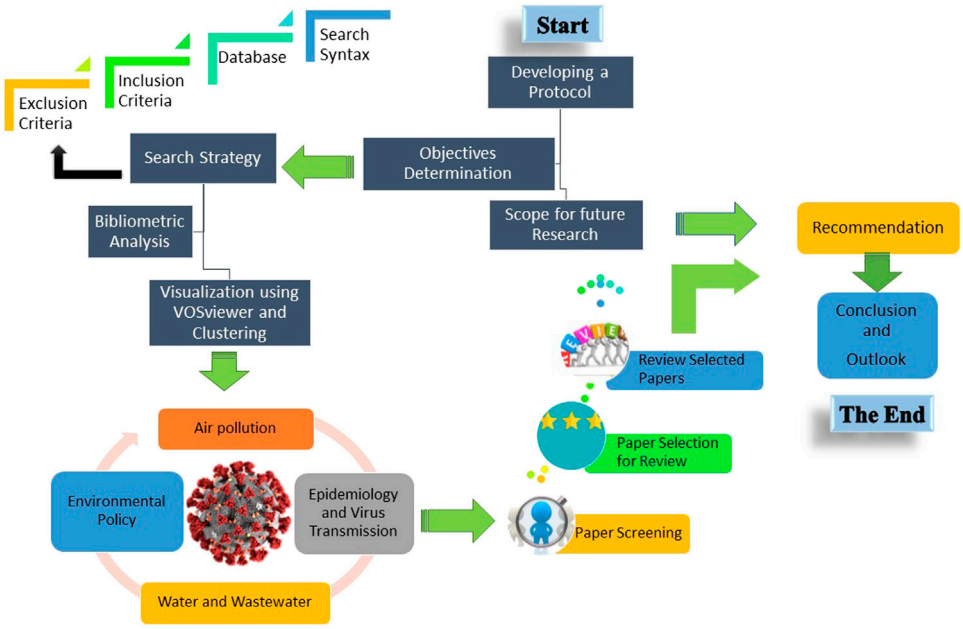

FIGURE 1
The general framework of the present studies. The research structure described in Section 2 includes the study's main objectives, search strategies, and methods for describing and systemizing the literature. Section 3 presents the descriptive analysis of relevant papers and continues with the knowledge and research trends, specifically, the scope for future research regarding COVID-19, suggestions for upcoming research, and restrictions on machine learning (ML). Finally, Section 4 presents the conclusion and outlook.

2020; Yin et al., 2020; Tan et al., 2021) to examine the publishing trends and patterns of the COVID-19 pandemic. Literature systematization techniques have been used to recognize the research topic patterns of the selected papers. The literature systematization techniques could also assess the critical research fields and potential research direction (Chen et al., 2014).

The trend, as a critical informative statistics, could be reflected by bibliometrics and literature systematization. It can also reveal publication activities, the review of the articles by the scientific community, and forming a specialized attitude on the environmental concerns besides the effect of the existing situation with COVID-19.

2.1 Search strategies

The present research data have been collected from the Scopus database, which covers a wide range of published papers in the literature (Singh et al., 2020). The search terms targeted instantaneously rooting out two main concepts: environment and pandemic. The search process has been focused on the terms: (COVID*) and (environment*). The asterisk granted different alternatives for the keywords in the terms such as COVID-19, COVID-19 pandemic, and environmental. Hence, an alternative term has been included regarding the pandemic, "Coronavirus." All these processes lead to a search string given as follows:

"[TITLE-ABS-KEY (covid*) OR TITLE-ABS-KEY (corona*) AND TITLE-ABS-KEY (environment*)] AND [LIMIT-TO (SUBJAREA, "ENVI") OR LIMIT-TO (SUBJAREA, "EART") OR LIMIT TO (SUBJAREA, "AGRI")] AND [LIMIT-TO (LANGUAGE, "English")] AND [LIMIT-TO (PUBYEAR, 2020) OR LIMIT-TO (PUBYEAR, 2021) OR LIMIT-TO (PUBYEAR, 2022)] AND [LIMIT-TO (SRCTYPE, "j")] AND [EXCLUDE(SUBJAREA, "MEDI")]."

The present study scrutinized different parts of literatures such as titles, abstracts, and keywords. Other characteristics of the published papers, in addition, were under exact consideration to be selected, namely, having a suitable quality level and being peer-reviewed, although the published literature only written in English were considered. Even though the analysis of critical terms showed the research area and tendency, it represented the authors' research area of interest. The current study included the papers published in "environmental science," "Earth and planetary sciences," and "agricultural and biological" study areas and excluded "medicine" papers related to COVID-19. The search process has mainly focused on important units of papers, such as titles and abstracts.

The substantial challenge in this subsequent purification procedure was ambiguity, emerging from the important parts of papers such as titles, keywords, and their abstracts. However, some papers discussed about the environment, containing the "COVID" term and/or its substitutes. The condition was allocated to a temporal connection with the COVID-19 crisis rather than assessing its environmental impacts. During data purification, some general terms, such as human, humans, article, and study, were eliminated. Removing the uninformative terms, however, improved the publications' relationship

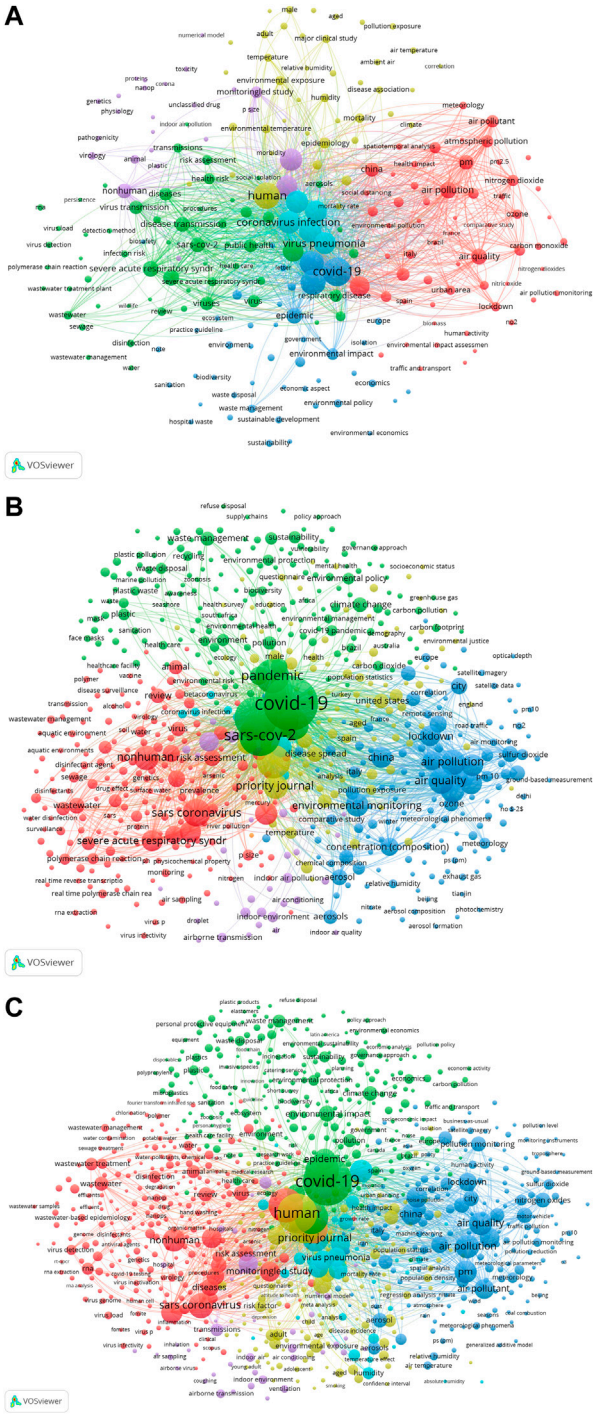

FIGURE 2
Term co-occurrence network map for all four clusters in 2020 **(A**, top**)**, 2021 **(B**, middle**)**, and 2022 **(C**, bottom**)**. The size of the circles represents the occurrences of the keywords. The thickness and distances of lines represent the strength and association of the keywords. VOSviewer signifies each category or cluster of keywords with a unique color.

and affected the clustering of the results. Additionally, similar terms were compiled into one term, such as "COVID-19," "COVID," "air pollution," and "atmospheric pollution."

