frontiers | Frontiers in Sustainable Cities

TYPE Systematic Review
PUBLISHED 18 July 2023
DOI 10.3389/frsc.2023.1154667

Check for updates

OPEN ACCESS

EDITED BY
Lauren Withycombe Keeler,
Arizona State University, United States

REVIEWED BY
Grigorios L. Kyriakopoulos,
National Technical University of Athens, Greece
Maurizio Tiepolo,
Polytechnic University of Turin, Italy

*CORRESPONDENCE
José Gescilam S. M. Uchôa
✉ gescilam@usp.br

RECEIVED 31 January 2023
ACCEPTED 27 June 2023
PUBLISHED 18 July 2023

CITATION
Uchôa JGSM, Bertotto LE, dos Santos MS, Reis A, Mendiondo EM and Wendland EC (2023) Tropical cities research boundaries: a bibliometric analysis to bridge the gaps through multi-dimensional and cross-disciplinary features. *Front. Sustain. Cities* 5:1154667. doi: 10.3389/frsc.2023.1154667

COPYRIGHT
© 2023 Uchôa, Bertotto, dos Santos, Reis, Mendiondo and Wendland. This is an open-access article distributed under the terms of the Creative Commons Attribution License (CC BY). The use, distribution or reproduction in other forums is permitted, provided the original author(s) and the copyright owner(s) are credited and that the original publication in this journal is cited, in accordance with accepted academic practice. No use, distribution or reproduction is permitted which does not comply with these terms.

Tropical cities research boundaries: a bibliometric analysis to bridge the gaps through multi-dimensional and cross-disciplinary features

José Gescilam S. M. Uchôa[1]*, Luis E. Bertotto[1], Matheus S. dos Santos[1], Alan Reis[1], Eduardo M. Mendiondo[1,2] and Edson C. Wendland[1]

[1]Department of Hydraulics and Sanitation, São Carlos School of Engineering, University of São Paulo, São Paulo, Brazil, [2]I-SITE Excellence Program, University of Montpellier, Montpellier, France

Tropical regions are known for their complex ecosystems and biodiversity, which play a vital role in regulating the global climate. However, researching tropical cities can be challenging due to the need for multi-disciplinary and multi-dimensional approaches. In this study, we conducted a bibliometric analysis to gain a structured understanding of the developments and characteristics of tropical cities research in the last decade. We identified the fundamental influences in tropical cities research, based on four major sub-topics: climate change, sustainable urbanization, protecting biodiversity, and urban resource management. We examined the connections between these themes and performed a systematic literature review on each. Our analysis provides a comprehensive trend analysis of tropical cities, both quantitatively and qualitatively. Our findings aim to provide a solid foundation for bridging the gaps for future crosscutting research.

KEYWORDS

tropical cities, interdisciplinary studies, climate change, sustainable urbanization, protecting biodiversity, urban resource management, bibliometric analysis, systematic literature review

1. Introduction

Tropical regions are home to ∼42% of the world's population (Harding et al., 2016; Aghamohammadi et al., 2021), and with population growth and rapid urbanization, developing countries are predicted to experience nearly 95% of the global urban expansion in the coming decades (Akbari et al., 2015). As a result, tropical cities will face numerous challenges stemming from unplanned urban expansion and climate change. These challenges encompass a wide range of areas, including human health, productivity, urban planning, sanitation, resilience, and biodiversity. They are already manifesting as increased risks of heat stroke and disease transmission (e.g., Burkart et al., 2011; Coccolo et al., 2016; Lee J. M. et al., 2019), reduced human comfort due to high levels of thermal stress (e.g., Roth, 2007; Méndez-Lázaro et al., 2016; Ramsay et al., 2021), heightened energy consumption driven by increased cooling demand (e.g., Gamero-Salinas et al., 2021), decreased water availability and heightened pollution (e.g., Chow and Yusop, 2013; Pérez-Villalona et al., 2015; Silva et al., 2019), alterations in local flora and fauna distribution caused by inadvertent climate modification (e.g., Roth and Chow, 2012; Oh et al., 2018; Alue et al., 2022), air pollution

challenges (e.g., Vailshery et al., 2013; Nipen et al., 2022), and the resilience challenges of the health-sanitation nexus (Macedo et al., 2022). Therefore, the development of tools and mechanisms to adapt to climate change and conserve urban resources and biodiversity in tropical cities is crucial due to the challenges they face.