2.2 Methods for explaining and systematizing the literature

Review papers, in the next phase, were checked in detail to define the vital data for assessments, particularly critical lessons, existing in the subsequent unit. Studying the abstracts of the papers, the nominated papers were categorized into individual clusters, and all sections of the selected papers were reviewed. For example, the clusters related to different forms of air pollution were merged into the "air quality" category.

3 Results and discussion

3.1 Descriptive and bibliometric analysis of the investigation trends

It is essential to quickly recognize the frontlines in each area, and the documents from forerunner writers and/or assemblies were followed. To understand the themes of concentration in papers databased on the environment and COVID-19, this study employed co-occurrence analysis, which was achieved in two approaches to reach more dependable results: title and keyword- and abstract-based (Singh et al., 2020; Kaur et al., 2021).

Upon using the search strategy, articles published in 2020, 2021, and 2022 were extracted. The quantity of published papers promptly increased every year, and the study trend is also more distinct. Publications consisted of 80% original research papers, 13% review papers, and 7% other forms of publications, including letters, editorials, and reports. We were very strict about using careful inclusion criteria to recognize studies related to the objective of this review. Although the database search was comprehensive, missing some articles is still possible. Before that, a brief screening was employed to exclude articles unrelated to this study.

Various types of bibliometric analysis software, such as Biblioshiny, VOSviewer, BibExcel, and Bibliometrix, are used by different researchers. VOSviewer 1.6.18 software was used in this study to assess the co-occurrence, bibliographic coupling, and clusters since it helps visualize the research clusters better. Standard weight features employed in this study are described as "Links attribute" and "Total link strength attribute" (Stephan et al., 2017). As the number of neighboring elements was more significant than the distance between them, the density of the elements was higher. Moreover, as the weight of neighboring elements was more significant, the element density was higher.

Figure 2A demonstrates the results of the co-occurrence evaluation based on the papers' keywords in titles, authors' keywords and abstracts of the manuscript, and the obtained clusters in 2020. The nodes are the main concepts or keywords, while the dimension of every node is compatible with their recurrence rate. VOSviewer signifies each category or cluster of keywords with a unique color. Figures 2B, C show the results of the co-occurrence analysis in 2021 and 2022, respectively.

Cluster 1, "air pollution" in orange color, has the term "air quality and air pollution" as its central node. It includes terms such as pollution monitoring, lockdown, and pollutants. The typical paper was titled "Association between short-term exposure to air

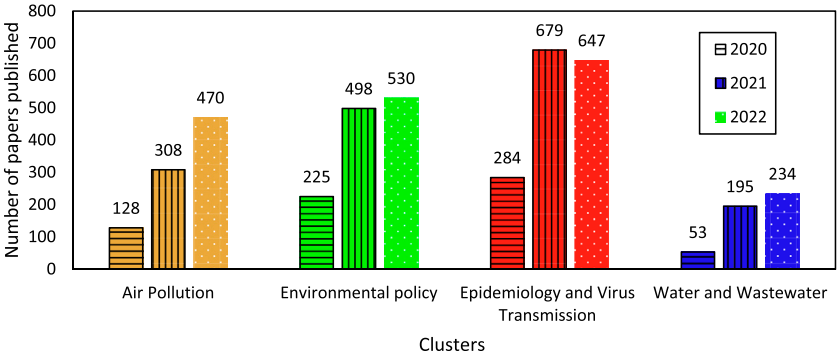

FIGURE 3
The published papers in 2020, 2021, and 2022 are presented based on the clusters (Air pollution, Environmental policy, Epidemiology and Virus Transmission, Water and Wastewater).

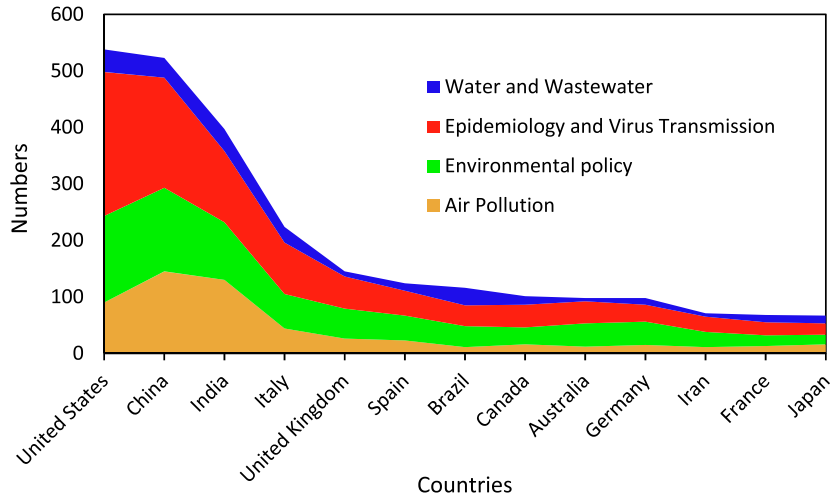

FIGURE 4
Papers published according to the clusters based on countries. The highest number of papers were published in the United States, followed by China, India, and Italy. The next countries are the United Kingdom, Spain, Brazil, and Canada. The air pollution cluster has the most published papers in China, while epidemiology and virus transmission attracted more scientists from the United States.

pollution and COVID-19 infection: Evidence from China" in the Science of the Total Environment journal by Zhu et al. (2020).

Cluster 2 (red color) has the term "epidemiology and virus transmission" as its central node and including other keywords such as mortality, infection rate, and adult and health impact. The "epidemiology and virus transmission" cluster covers issues related to society, which is strongly marked by infection and virus transmission during the pandemic. The typical paper was titled "COVID-19 outbreak: Migration, effects on society, global environment, and prevention" by Chakraborty and Maity (2020) in the Science of the Total Environment journal.

Considering the virus occurrence in water and wastewater, cluster 3 (blue) titled "water and wastewater." Research on this cluster is mainly focused on monitoring and sampling SARS-CoV-2 or RNA fragments in sewage and wastewater in the environment. It includes terms such as disinfection, sanitizers, and RNA (Ahmed W et al., 2020). The representative paper was published in the Water Research journal by Randazzo et al. (2020)titled "SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low prevalence area."

Cluster 4 (green) "environmental policy" has the term "management" and includes keywords like waste management, sustainability, governance, ecosystem, and climate change. So, the cluster involves governance and management concerns during the pandemic. The representative paper was titled "Indirect effects of COVID-19 on the environment," published in the Science of the Total Environment journal by Zambrano-Monserrate et al. (2020). In general, the occurrence of these clusters shows the top four continuing research facets at present conducted at worldwide level.

Most articles in 2021 were involved in the epidemiology and virus transmission cluster, followed by the environmental policy cluster. Each paper was categorized in a cluster depending on its

TABLE 1 Brief detail of the selected papers.