Despite the significance of this topic, tropical cities have not received as much attention as their temperate counterparts (Velasco et al., 2016; Sari, 2021) and existing studies on tropical cities often remain descriptive in nature (Roth, 2007). However, recent progress has been made in this field, with research focusing on climate change (e.g., Eccles et al., 2019; Palafox-Juárez et al., 2021; He et al., 2022), biodiversity conservation approaches (e.g., Richards and Friess, 2017; Hwang et al., 2021; Tan et al., 2022), sustainable techniques in urban environments (e.g., Olivero-Lora et al., 2019; Grêt-Regamey et al., 2020; Grullón-Penkova et al., 2020), and mitigation of adverse effects resulting from poorly managed urban resources (e.g., Rodríguez-Algeciras et al., 2018; Bertrand et al., 2021; Ramsay et al., 2022). These diverse topics underscore the need for interdisciplinary studies to comprehensively understand and characterize tropical cities, enabling the evaluation of management strategies and support for decision-making processes. Nevertheless, research indicating the primary scientific trends in the study of tropical cities remains scarce. Therefore, this paper aims to identify the key aspects of this field through a comprehensive bibliometric analysis and systematic review. We present a novel review methodology and assess the advancements and challenges in scientific research related to tropical cities from 2010 to October 2022, with a particular focus on four subtopics: climate change, sustainable urbanization, protecting biodiversity, and urban resource management. The bibliometric review, encompassing all tropical cities studies obtained from the Web of Science and Scopus databases, provides valuable insights into the trends within this field. Our systematic review does not aim to exhaustively list and discuss every study on tropical cities, but rather to address central questions within the aforementioned subtopics. We also discuss the limitations of this study and the challenges associated with conducting systematic reviews. Ultimately, the goal of this research is to establish a robust conceptual foundation and guide future research directions, ensuring that rapidly expanding tropical cities in the developing world incorporate climate, ecological, and sustainable concerns into their design.

2. Methods

The articles included in the bibliometric and systematic review were selected using the ProKnow-C methodology (Knowledge Development Process—Constructivist) (Ensslin et al., 2010) and the Prisma 2022 guideline (Page et al., 2020) to avoid potential biases in the methodology and clearly outline the steps taken. This process involved mapping the number of papers identified, included, and excluded, as well as the reasons for exclusion at each stage.

The systematic review was divided into four subtopics. The selection of the topics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management in the context of tropical cities is justified based on their relevance to the main theme. Each of these subtopics addresses critical aspects of sustainable development and environmental management in urban areas.

In fact, climate change refers to long-term alterations in Earth's climate patterns, including temperature, precipitation, wind patterns, and other aspects of the planet's climate system (United Nations, 2023). The increasing frequency of extreme heat, dry events, and intense rainfall observed in cities globally underscores the urgency of understanding and mitigating the impacts of climate change (Mukim and Roberts, 2023). Moreover, tropical regions are projected to experience the strongest warming according to the Intergovernmental Panel on Climate Change (IPCC, 2014), making it essential to examine the specific challenges and vulnerabilities faced by tropical cities.

Sustainable urbanization refers to the planning, development, and management of cities and urban areas in a way that promotes environmental, social, and economic sustainability. It involves creating cities that are livable, inclusive, resilient, and environmentally friendly, while also addressing the challenges posed by rapid urbanization (United Nations, 2012). Rapid urbanization in tropical regions brings unique challenges related to population growth, resource demands, and infrastructure development. By exploring sustainable urbanization in the context of tropical cities, we can identify strategies that promote livability, resilience, and environmental friendliness, while addressing the specific needs and complexities of these regions.

Biodiversity conservation in urban areas refers to the efforts and strategies implemented to protect and enhance biodiversity within cities and other densely populated urban environments. It recognizes the importance of preserving and promoting the diversity of species, ecosystems, and ecological processes in urban settings (Secretariat of the Convention on Biological Diversity, 2012). Urban environments can support diverse species and ecological processes, and conserving biodiversity within cities contributes to the overall preservation of global biodiversity. Recognizing the significance of urban areas in biodiversity conservation efforts is crucial for effective urban planning, land management, and the creation of green spaces that support urban biodiversity (United Nations, 2015).

Urban resource management refers to the planning, allocation, and sustainable use of resources within urban areas to meet the needs of the population while minimizing negative environmental impacts. Urban resources refer to the various materials, energy sources, and natural elements available within an urban environment that can be utilized by humans for their needs and activities. Urban resource management involves the efficient and responsible management of various resources, including land, water, energy, waste, and materials, to ensure the long-term sustainability and resilience of urban environments (Zucaro et al., 2022). By studying urban resource management in tropical cities, we can identify innovative approaches that promote sustainable resource use, minimize environmental impacts, and enhance the resilience of urban systems.

Therefore, the chosen topics of climate change, sustainable urbanization, protecting biodiversity, and urban resource

management are highly relevant in the study of tropical cities. Understanding and addressing these key areas of concern are crucial for achieving sustainable development, resilience, and environmental stewardship in tropical urban contexts.

A set of flowcharts was created to show all the steps of the analysis of the 4 subtopics and the main topic of tropical cities. Figure 1 indicates the first steps of the analysis. The following objectives were chosen to guide this analysis.

- How do the aforementioned subtopics impact tropical cities?
- What are the contributions of tropical cities to the subtopics?
- How are tropical cities adapting to climate change?
- What are the strategies to protect biodiversity, achieve urban resource management, and sustainable urbanization in tropical cities?

To achieve our objectives, the bibliometric review was initiated by using the keyword "tropical cities" and its various variations. Additionally, a specific set of keywords was defined for each of the subtopics under investigation. The analysis was limited to the period from 2010 to October 2022, focusing exclusively on articles as the document type to be analyzed. To ensure a comprehensive scope, both Web of Science and Scopus databases were utilized as they are widely recognized as the largest repositories of scholarly articles. In order to maximize inclusivity, keyword searches were conducted across all fields within these databases, including Title, Abstract, Keywords, and Keywords Plus.

Following this initial search, a keyword adherence test was conducted. The top 10 most cited articles from each database were selected, and their titles and abstracts were manually reviewed to ensure alignment with our research objectives. The keywords employed in these articles were compared to the original set of keywords. This iterative process was repeated until the keywords and the number of articles for each topic reached a stable state. The final set of keywords utilized for each topic is indicated in Table 1. The combinations of keywords used can be found in the Supplementary material. Figure 1 illustrates the step-by-step approach undertaken, highlighting the total number of articles pertaining to tropical cities and the respective number of articles within each analyzed subtopic in each of the databases analyzed.

Then, duplicate documents were removed by using the title in the R language. A visual inspection was performed, as the number of articles was small, to ensure that there were no duplicate articles. These articles were grouped into a single database called non-repeated article database c. The bibliometric review was conducted on the non-repeated article database c according to the indications by Donthu et al. (2021) with the assistance of the R bibliometrix package (Aria and Cuccurullo, 2017). The bibliometric review was conducted before the stages of alignment with the proposed objectives that make up the systematic review of this study to ensure a global view of the topic of tropical cities and the subtopics analyzed in this first stage.

As shown in Figure 2, the subsequent stages entail conducting a systematic review to determine the relevance of the articles to the stated research objectives. Initially, the alignment of each article with the research objectives was assessed through an examination of the title. Consequently, articles with titles that did not align with the four objectives of bibliometric review were excluded from further analysis. In cases where the alignment could not be definitively determined based on the title alone, the article proceeded to the next step for further evaluation.

As indicated in Figure 3, the total number of citations (TC) for all articles was extracted. The Pareto principle was employed to identify the most significant papers within the database. To achieve this, the total cumulative citations for each of the subtopics were determined using a Pareto chart. The citations were arranged in descending order, and a cutoff value was calculated by selecting the most highly cited documents until their cumulative citations constituted more than 90% of the total citations obtained within each subtopic. Detailed Pareto charts for each subtopic can be found in the Supplementary material. Articles with citations above this cutoff value were considered scientifically recognized and were further evaluated for alignment with the research objectives using their abstracts. Again, in cases where the alignment could not be definitively determined based on the abstract alone, the article proceeded to the next step for further evaluation.

For articles that were not considered scientifically recognized in our analysis, it was determined whether they were recently published, that it, in 2020 or later. If this was the case, the article was evaluated using its abstract. That is, recent articles that potentially do not have many citations were evaluated in the same way as articles considered scientifically recognized to avoid potential bias.

On other hand, for articles that were not recently published and initially were not scientifically recognized in our analysis, an examination of the authors was conducted. Specifically, it was checked whether any of the authors were included in the e database, which contains scientifically recognized articles with abstracts aligned with the objectives of this research (see Figure 3). If at least one of the authors was found in the e database, the article was further evaluated based on its abstract. However, if none of the authors were present in the e database, the article was excluded from the analysis. Figure 3 outlines the steps in this process and shows the number of articles removed at each stage.