Reference	Title	Corresponding author	Document type	CODEN	Cluster
Zhu et al. (2020)	Association between short-term exposure to air pollution and COVID-19 infection: Evidence from China	Xie, J., China	Article	STOTEN	Air pollution
Mahato et al. (2020)	Effect of lockdown amid the COVID-19 pandemic on air quality of Delhi, India	Ghosh, K.G., India	Article	STOTEN	Air pollution
Conticini et al. (2020)	Can atmospheric pollution be considered a co-factor in extremely high level of SARS-CoV-2 lethality in Northern Italy?	Caro, D., Denmark	Note	STOTEN	Air pollution
Ogen (2020)	Assessing nitrogen dioxide (NO_2) levels as a contributing factor to coronavirus (COVID-19) fatality	Ogen, Y., Germany	Article	STOTEN	Air pollution
Tobías et al. (2020)	Changes in air quality during the lockdown in Barcelona (Spain) 1 month into the SARS-CoV-2 epidemic	Tobías, A., Spain	Article	STOTEN	Air pollution
Nakada and Urban (2020)	COVID-19 pandemic: Impacts on the air quality during the partial lockdown in São Paulo, Brazil	Nakada, L.Y.K., Brazil	Article	STOTEN	Air pollution
Dantas et al. (2020)	The impact of COVID-19 partial lockdown on air quality in the city of Rio de Janeiro, Brazil	da Silva, C.M., Brazil	Article	STOTEN	Air pollution
Fattorini and Regoli (2020)	Role of chronic air pollution levels in the COVID-19 outbreak risk in Italy	Regoli, F., Italy	Note	ENVPOL	Air pollution
Zambrano-Monserrate et al. (2020)	Indirect effects of COVID-19 on the environment	Zambrano-Monserrate, M.A., Ecuador	Article	STOTEN	Environmental policy
Muhammad et al. (2020)	COVID-19 pandemic and environmental pollution: A blessing in disguise?	Muhammad, S., China	Article	STOTEN	Environmental policy
Saadat et al. (2020)	Environmental perspective of COVID-19	Rawtani, D., India	Review	STOTEN	Environmental policy
Vellingiri et al. (2020)	COVID-19: A promising cure for the global panic	Vellingiri, B., India	Review	STOTEN	Environmental policy
Wang and Su (2020)	A preliminary assessment of the impact of COVID-19 on the environment—A case study of China	Wang, Q	Article	STOTEN	Environmental policy
Mollalo et al. (2020)	GIS-based spatial modeling of the COVID-19 incidence rate in continental United States	Mollalo, A., United States	Article	STOTEN	Environmental policy
Fadare and Okoffo (2020)	COVID-19 face masks: A potential source of microplastic fibers in the environment	Fadare, O.O., China	Article	STOTEN	Environmental policy
Patrício Silva et al. (2021)	Increased plastic pollution due to COVID-19 pandemic: Challenges and recommendations	Patrício Silva, A.L., Portugal	Review	CEJ	Environmental policy
Chakraborty and Maity (2020)	COVID-19 outbreak: Migration, effects on society, global environment, and prevention	Maity, P., India	Article	STOTEN	Epidemiology and virus transmission
Ma et al. (2020)	Effects of temperature variation and humidity on the death due to COVID-19 in Wuhan, China	Luo, B.h, China	Article	STOTEN	Epidemiology and virus transmission
Rizou et al. (2020)	Safety of foods, food supply chain, and environment during the COVID-19 pandemic	Galanakis, C.M., Greece	Note	TFST	Epidemiology and virus transmission
Acter et al. (2020)	Evolution of severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2) as a coronavirus disease 2019 (COVID-19) pandemic: A global health emergency	Uddin, N., Bangladesh	Review	STOTEN	Epidemiology and virus transmission
Shi et al. (2020)	Impact of temperature on the dynamics of the COVID-19 outbreak in China	Xi, S., China	Article	STOTEN	Epidemiology and virus transmission
Bennett et al. (2020)	The COVID-19 pandemic, small-scale fisheries, and coastal fishing Communities	Bennett, Canada	Article	CM	Epidemiology and virus transmission
Jayaweera et al. (2020)	Transmission of the COVID-19 virus by droplets and aerosols: A critical review on the unresolved dichotomy	Jayaweera, M., Sri Lanka	Review	ER	Epidemiology and virus transmission

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TABLE 1 (*Continued*) Brief detail of the selected papers.

Reference	Title	Corresponding author	Document type	CODEN	Cluster
Prata et al. (2020a)	Temperature significantly changes COVID-19 transmission in (sub)tropical cities of Brazil	Prata, D.N., Brazil	Article	STOTEN	Epidemiology and virus transmission
Randazzo et al. (2020)	SARS-CoV-2 RNA in wastewater anticipated COVID-19 occurrence in a low-prevalence area	Sánchez, G., Spain	Article	WR	Water and wastewater
La Rosa et al. (2020b)	First detection of SARS-CoV-2 in untreated wastewaters in Italy	La Rosa, G., Italy	Article	STOTEN	Water and wastewater
Kitajima et al. (2020)	SARS-CoV-2 in wastewater: State of the knowledge and research needs	Kitajima, M., Japan	Review	STOTEN	Water and wastewater
La Rosa et al. (2020a)	Coronavirus in water environments: Occurrence, persistence, and concentration methods—A scoping review	La Rosa, G., Italy	Review	WR	Water and wastewater
Wang et al. (2020c)	Disinfection technology of hospital wastes and wastewater: Suggestions for disinfection strategy during the coronavirus disease 2019 (COVID-19) pandemic in China	Pan, L., China	Review	ENVPOL	Water and wastewater
Haramoto et al. (2020)	First environmental surveillance for the presence of SARS-CoV-2 RNA in wastewater and river water in Japan	Haramoto, E., Japan	Article	STOTEN	Water and wastewater
Yunus et al. (2020)	COVID-19 and surface water quality: Improved lake water quality during the lockdown	Yunus, A.P., China	Article	STOTEN	Water and wastewater
Foladori et al. (2020)	SARS-CoV-2 from feces to wastewater treatment: What do we know? A review	Foladori, P., Italy	Article	STOTEN	Water and wastewater
Kumari and Toshniwal (2022)	Impact of lockdown measures during COVID-19 on air quality—A case study of India	Kumari, P., India	Article	IJEHR	Air pollution
Tian et al. (2022)	Global low-carbon energy transition in the post-COVID-19 era	Shan, Y., Netherlands	Article	AE	Environmental policy
Deng et al. (2022)	Antiviral/antibacterial biodegradable cellulose non-wovens as environmentally friendly and bioprotective materials with the potential to minimize microplastic pollution	Xiao, H., Canada	Article	HAZMAT	Environmental policy
Coccia (2022)	Optimal levels of vaccination to reduce COVID-19-infected individuals and deaths: A global analysis	Coccia, M., Italy	Article	ER	Epidemiology and virus transmission
Irfan et al. (2022)	On the indirect environmental outcomes of COVID-19: Short-term revival with futuristic long-term implications	Irfan, M., China	Article	IJEHR	Environmental policy
Yang et al. (2022)	Implications of COVID-19 on global environmental pollution and carbon emissions with strategies for sustainability in the COVID-19 era	Yap, P.S., China	Review	STOTEN	Environmental policy
Dinoi et al. (2022)	A review on measurements of SARS-CoV-2 genetic material in air in outdoor and indoor environments: Implication for airborne transmission	Conticini, D., Italy	Review	STOTEN	Epidemiology and virus transmission
Kumar-Muniasamy et al. (2022)	Impact of COVID-19 on greenhouse gases emissions: A critical review	Hussain, C.M., United States of America	Review	STOTEN	Environmental policy
Peng et al. (2022)	Practical indicators for risk of airborne transmission in shared indoor environments and their application to COVID-19 outbreaks	Jimenez, J.L., United States of America	Article	EST	Epidemiology and virus transmission
Brillas (2022)	A critical review on ibuprofen removal from synthetic waters, natural waters, and real wastewaters by advanced oxidation processes	Brillas, E., Spain	Review	JC	Environmental policy
Harussani et al. (2022)	Pyrolysis of polypropylene plastic waste into carbonaceous char: Priority of plastic waste management amid the COVID-19 pandemic	Sapuan, S.M., Malaysia	Review	STOTEN	Environmental policy

(Continued on following page)

TABLE 1 (*Continued*) Brief detail of the selected papers.

Reference	Title	Corresponding author	Document type	CODEN	Cluster
Mghili et al. (2022)	Face masks related to COVID-19 in the beaches of the Moroccan Mediterranean: An emerging source of plastic pollution	Mghili, B., Morocco	Article	MPB	Environmental policy
Kutralam-Muniasamy et al. (2022)	A critical synthesis of current peer-reviewed literature on the environmental and human health impacts of COVID-19 PPE litter: New findings and next steps	Shruti, V.C., Mexico	Review	HAZMAT	Environmental policy

Abbreviation: STOTEN: Science of the Total Environment; ENVPOL: environmental pollution; CEJ: Chemical Engineering Journal; EST: Environmental Science and Technology; TFST: Trends in Food Science and Technology; CM: coastal management; EI: environment international; ER: Environmental Research; EDSNB: Environment Development and Sustainability; IJEHR: International Journal of Environmental Health Research; WR: Water Research; AE: Applied Energy; HAZMAT: hazardous material; JC: chemosphere; MPB: Marine Pollution Bulletin.

main thematic aim. Figure 3 presents papers published in 2020, 2021, and 2022 based on the clusters. The number of published studies on "air pollution" and "water and wastewater" classes increased from 2020 to 2022, representing the highest increase among the four clusters.