The subsequent step involved evaluating the alignment of the articles with the research objectives through a comprehensive reading of the entire articles. However, during this process, a few articles were encountered that were listed in the Web of Science and Scopus databases but were no longer accessible. Therefore, an additional step was added to the methodology to verify the availability of each article. Subsequently, all the articles were thoroughly read, and those that demonstrated alignment with the objectives of this analysis were examined further. Any articles that were determined to be not aligned with the objectives were removed. The remaining articles were used to perform the systematic review as indicated in Figure 4. The final list of 149 articles analyzed in the systematic literature review stage can be found in the Supplementary material as well as its main information, including the study area, that is, which tropical city the article studied. A discussion about the limitations of the analysis performed here will be discussed in the sections assessment of risk of bias and limitations.

3. Results

Regarding the bibliometric review, conducted with the non-repeated article database c (see Figure 2), this means with a total

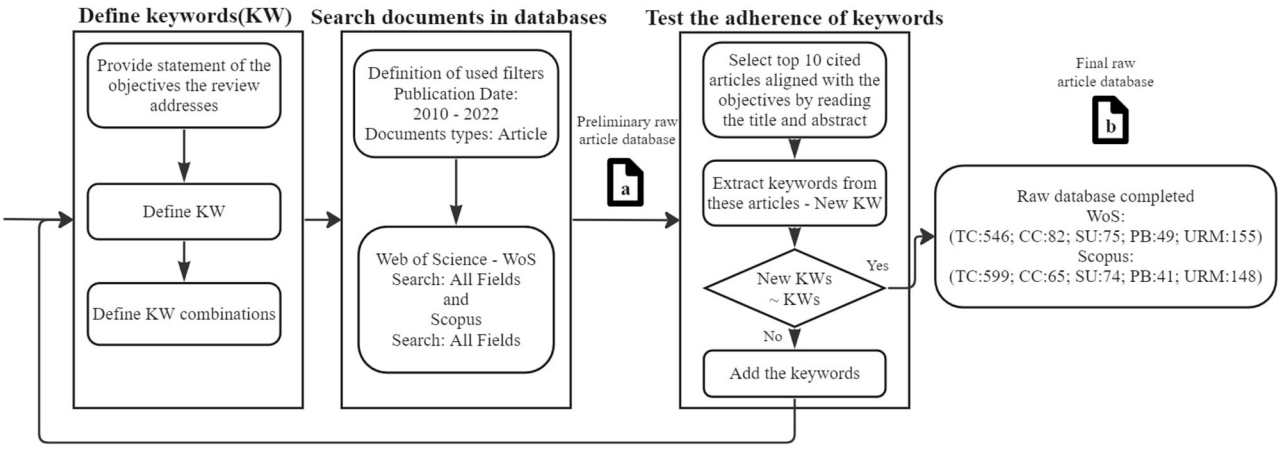

FIGURE 1
Keyword definition steps, database search and keyword adherence test. In brackets the number of articles on tropical cities topic (TC), and on the subtopics of climate change (CC), sustainable urbanization (SU), protecting biodiversity (PB), and urban resource management (URM) in the Web of Science (WoS) and Scopus database.

TABLE 1 Final set of keywords used in the main topic of tropical cities and in the subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management.

Main topic	Tropical cities			
Keywords	Tropical city*, tropical urban			
Subtopics	Climate change	Sustainable urbanization	Protecting biodiversity	Urban resource management
Keywords	Climate change, climate emergency, climate crisis*, climate breakdown, global heating, global warming	Sustainable urbanization, eco city*, urban development, sustainable urbanization, eco-environment, sustainability science, urban ecology, sustainability	Protecting biodiversity, wildlife conservation, conservation targets, conservation	Urban resource management, resource management, urban planning, urban climate governance, circular economy, environmental planning, management

The asterisk (*) represents any group of characters, including no character. It was used to ensure that all keyword variations were considered.

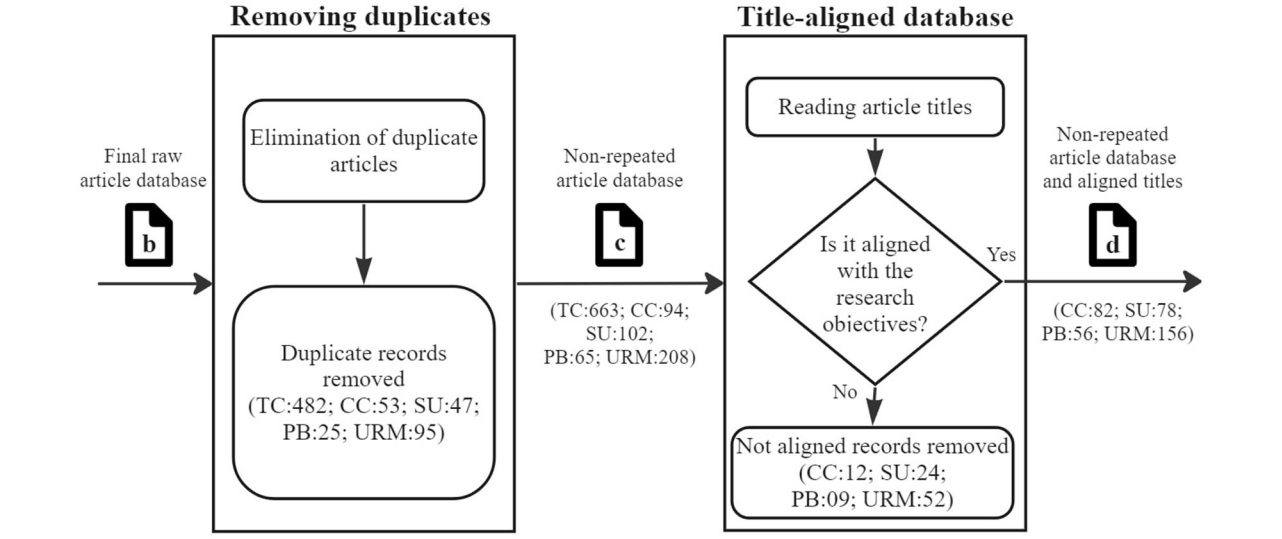

FIGURE 2
Duplicate removal steps, and adherence testing through the title. In brackets the number of articles on tropical cities topic (TC), and on the subtopics of climate change (CC), sustainable urbanization (SU), protecting biodiversity (PB), and urban resource management (URM) in a single database.

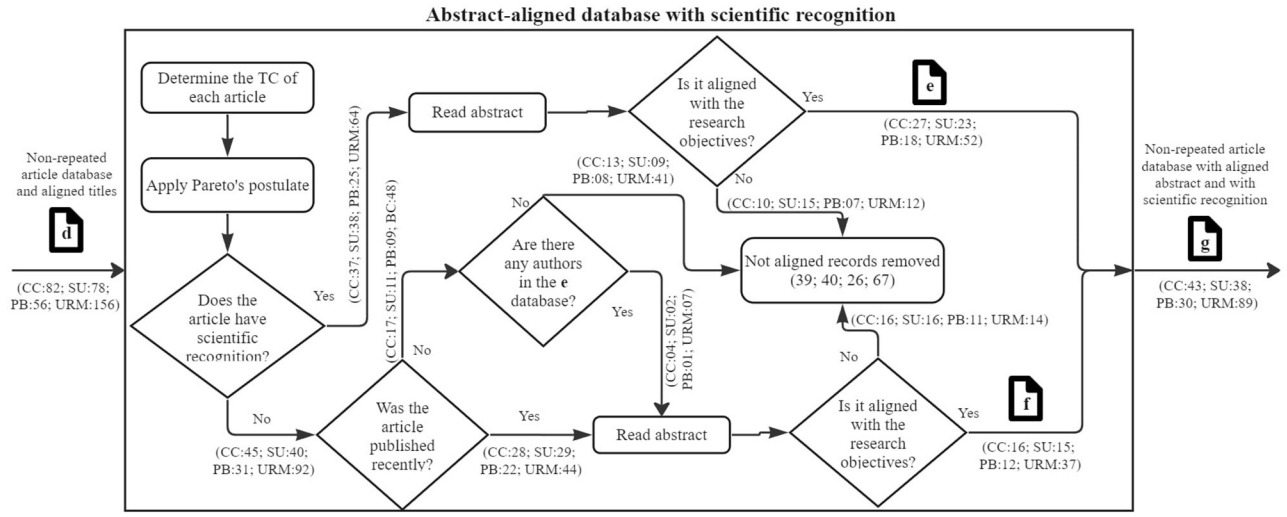

FIGURE 3
Verification of scientific recognition steps and adherence test. In brackets the number of articles on the subtopics of climate change (CC), sustainable urbanization (SU), protecting biodiversity (PB), and urban resource management (URM).