Figure 4 presents the papers published according to the clusters based on countries such as the United States and China, followed by India and Italy. The other countries included the United Kingdom, Spain, Brazil, and Canada. The air pollution cluster has the most published papers in China, while epidemiology and virus transmission attracted more scientists from the United States.

3.2 State of the knowledge and research trends

A substantial increase and confirmed case numbers have been shown among scientific publications during the pandemic (Ji et al., 2021b). A brief detail of the selected papers is provided in Table 1. These papers were selected based on their thematic focus after checking the abstracts and contents and assigning each paper to four clusters. All COVID-19 papers related to the scope of the current research have been published in unique journals. Science of the Total Environment has the largest source of publications, and Environmental Research ranked second. Environmental Science and Pollution Research, Environmental Pollution, Environmental Science and Technology, Environment International, Water Research and Journal of Environmental Management were in the following rankings. The following concise evaluation of the literature related to the clusters is carried out.

3.2.1 Air quality

Air as a part of our surrounding environment is vital. Jana et al. (2023) discussed the possible relationship between COVID-19 infection rate with different air quality parameters (Jana et al., 2023). They used mathematical modeling between various factors such as district-level COVID-19 data infected number and case fatality rate with environmental parameters such as land surface temperature, relative humidity (RH), sulfur dioxide (SO_2), nitrogen dioxide (NO_2), ozone (O_3), and aerosol optical depth (AOD). They noticed a pattern of spatial shifting of COVID-19 parameters from the western to the southern and eastern parts of India. The time-series analysis significantly indicates more CFR with higher AOD, O_3, and NO_2 in India. However, the high infection rate in their study in Northern India and Maharashtra can be originated from a high population density in these regions.

Wearing masks and social distancing was an easy and effective way to control the virus-loaded aerosol and droplet spread (Jayaweera et al., 2020). More specifically, even with scientific proof, airborne transmission is not appropriately studied (Buonanno et al., 2020). To manage the ongoing pandemic condition, it is essential to find out the related factors linked with the rapid spreading of COVID-19. Many regions of the world were forced to partial and total lockdowns in response to the pandemic. Transportation policy intervenes and reforms the air pollution patterns due to lockdown (Kerimray et al., 2020; Morawska and Cao, 2020). However, all these changes have resulted in some surprising outcomes. A sudden drop in carbon emissions happened because of the shutting down of many industries, transportation systems, and other businesses. The effects of lockdown on particulate matter (PM), $PM_{2.5}$, PM_{10}, and other pollutants like CO, NO_2, O_3, and SO_2 have primarily been discovered compared to pre-lockdown concentration levels.

Significantly reducing NO_2 and CO, which are pollutants rooted in travel restrictions and correlated with the transport section, is the result shown in most cases (Baldasano, 2020; Dantas et al., 2020; Saadat et al., 2020). Considerable decreases reported in Asian and Brazilian cities indicate that the transportation sector's rejuvenation can return substantial air quality gains (Filonchyk et al., 2020; Kanniah et al., 2020; Sharma et al., 2020). PM concentrations during the lockdown period have even been evidenced in some cases. For instance, in some regions of China, this was happening owing to a rise in house heating systems and a boost in business activities in the marginal regions compensating for the shutdown of manufacturing activities in prominent residential regions (Nichol et al., 2020). Studies from Brazil and Morocco show that PM concentration levels may increase due to long-variety transport of flakes from adjacent industrial or rural districts (Dantas et al., 2020; Otmani et al., 2020). This indicates the insufficiency of strategic procedures to decrease traffic-linked pollution (Nichol et al., 2020).

Decreasing air pollution levels due to lockdowns could enable people to cope with COVID-19, especially susceptible ages and patients. According to the early evidence, the other important issue is air quality. Strong relationships between the pandemic and air pollution levels have been observed in several studies (Coccia, 2020;

Xu et al., 2020; Yao et al., 2020). For example, higher spread rates of COVID-19 in Northern Italy have been reported to be indicated by above-average air pollution levels (Cartenì et al., 2020). Furthermore, increasing vulnerability to COVID-19 by affecting the respiratory system can be indirectly affected by long-term contact with pollution (Berman and Ebisu, 2020). Hence, upgrading the air quality could focus on COVID-19 and other upcoming short- and long-term pandemics.

Zhu et al. (2020) studied the association between daily confirmed cases, short-run exposure to air pollutants ($PM_{2.5}$, PM_{10}, SO_2, CO, NO_2, and O_3), and meteorological variables in 120 cities in China. Their results indicate a meaningful positive correlation between $PM_{2.5}$, PM_{10}, NO_2, and O_3 with COVID-19-confirmed infection cases. Conticini et al. (2020) investigated the correlation between air pollution parameters and the fatality of COVID-19 in the two most common air-polluted cities in Northern Italy. Their results showed that the residents of Lombardy and Emilia Romagna are significantly prone to COVID-19 infection.

Mahato et al. (2020) explored the enforced countrywide lockdown and its impacts on the air quality of Delhi, India, using representative air pollution parameters in 34 air monitoring stations (PM_{10}, $PM_{2.5}$, SO_2, NO_2, CO_2, O_3, and NH_3). The air quality index was used to investigate the spatial outline of air quality in pre- and syn-lockdown stages. The results showed air quality improvement (50%), especially in PM_{10} and $PM_{2.5}$ concentrations, compared to the pre-lockdown and about 60% and 39% reduction of PM_{10} and $PM_{2.5}$, respectively, compared to the same period in 2019. Fattorini and Regoli (2020) investigated the chronicity of air pollutants (NO_2, O_3, $PM_{2.5}$, and PM_{10}) in the risk of COVID-19 infection in Italy during the last 4 years. The results highlighted that Northern Italy has been continuously subjected to chronic air pollution.

Ogen (2020) assessed the correlation between COVID-19 fatality level and long-run exposure to NO_2 using a satellite dataset concerning 66 areas in Italy, Spain, France, and Germany. The outcomes displayed that 78% of death cases occurred in five areas in central Spain and north Italy, the same five areas with the highest level of NO_2. Tobías et al. (2020) assessed the air quality changes during the lockdown in Barcelona, Spain, for a month. The results showed a significant reduction in NO_2, a lower reduction in PM_{10}, and an increase in O_3 levels due to different factors.

Nakada and Urban (2020) assessed the impacts of the lockdown on the air quality in São Paulo—Brazil, for the average monthly interval for 5 years and 4 weeks prior to the imposed partial lockdown. In general, extreme drops in the level of NO (about −77%), NO_2 (about −54%), and CO (about −65%) and an increase in ozone level (about +30%) are highly inspired by traffic emissions in the urban area. In another outstanding research conducted in Brazil, Rio de Janeiro, Dantas et al. (2020) studied the impacts of lockdowns on air quality. Their study showed considerable reductions in NO_2, PM10, and CO levels (from 30 to 48 percent) in the first lockdown weeks, while ozone concentrations increased. Compared to 2019, the average values of NO_2 and CO were 24–33% and 37–43% percent lower, respectively. Therefore, air quality and air pollution grouped pollution monitoring, lockdown, and pollutant terms in cluster 1 with orange color. Numerous papers studied the association between short air pollution and the COVID-19 pandemic.

3.2.2 Epidemiology and virus transmission

Pandemics have excessively harmed individuals at the bottom side of the social and economic span. Preexisting situations due to further disclosure to threats, economic obstacles, and restricted approaches to services often affect people more (Wade, 2020). If not possible, it is tough to limit the pandemic in slum areas by encouraging quarantine and social distancing strategies due to a combination of high intensity, insufficient provision of essential public services, and dangerously low incomes (Wasdani and Prasad, 2020). This and other variation problems cause social distancing struggles, thus discouraging the efficacy of "homestay" instructions for limiting the pandemic (Mishra et al., 2020).