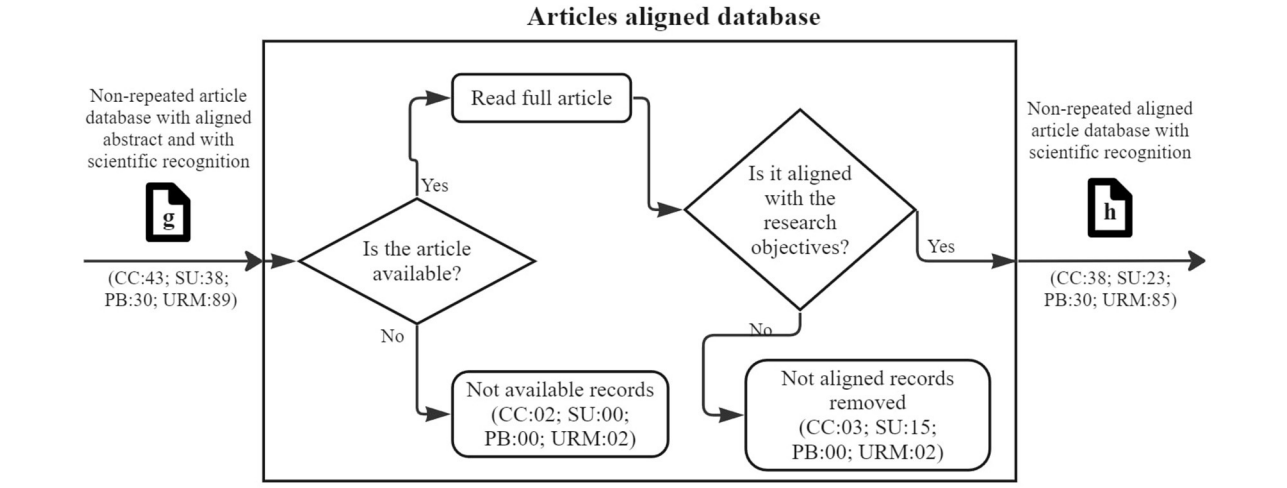

FIGURE 4
Final adherence test. In brackets the number of articles on the subtopics of climate change (CC), sustainable urbanization (SU), protecting biodiversity (PB), and urban resource management (URM).

of 663 articles, Table 2 shows an overview of the topics selected for this study. It is clear that the main tropical cities topic had the highest number of published papers, leading to the lowest annual growth rate. However, the protecting biodiversity subtopic had the lowest number of papers but the highest annual growth rate. Still, the four subtopics showed similar annual growth rates and document average age, indicating a general increase in the scientific production in these fields of knowledge. Among the subtopics, urban resource management had the most papers, likely due to its broader scope, as evidenced by the number of journals and keywords (see Table 2) in this subtopic. Nevertheless, the papers that received the most citations on average belonged to the climate change topic. The average citation per paper in the climate change field even exceeded that of the main tropical cities' topic. This is probably because climate change is a current topic of interest in a range of fields, and also because the topic itself is more likely to be discussed on a global scale, leading to higher internationalization in the climate change subtopic compared to the others. In contrast, the protecting biodiversity subtopic had the lowest internationalization, which may be because it deals more with local issues, such as the characteristics of flora and fauna in a specific region/biome. On the other hand, all subtopics presented a similar number of co-authors per paper.

Figure 5 shows the scientific production by year on tropical cities topic and subtopics analyzed. The main tropical cities topic exhibits parabolic growth in the period from 2010 to 2021 (R^2

TABLE 2 Overview of main topic of tropical cities and in the subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management.

	Tropical cities	Climate change	Sustainable urbanization	Protecting biodiversity	Urban resource management
Papers	663	94	102	65	208
Annual Growth Rate (%)	10.46	21.15	22.12	23.28	19.72
Document Average Age	4.55	4.00	3.35	3.47	4.19
Average citations per paper	16.08	22.36	13.14	7.25	14.21
Sources (Journals)	313	64	67	44	122
Authors	2,222	370	362	233	787
Co-authors per paper	4.60	4.28	4.22	4.22	4.39
International co-authorships (%)	34.99	46.81	31.37	21.54	34.13
Author's keywords (DE)	2,174	384	406	264	842
Keywords plus (ID)	2,813	519	556	428	1,444

91.54%). The results indicated that from 2015 onwards there has been an increasing number of publications on this topic, and the same trend is observed for the analyzed subtopics. As previously mentioned, urban resource management was the subtopic with the most papers (as shown in Table 2). Furthermore, when analyzing Figure 5, it is observed that this subtopic always led the number of publications per year throughout the period studied indicating its dominance over the other subtopics since 2010. Meanwhile, the other subtopics had similar numbers of publications per year, indicating that they received similar levels of attention from researchers. It is worth noting that no conclusion can be drawn for 2022 as this study is limited to documents published from 2010 to October 2022 when the database was analyzed.

Figure 6 shows the average number of citations per year in the analyzed tropics from 2010 to 2021. The main tropical cities topic presented an increase in the average number of citations, with a slight decrease in 2021, indicating a growing interest in this topic (as previously seen in Figure 5). Only the urban resource management subtopic had a constant result in terms of average citations, which could suggest that it is a more established topic in the tropical cities field. The peaks in the other subtopics may be due to papers presenting impactful results, introducing new methodologies and technologies.

In the climate change subtopic, the peak in 2015 can be linked to the study published by Mohan and Kandya (2015), which demonstrated that in tropical cities there may be an increase in the heat-related mortality rate with an expectation of an increase in average temperature. The peak in 2019 is primarily attributed to the study of Manoli et al. (2019), which introduced a coarse-grained model linking population, background climate, and urban heat island intensity. In the sustainable urbanization subtopic, three peaks are observed. The first in 2012 is largely due to the study by Roth and Chow (2012), which conducted a historical review in Singapore to examine the effect of urban development on its thermal environment. The second peak in 2013 can be attributed to the study of Vailshery et al. (2013), who evaluated the impact of street trees on addressing the challenges of changing the urban microclimate and increasing levels of air pollution. The most recent peak in 2020 is primarily caused by the study by Morakinyo et al. (2020), which proposed a methodological framework as a "right tree, right place" approach to urban heat mitigation. The protecting biodiversity subtopic presented a peak in 2011 linked to the study published by de Jesús-Crespo and Ramírez (2011) on the physicochemistry, physical habitat, and macroinvertebrate assemblages on a tropical island. This subtopic presented a gross drop in 2013 due to the small number of articles published in this field as indicated by Figure 5. Then, this subtopic presented a certain level of constancy with a new peak in 2020 with the study authored by Silva et al. (2020) who investigated the origin of tree species occurring in urban green spaces in a tropical city, since exotic plants are widely used in tropical urban ecosystems this can have several negative effects on native plants and pollinator communities.

Figure 7 presents Venn diagrams for the four subtopics analyzed, which allow for analysis of their interconnection. The Venn diagram for papers indicates that we have 342 documents in the 4 analyzed subtopics, which represents more than 50% of the total document in the main topic of tropic cities which highlights the importance of these 4 subtopics for the study of tropical cities. The Venn diagram for papers still shows that about 33% of the analyzed documents pertain to at least two subtopics. Similarly, around 36% of the authors are involved in at least two subtopics, demonstrating the interdisciplinary nature of research on tropical cities. The Venn diagram for authors' keywords also suggests interdisciplinarity, with ∼40% belonging to at least two subtopics. The interconnection between countries and educational institutions in the analyzed documents is also noteworthy. Most countries (72%) conducted research in more than one subtopic, while only about 37% of institutions published in more than one topic, suggesting that some institutions may specialize in a single field of study.

Through Figure 7, it was noticed that the topic of urban resource management had a higher proportion of isolated documents, at around 56.73% of the total documents in this topic. Meanwhile, climate change, sustainable urbanization, and protecting biodiversity had 45.75, 35.29, and 47.69%, respectively,