Therefore, epidemiological alterations should be observed in coronavirus infections, although a significant number of questions have not been thoroughly answered yet, such as how many persons tested, turned positive, and recovered. The variation, evolution, and circulation of COVID-19 among humans and wildlife must be considered by epidemiological alterations in coronavirus infections (Islam et al., 2021; Gu et al., 2023). Some doubts have remained and must be considered. The most important things are the number of people tested, the number of positive cases, and whether this range stays constant or variable. The reported pediatric cases have been fewer, for which the reason could be lack of testing, not the actual infection, although what must be considered are the possible paths of virus transmission, infections, adaptation progression, virus spread among individuals, and possible wildlife. SARS-CoV-2 passes in the target cell, the main upper respiratory tract, due to its relation with angiotensin-converting enzyme 2 (ACE2), being produced in the epithelial cells of the respiratory tract, GI tract, and excretory system, and uses the host cellular machinery to spread, before being adopted by receptor-mediated endocytosis, forming early endosomes including virus (Islam et al., 2022b).

Masks are long-lasting plastic-based textiles and are disposed in landfills or water bodies (Saadat et al., 2020). The quantity of garbage produced will significantly increase due to people suddenly wearing masks, especially medical waste. Prata D. N. et al. (2020) examined the correlation between climatological and COVID-19 datasets in subtropical cities of Brazil. The results showed that a −4.8951% reduction in the rising cases of confirmed COVID-19 in a day is associated with each 1°C increase in the temperature. In general, more studies are required to comprehend the correlation between temperature and COVID-19.

Chakraborty and Maity (2020) evaluated the social and environmental effects of COVID-19 outbreak and the potential circumstances to control the pandemic. In another study, Ma et al. (2020) evaluated the effects of humidity and temperature changes and the daily COVID-19 fatalities in Wuhan, China, from 20 January 2020 to 29 February 2020. They employed the generalized additive model to investigate the role of humidity, temperature, and diurnal temperature ranges in death-confirmed cases.

Rizou et al. (2020) reviewed foods' safety and supply chain by summarizing the potential transmission aspects of the COVID-19 virus through different food sectors. Acter et al. (2020) reviewed the global health emergency perspective of the COVID-19 pandemic in another study. Shi et al. (2020) explored the effect of temperature on the dynamics of the COVID-19 pandemic in 31 provincial-level

areas of China. In this regard, distributed lag non-linear models (DLNMs), locally weighted regression and smoothing scatterplot (LOESS), and random-effects meta-analysis were applied to assess the correlation between daily average temperature and confirmed infected cases. The results showed that, generally, the intensity of COVID-19 decreased to some extent with higher temperatures. This is not in agreement with the results of Chakraborty and Maity (2020). This can be explained by the fact that there should be other effects that were not considered in the related studies. It should also be noted that the temperature effects of COVID-19 cannot be easily explained because traveling or social activities will increase with the temperature to some ranges. This is also effective in the increase of COVID-19 infection.

Elavarasan and Pugazhendhi (2020) reviewed the literature to delineate the possible technical schemes to control the COVID-19 pandemic, emphasizing society and the environment. Their study intended to uncover the obscure roles of technologies that assist in controlling the pandemic. This study clarifies the different applied skills that help the healthcare procedures, government, and society in various phases of fighting against the COVID-19 pandemic. Also, Bennett et al. (2020) focused on the effects of the COVID-19 pandemic on the marketing and managing facets of the fishery sector and coastal populations, including social and environmental stressors.

La Rosa et al. (2021) investigated the likelihood of the emergence of SARS-CoV-2 by analyzing 40 samples from five WWTPs in three cities and areas in northern Italy in the context of wastewater-based epidemiology projects. Their research emphasizes the value of environmental surveillance as an initial alarm system to check the spreading of virus in the residents. Therefore, epidemiology and virus transmission included mortality, infection rate, adult, and health impact terms in cluster 2 with red color. Numerous papers studied the transmission of COVID-19 and its effects on the society and the global environment.

3.2.3 Water and wastewater

CUAHSI Board of Directors & Officers (2022) analyzed the literature from 2018 to June 2021 to evaluate the early indication of the effect of COVID-19 on water resources. First, they initiated the evidence of the increase in submitted papers from corresponding female authors in the United States, with more time devoted to writing and less time in the field or lab (Gonzales and Keane, 2020a, 2020b). The research showed that the secondary COVID-19's effect on the ecosystem could be harmful (Zambrano-Monserrate et al., 2020; Petrosino et al., 2021; Sayeed et al., 2021). There are reports from different locations worldwide about the existence of SARS-CoV-2 RNA in municipal sewage (Gonzalez et al., 2020c; Medema et al., 2020). However, the significant knowledge gaps, like the potency and time of SARS-CoV-2 occurrence in sewage, need to be more widely addressed (Kumar et al., 2021a). It should be mentioned that SARS-CoV-2 has been believed to be "not tough," and its stability in the environment is less, while its vulnerability to inactivation is more (Vadiati et al., 2010; Kumar et al., 2021b). Jakariya et al. (2022) examined the best place to collect urban and rural 168 samples in Bangladesh from 14 sanitation infrastructures to predict COVID-19 occurrence. The typical commercial RT-qPCR kits were utilized to detect *ORF1ab* and *N* genes, and genetic materials of SARS-CoV-2 in wastewater samples were detected in the first round of sampling, which equaled 98% and 95% for the second round. WBS is an important tool to fight against COVID-19 as it allows for rapid diagnosis, cost-effectiveness, and non-invasive insights into the health of large or targeted groups, including municipalities, domestic houses, and dormitories.

SARS-CoV-2 RNA can be used to detect the number of probable patients from air, surface, and wastewater samples. Solo-Gabriele et al. (2023) conducted a SARS-CoV-2 surveillance study in a college–campus housing in Florida, United States, and reported that from March to May 2021, monitoring SARS-CoV-2 from the air, surface swabs, and wastewater samples is adequate for predicting COVID-19 cases at the building level (Solo-Gabriele et al., 2023). The genetic markers of SARS-CoV-2 were identified from all three sampling types. Multiple samples from the environment are helpful in monitoring hotspots and patient numbers.

Some of the challenges still a concern in different countries are water availability, accessibility, and quality because of the epidemic's impact (Rafa et al., 2020; Maison et al., 2021; Singh and Mishra, 2021). On the other hand, water disinfection endangers the aquatic ecosystem and using excessive sanitizers is destructive for fragile water bodies (Kumar et al., 2020b; Chu et al., 2020; Zhang et al., 2020; Chen et al., 2023). Undoubtedly, the most significant research in 2020 was sampling, separation, procedure, recognition, and spotting SARS-CoV-2's RNA fragments in wastewater in each study (Alygizakis et al., 2021).

The fundamental design of WWTPs is based on the assumption that WWTPs can prevent pathogens from spreading in effluents. The degree of infection of SARS-CoV-2 still requires more investigation, while the RNA of SARS-CoV-2 has been detected in effluents (Haramoto et al., 2020; Randazzo et al., 2020). Furthermore, tertiary care and disinfection can inactivate the SARS-CoV-2 in WWTPs (Saawarn and Hait, 2021). Accordingly, what is still a concern and has also been highly investigated is the persistence and permanence of SARS-CoV-2 in the ecosystem through water pathways (Bhattacharya et al., 2021). According to the environmental conditions, the virus infection can remain for a few days in wastewater (Bivins et al., 2020). Therefore, the effect of COVID-19 on water bodies, the environment, and its consequence on human health is substantial.

Measurement procedures of SARS-CoV-2 RNA in sewage sludge and wastewater are as follows (Peccia et al., 2020); analysis of the persistence of SARS-CoV-2 in wastewater and water resources (Bivins et al., 2020); analysis of the possibility of SARS-CoV-2 transmission in water resources (Vadiati et al., 2010); wastewater-based epidemiology (WBE) usage to track COVID-19 (Fernandez-Cassi et al., 2021); water law and planning for implementing actions against COVID-19 (Larson, 2020); and focus on water quality during the pandemic (Hallema et al., 2020).

Table 1 shows the top-cited papers considering COVID-19 and the environment. Antwi et al. (2021) declared that policymakers and managers of water resources might consider the fate of SARS-CoV-2 in the water cycle. The authors also proposed future research needs, which involve advancing the current standard WWTP organization, considering the effectiveness of disabling the SARS-CoV-2, and checking the potable water supply system. For SARS-CoV-2 and RNA fragment detection in medical sewage, Wang et al. (2020b) used quantitative real-time reverse transcription PCR (qRT-PCR). The result indicated that after the disinfection process in the

pool, the entrance sewage's SARS-CoV-2 content was removed entirely (Rakib et al., 2021; Rakib, 2022).

In other studies, Lodder and de Roda Husman (2020) presented a viewpoint on SARS-CoV-2 in wastewater. They believed it had potential health risks, but according to data sources, the wastewater could be a sensitive inspection system and primary caution in the epidemic. Wastewater-based epidemiology has been rapidly and extensively examined in various countries, such as Italy (La Rosa et al., 2021), the United Kingdom (Martin et al., 2020), the Netherlands (Medema et al., 2020), Spain (Randazzo et al., 2020), the United States (Gonzalez et al., 2020c; Graham et al., 2020), India (Kumar et al., 2020a; Arora et al., 2020), Bangladesh (Ahmed F. et al., 2021; Jakariya et al., 2021; 2022; Haque M. A. et al., 2022), Japan (Haramoto et al., 2020), Germany (Westhaus et al., 2021), Australia (Ahmed F et al., 2020; Ahmed W. et al., 2021), and the United Arab Emirates (Albastaki et al., 2021). The main aims of these studies are to provide differentiated ways to interpret SARS-CoV-2 in water bodies.

Bhowmick et al. (2020) believed that SARS-CoV-2 has different means of transmission in the water system. The SARS-CoV-2 might first enter the sewage system from the infected person's feces, urine, or vomit. In predictable wastewater treatment processes, the initial treatment processes, such as using a grit chamber and screens, are not operative due to the size of the coronavirus (60–220 nm). Hence, membrane filtration and activated sludge flocs adsorption could successfully eliminate SARS-CoV-2 (Chaudhry et al., 2015; Arora et al., 2020). However, the additional treatment using UV and chemical oxidation disinfection can inactivate the SARS-CoV-2 virus in wastewater (Ji et al., 2021a). Based on the operational and procedure circumstances, the concentration of SARS-CoV-2 RNA before and after wastewater treatment indicates that 1–2 log10 viral titers could be eliminated (Farkas et al., 2020).

Randazzo et al. (2020) investigated the occurrence of SARS-CoV-2 RNA in six WWTPs in Murcia, Spain. Their study showed that residents were shedding SARS-CoV-2 RNA earlier, confirming the first case of COVID-19 infection in many towns, where sewage has been tested. Foladori et al. (2020) aimed to understand the viral load of SARS-CoV-2 in feces and wastewater and its fate in WWTPs. SARS-CoV-2 monitoring in wastewater can be strategically utilized as an initial indication of epidemics. However, the viral RNA discovery in stools does not indicate that the virus is infectious and viable. La Rosa et al. (2020b) tested 12 effluent wastewater samples collected from Milan and Rome. Overall, six out of 12 samples were positive. Their study confirms that WBE can be employed for SARS-CoV-2 as a precise means to analyze spatio-temporal trends of virus spread in inhabitants.

Kitajima et al. (2020) reviewed the current knowledge regarding the possibility of SARS-CoV-2 surveillance in wastewater to comprehend the epidemiological and methodological ability to detect and quantify SARS-CoV-2 in wastewater. However, knowledge about human health risks is inadequate to perform a quantitative microbial risk assessment for SARS-CoV-2 exposure routes. Wang and Su, (2020) proposed using a disinfection strategy for hospital wastes and wastewater during the COVID-19 pandemic in China based on the types of different hospital wastes, categorization, and choice of disinfection methods.

Yunus et al. (2020) utilized remote sensing images to quantitatively determine the progress in surface water quality based on suspended particulate matter (SPM) in Vembanad Lake, India. The results showed that SPM concentration decreased by 15.9% after the lockdown period. Haramoto et al. (2020) used WBE in Japan to identify the actual rate of COVID-19 in a population. River water, influent, and secondary-treated sewage samples were collected to compare the confirmed COVID-19 cases. The results showed that SARS-CoV-2 RNA was detected in the sewage (the secondary-treated) sample at the peak of confirmed COVID-19 cases. La Rosa et al. (2020a) reviewed coronavirus occurrence, survival, load, and recovery methods in water environments using literature on PubMed, EMBASE, and Web of Science Core Collection electronic databases.

3.2.4 Environmental policy

Environmental policy could be a driving force in attaining SDGs (Hasan et al., 2023). Achieving SDGs in developing countries is a complicated mission since the government focuses more on economic growth than on environmental policy (Sajeev and Kaur, 2020; Giannetti et al., 2023). The environmental policy mechanisms obtained increased interest of policymakers in developed countries. Hence, the environmental policy perspective is multi-faceted based on the countries' interests and concerns (Purnaweni et al., 2021).

Following proper medical guidelines to handle COVID-19, numerous plastic products, such as polyethylene, polystyrene, and polyacrolein wastes, have been produced. The main method of discarding such types of wastes is incineration, which generates toxic environmental byproducts like dioxins, CO_2, and heavy metals such as lead and cadmium. To decrease the levels of these hazardous substances, multi-departmental steps need to be carried out, using mixed microbes, including bacteria, fungi, and microalgae.

Dey et al. (2023) evaluated the fate of plastic wastes, an additional challenge posed by the COVID-19 pandemic. Significant amounts of municipal waste due to use-and-throw plastic products such as gloves, masks, hand towels, and other personal protective equipment (PPEs) are produced as additional waste (Dey et al., 2023). Such wastes are highly persistent in nature and leave microplastics as byproducts. Furthermore, these wastes are mostly incinerated, but this phenomenon produces significant amounts of aforementioned toxic substances. Typically, leaving or dumping such waste poses a microplastic load on the environment.

Idowu et al. (2023) discussed the release of different secondary pollutants during the degradation of use-and-throw plastic waste (hand sanitizers, hand gloves, face shields, and face products) produced during the COVID-19 era. They estimated that about 1.24 trillion face masks were produced during the COVID-19 era and simulated how these plastic waste (face masks) decomposed in the presence of UV and reported the creation of different harmful secondary products such as diethyl phthalate; di(2-ethylhexyl) phthalate; and heavy metals, including Cu, Pb, Cd, As, Sn, and Fe.

Tepe (2023) assessed the effect of socioeconomic characteristics (such as human behavior, economy, and travel restriction) on COVID-19 cases at the local level. They reported a relationship between educational and health facilities. The pandemic affected health and education facilities less than the other parts. They concluded, thus, that government policy could have a significant role in controlling COVID-19.

Hospital-contaminated waste and wastewater is a considerable concern since coronavirus spreads rapidly to other parts of the

world. However, medical waste management firms have begun the SARS-CoV-2 sanitization public services (Saadat et al., 2020). One more surprising environmental effect of COVID-19 has been witnessed in Venice, Italy. As the tourist statistics have decreased due to the pandemic, Venice's waterways are cleaner and fresher than during the pre-pandemic period; while tourist boats churned deposits every day, the local people were surprised by observing the clean water and fish in the waterways again.

Zambrano-Monserrate et al. (2020) assessed the pandemic's positive and negative indirect impacts, particularly in the most affected countries. Their research positively affected air quality improvement and clean coastlines. In contrast, negative facets such as reducing recycling and increasing waste further endangered water, soil, and air. In another study, Muhammad et al. (2020) compiled the satellite data before and after the pandemic to investigate its impact on environmental quality in China, Italy, Spain, and the United States.

Saadat et al. (2020) studied the environmental perspective of COVID-19. They mainly focused on wearing a mask, using gloves and hand sanitizers by individuals, and generating massive medical waste in the environment. At the societal level, they focused on the economic effects of the COVID-19 pandemic lockdown on the reduction in water pollution and carbon emissions around the world. Interestingly, some researchers studied the importance of a few Indian medicinal plants in treating the COVID-19 infection or producing plant-based vaccines or drugs (Vellingiri et al., 2020).

Wang and Su (2020) tried to assess the impact of COVID-19 on the environment in China as a case study. The assessment implies that the pandemic improves air quality and decreases carbon emission in the short term, and more evidence is highly needed for the long term. Mollalo et al. (2020) used GIS-based county-level modeling of the COVID-19 incidence rate using 35 environmental, topographic, socioeconomic, and demographic parameters. Mapping the impacts of essential parameters such as income inequality, gender inequality, median income, and nurse practitioners on spatial variation of infection rates provides significant visions to legislators.

Fadare and Okoffo (2020) evaluated the environment of microplastic fibers, specifically face masks, and suggested reinforcement of critical thinking in the study to offer eco-friendly replacements to find a sustainable waste management solution for plastic pollution. Also, Silvaa et al. (2021) studied the challenges of plastic pollution and suggested some recommendations for the plastic increase during the current pandemic considering short- and long-run phases. Their review underlines the need to balance public health and environmental protection. However, plastic materials considerably improved modern life, and bio-based plastics need to attain SDGs.

COVID-19 not only caused a significant number of deaths but also hampered sustainability, sanitation, social activities, economy, and gross domestic product (GDP), where the poorest countries are mostly affected rather than wealthier countries (Hossain F E et al., 2021; Dhama et al., 2022). Giannetti et al., 2023 evaluated the effect of the COVID-19 pandemic on different parameters of the UN sustainable development goals (natural environment, gross domestic product, productivity, and happiness), collecting data from 89 countries around the world (Giannetti et al., 2023). They reported that COVID-19 has negatively impacted all considered parameters (of UN SDG parameters) after the first year of the pandemic. Such effects were significantly higher in low- and middle-income countries than in rich and higher-income ones. However, after 1 year of COVID-19, negative effects due to deforestation, production of medical wastes (masks, PPE, syringe, etc.), and biomedical product were observed.

3.3 The scope for further research

This subsection presents potential research gaps that could provide a route to prospective areas for upcoming studies (Islam et al., 2022a; Islam et al., 2022b; Islam et al., 2022c; Islam et al., 2022d). However, a long-term view is necessary since the environment's response time is much longer than that of the COVID-19 pandemic. We tried to provide a brief evaluation of future research and directions of essential environmental study themes (Solo-Gabriele et al., 2023). Further analyses and studies are needed, undoubtedly, to investigate the relationship between COVID-19 and the environment.

The word "ecosyndemic" means environmental alteration, including physical, chemical, and biological factors. The multi-factor changes involved in climate alteration, temperature increase, and degradation in wildlife habitats can be used to predict or measure the pandemic situation. Begou and Kassomenos (2023) comprehensively analyzed SARS-CoV-2 and other emerging pandemics (Begou & Kassomenos, 2023).

The COVID-19 disaster also affected agriculture, transport, fisheries, and livestock, due to which consumption is decreased, while it increased the electricity demand (25.4%), PM_{10}, nitrogen dioxides, atmospheric emissions, and carbon-related chemicals. Russo et al. (2023) studied the effect of COVID-19 on energy consumption and its environmental consequences (e.g., atmospheric emission, carbon release, PM10, and NOx) in Portugal. According to their article, energy consumption in transportation and industry was reduced but increased in the domestic sector, during the pandemic. Air quality parameters in residential areas and elsewhere improved.

Disinfectants are essential to protect and control infectious diseases (Islam et al., 2022c; Islam et al., 2022e; Islam et al., 2023). However, the COVID-19 pandemic resulted in the use of disinfectants, which caused many issues in the environmental ecosystem. UV can be used as an alternative to the chemical disinfectants, a more common method in the physical system. It can be used to disinfect N95 masks, PPE, or laboratory apparatus, even the air, using this method (Chen et al., 2023). Respiratory raindrops, air particle size, charges, temperature, and moisture play significant roles in spreading the virus from one infected person to another one (Gu et al., 2023). Electrostatic properties and the percentage of humidity in the environment control the virion existence in the environment. It can be stated that scholars from all sectors plan and conduct research studies to control the COVID-19 pandemic and find out its sources, ways of transmission, effective treatment systems, and vaccines (Swelum et al., 2020).

3.3.1 COVID-19 and future studies

The environmental policy continues to be of special concern for scientists worldwide because of the COVID-19 crisis, which can cause environmental risks in the future. The existing literature

generated robust findings on environmental policy and its dimensions. Future research can emphasize the SDGs in environmental resilience as an effect of the pandemic.

The core issues are vaccines, disease treatment, drug side effects, and point protein (Roy et al., 2022a; b). More studies have been published recently. While one of the study priorities for further research is the effectiveness of medication treatment, such as monoclonal antibody therapy (Wang C. et al., 2020; Sakib et al., 2021), on the other hand, the various applications of sanitizers and toxic sterilization byproducts will cause possible threats to the quality and safety of water bodies (Chu et al., 2020). It is necessary to evaluate water quality in three stages of the COVID-19 pandemic: before, during, and after. Developing innovative sterilization tools to lessen the environmental risk load of sanitizers in WWTP seems vital. Likewise, as the health check provision increased administration of antiviral drugs to cure patients, its deposits or metabolites were discharged into wastewater (Hossain M et al., 2021; Haque R. et al., 2022).

The stagnant water in reopening buildings is a possible secondary risk as it contains toxic compounds and *Legionella pneumophila* growth. Additional research is required to define the correlation between related diseases and lockdowns (Proctor et al., 2020; Rhoads and Hammes, 2021).

Personal protective equipment usage has considerably increased in the requirement and utilization as an efficient and economical means during the epidemic (Prata J. C. et al., 2020; De-la-Torre et al., 2021). After a significant number of PPE have been used, how to discard about 1.56 billion masks could be an empirical menace to the environment. In particular, it is to be noted that microplastics, regarded as emergent pollutants, are the products of further breaking down of plastics (Dey et al., 2023; Idowu et al., 2023). Limited information has existed in the literature on the amount, source, and circulation of PPE in water bodies; however, many researchers have studied this challenge (Aragaw, 2020; De-la-Torre and Aragaw, 2021), and it has remained ambiguous in the freshwater environment.

3.3.2 Recommendations for future studies

The present review puts aside essential recommendations for future studies. Scientists should mainly consider sudden environmental shock in the applied analysis methods or modeling. For instance, social media play a significant role during and after the pandemic or other crises, which may have been considered. Second, future studies must consider dealing with the direct/indirect or short-/long-term hazard perceived by environmental shock. Several publications have explored the potential SARS-CoV-2 spread *via* sewage testing systems in buildings (Singh et al., 2021). There are potential infection risks for wastewater distribution systems of WWTP effluents and the environment. A few types of research studies have explored the survival rates of SARS-CoV-2 under stable or unstable conditions from sources to sinks.

Additional study is required to successfully recover and enhance RNA extraction methods such as the RT-qPCR method from various water substances since the PCR-based viral nucleic acid detection methods are costly and time-consuming. Improving dependable, low-cost, and straightforward protocols or instruments is essential to evaluate wastewater (Thakur et al., 2021).

Based on the literature review, public transport, considered the green method of transportation, could provide substantial advantages for the public. However, further research is essential for more in-depth information on the role of climatological conditions that are commonly neglected (Sabarathinam et al., 2022). Finally, there is a dynamic mixture of both old and new behaviors of the non-linear and unspecified simulation of COVID-19 and environmental behavior across the phases of the epidemic, which highly points the requirement for future studies to integrate flexibility and quickness into their modeling processes, and will be entirely aligned with SDGs.

3.4 Machine learning

The increase in ML methods, mainly through natural language processing artificial intelligence, allowed the processing of significant textual social media data. Reasonable modeling could be carried out using ML models that assist policymakers and provide an effective and promising tool to solve complicated environmental concerns. Internet of Things (IoT) technology is a promising tool for collecting water resource datasets simultaneously, where information can be analyzed through a more innovative approach and applied to broader user communities. Smart control of the environment will be possible through variable factors involving advances in computational and internet coverage. Integrating ML models and IoT would provide a perfect real-time and low-cost professional system for data analysis. Also, the review showed that further studies are highly recommended to integrate the usage of ML models and environmental parameters such as land-use change, seawater intrusion, climate change, and WWTP effluents (Wang et al., 2020b). The water treatment procedure and integrated water resource management can be optimized to support the accomplishment of SDGs in the COVID-19 pandemic (Barbier and Burgess, 2020; Poch et al., 2020).

Lalmuanawma et al. (2020) reviewed the applications of ML and AI in the areas of assessment, simulating, forecasting, tracing, and drug development of SARS-CoV-2. A critical analysis of the paper's abstract, methodology, and conclusion was performed to relate the model's capability. The results showed that the continuing progress in AI and ML would considerably improve different areas of ML usage during the COVID-19 pandemic to reduce the interference of health workers in the medical procedure. In another study, Iyer et al. (2021) focused on the safe disposal procedures for medical waste by using safe, secure, and novel bio-inspired techniques such as AI.

Mottaqi et al. (2021) aimed to overview the current usage of ML models that contribute to the prevention, diagnosis, monitoring, and treatment of the SARS-CoV-2 virus. The results showed that the deep learning convolutional neural network (CNN) and support vector machine (SVM) are mostly used models for patient diagnosis and screening by image processing. This shows the necessity of hybrid ML methods, including other deep learning methods and advanced metaheuristic algorithms.

Amoroso et al. (2022) used satellite data and ML methods to discover the correlation between NO_2 and COVID-19 mortality for

a 2-year dataset using the random forest method. The results showed a considerable statistical correlation between NO_2 and COVID-19 mortality rates. The results also revealed that health workers and hospital beds play a crucial role in controlling COVID-19 mortality. Gatti et al. (2020) used ML methods to delineate the correlation of air pollution with SARS-CoV-2 mortality in Italy. They discovered that green gas emissions could be responsible for over 70% of the confirmed deaths with SARS-CoV-2 on a national scale. The results showed that $PM_{2.5}$ is the essential parameter in predicting the impacts of SARS-CoV-2. Magazzino et al. (2021) investigated the relation between deaths based on COVID-19 pandemic and economic growth, PM_{10}, $PM_{2.5}$, and NO_2 concentrations in New York utilizing daily data and two ML methods. They observed that the most effective pollutants in COVID-19-related deaths are $PM_{2.5}$ and NO_2. González-Pardo et al. (2022) investigated the effect of restricted anthropogenic emissions of air pollutants by the governments throughout 2020 on air quality and COVID-19 using ML methods in Spain. They compared air quality data involving NO, NO_2, O_3, PM_{10}, and $PM_{2.5}$ concentrations for 2013–2019 and 2020. The outcomes showed a decreasing pattern for NO_2 by more than 50% during the lockdown, while there was an increase in O_3 by 23.9% and a slight decrease in PM_{10} by 4.1% and $PM_{2.5}$ by 2.3% during the same period.

Rahman et al. (2021) reviewed the ML model's usage on community travel patterns and air pollution. The authors argued that ML is a robust, efficient, and promising tool to cope with complicated issues. Their research also investigated the spatio-temporal phases of lockdown, human travel patterns, and air pollution. Furthermore, they argue about strategies that will be useful for legislators to improve the environment. In another study, Han et al. (2022) used ML methods to predict COVID-19 occurrence and intensity in China using several input parameters. Out of 113 input parameters, they eliminated some which have a negligible effect on COVID. They reported that i) COVID-19 is more likely to occur in prosperous cities closer to the epicenter and situated on higher altitudes, ii) occurrence is higher under extreme weather conditions and higher minimum humidity (relative), and iii) risk of COVID-19 occurrence is increased with exposure to most air pollutants, except NO_2 and O_3.

Travel patterns may cause air pollution; for example, an increase in $PM_{2.5}$ and traveling people also increase the spread of COVID-19 infections. For this reason, there may be a good correlation between $PM_{2.5}$ or other air pollution parameters and SAR-COV-2 impacts, as Gatti et al. (2020) reported. This should also be taken into account in such studies; otherwise, the research outcomes may mislead the modelers or policymakers. On the other hand, additional research and datasets are needed to reach more generalized and robust outcomes, mainly from various regions. With the recent technological advancement, high-resolution climate (e.g., evapotranspiration, temperature, rainfall, and solar radiation), land cover, and land use data are freely available. With such data, spatial modeling of COVID-19 for different climatic conditions can be carried out using new hybrid ML methods with novel metaheuristic algorithms or deep learning methods such as long short-term memory (LSTM), CNN, and recurrent neural networks (RNN). In addition, some relationships may be found between long-term climatic signals (e.g., El Niño–Southern Oscillation, El Niño and La Niña, Pacific Decadal Oscillation, Atlantic Multidecadal Oscillation, and Arctic Oscillation) and COVID-19 using efficient ML methods. A significant portion of these ML studies was related to correlating air pollution and COVID-19 since the meteorological and remote sensing datasets are readily available and accessible. Considering additional input datasets for ML models, such as social and economic datasets, would be a limitation that could be considered in future studies.

4 Conclusion and outlook

COVID-19 virus does not have a similar impact on every element of the environment. To control the rapid spreading of SARS-CoV-2, it is crucial to determine the potential determinants, such as environmental factors and their role. There are various reasons why this pandemic influences environmental issues in various ways. Researchers have shed more light on its fundamental dynamics. In the present study, we attempted to realize the significant effects of the environment, classify critical aspects that had better be deemed for good organization and reaction to potential future issues, and focus on the gaps that required more studies in the future. However, many foci on the positive side of the COVID-19 pandemic have decreased water and air pollutants and most likely rescued people's lives. After the pandemic, air pollution will occur without enduring impact. Although researchers' goals for quick turn-outs of the pandemic are expected to be even limited by the pandemic, COVID-19 was the most recent subject of research throughout 2020, 2021, and 2022. By the end of 2022, authors from different countries had reported the critical role of environmental perspectives during the COVID-19 pandemic.

The review demonstrates that initial evidence correlates to four significant clusters: air quality, epidemiology and virus transmission, water and wastewater, and environmental policy. However, there is no balanced reporting of these clusters. This is likely due to the dataset availability for water and wastewater and air quality, whereas accessing and analyzing data associated with other clusters is more time-consuming. Publications comprised 80% original research papers, 13% review papers, and 7% other publications. The United States has the most published papers, followed by China, India, Italy, the United Kingdom, and other countries. The air pollution cluster has the most published papers in China, while epidemiology and virus transmission attracted more scientists from the United States. The COVID-19 pandemic is expected to fundamentally revise how the environment will be handled in the future. Actions taken almost immediately are vital to achieve this purpose and determine whether the post-COVID situation will be sustainably managed. The epidemic has provided prospects to increase the number of cyclists in many cities worldwide due to the spread of infection by public transport. This challenge gives cities an outstanding chance to support cycling culture and shift short-term cyclists into long-term ones (Chandran et al., 2022; Dhama et al., 2022). There is hope that policymakers and local decision-makers will support policies dealing with global crises such as climate change (Begou and Kassomenos, 2023). The significant effects result in hope of the epidemic on the environment. These findings also motivate

scientists, organizations, and countries to pay more attention to environmental policy. For example, the following topics can be of significant value and are suggested by the authors of this article to be investigated: waste management, sustainability, governance, ecosystem, and climate change. The bibliometric findings have highlighted a thematic move in environmental research from qualitative studies like air pollution in 2020 to governance and management concepts in 2021 and 2022. Environmental studies also experienced development from conventional stand-alone attitudes toward integrated environmental management or policy techniques. This thematic shift reveals the growing acceptance of interdisciplinary themes in environmental studies. Finding the evolution of topics in environmental research is fascinating, and thinking of what shifts could appear if an analogous study is repetitive in the following years. It should be acknowledged that research on the environment is not wholly conclusive. Hence, more review studies in the upcoming years are considered necessary to revise the results of this review and offer perceptions such as the long-term environmental consequences and how the epidemic will renovate human actions and environmental authority.

Author contributions

MV, MI, and PB conceptualized the initial structure of this review. All authors were involved in writing and editing the manuscript and provided data interpretation and critical insights.

Conflict of interest

LG was employed by Gamasiab Consulting Engineers Company.

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.

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