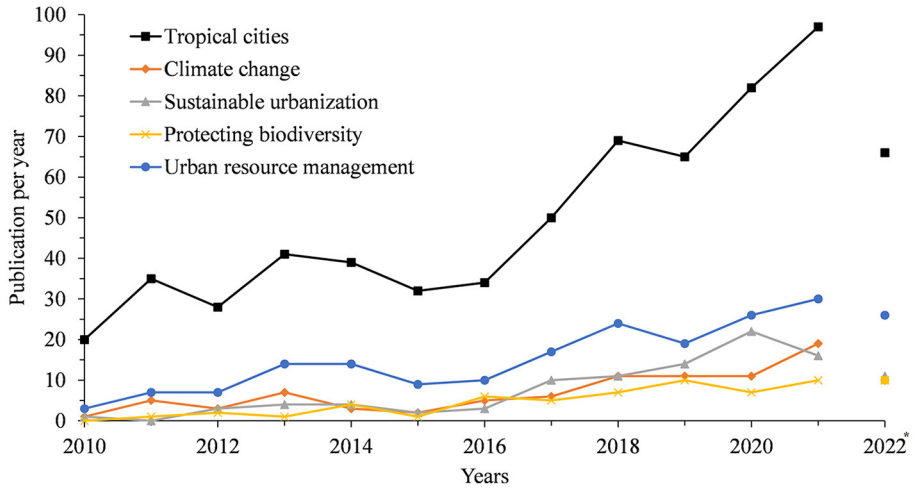

FIGURE 5
Scientific production on tropical cities topic and subtopics of climate change, sustainable urbanization, biodiversity conservation, and urban resource management by year from 2010 to October 2022.

of their documents in a single category. The same pattern was observed in the number of authors. Only 45.62% of the authors of urban resource management subtopic studied on other topics, while 62.03, 65.75, and 56.65% of the authors of climate change, sustainable urbanization, and protecting biodiversity, respectively, studied on more than one subtopic.

Figure 8 shows the countries that have published on the topic of tropical cities and their collaborations through lines. The results indicate that at least 53 countries have published on this subject in the 663 articles analyzed, demonstrating the widespread interest and international network among researchers, including those from non-tropical regions. However, India, Singapore, Brazil, the USA, China, and Malaysia account for about 72% of all publications, indicating a strong concentration in these countries. The subplot in Figure 8 shows the top 15 countries by number of documents published in terms of single countries publications (SCP) and multiple countries publications (MCP) through color. These results suggest that while India has the most publications, Singapore has the most international connections, followed by China and Brazil, indicating the important role these countries play in advancing knowledge on tropical cities.

Figure 9 lists the top 10 journals based on the number of publications, h-index, and number of citations on the analyzed subtopics. A Venn diagram is also included to illustrate the intersections between them. Upon analyzing the intersections of each pair of subtopics, it is observed that the most significant relationships are found in the pair climate change and urban resource management (9.6%), and in the pair sustainable urbanization and urban resource management (7.0%). It is worth noting that other pairs also had relationships between journals >3.0%, including protecting biodiversity and urban resource management (3.7%), and sustainable urbanization and protecting biodiversity (3.2%). These results again highlight the urban resource management subtopic is consolidated, once it appears in the three highest intersection pairs. In addition, when evaluating the intersections for each possible trio of subtopics, it is observed that, naturally, the areas climate change, sustainable urbanization and urban resources management form the group with the most expressive relation (7.0%). Further, as the pairs of subtopics had already indicated, the trio sustainable urbanization, protecting biodiversity and urban resource management showed 3.2% in its intersection.

From these results, two trends were identified between the most relevant intersections that include the four different fields of knowledge. The first and most pronounced one involves the subtopics of climate change, sustainable urbanization and urban resources management. These results showed a concern with climate issues in the context of tropical cities, in particular, related to sustainable urban environments and their well-managed resources. In this tendency, the subtopic protecting biodiversity was the subtopic left out. However, it appeared in the place of climate change in the second most relevant trend that we identified, in which the areas sustainable urbanization, protecting biodiversity and urban resource management stand out. In this scenario, we can point out that there is an interest in investigating the effects of the unmoderated and unplanned urbanization on the fauna and flora of tropical cities.

Finally, the results highlight that 2.7% of the subtopics intersections presented in the Venn diagram in Figure 9 were included in all of the four themes. This demonstrates that tropical cities' studies encompass multiple complex aspects, even though we identified two main trends. However, due to the limitations and scope of this paper, our results only provide a general overview of the database we collected. The discussion of the trends in scientific interests in tropical cities studies will continue with an analysis of the trends in authors' keywords, which are shown in Figure 10.

Figure 10 presents the evolution of the main author's keywords (minimum frequency of 7) in publications on tropical cities. Keywords referring to places were excluded, and synonyms were added. The gray bars indicate the first and third quartile, the circle's position indicates the median year of publication, and the circle size indicates its frequency in the database. In general, Figure 10 showed

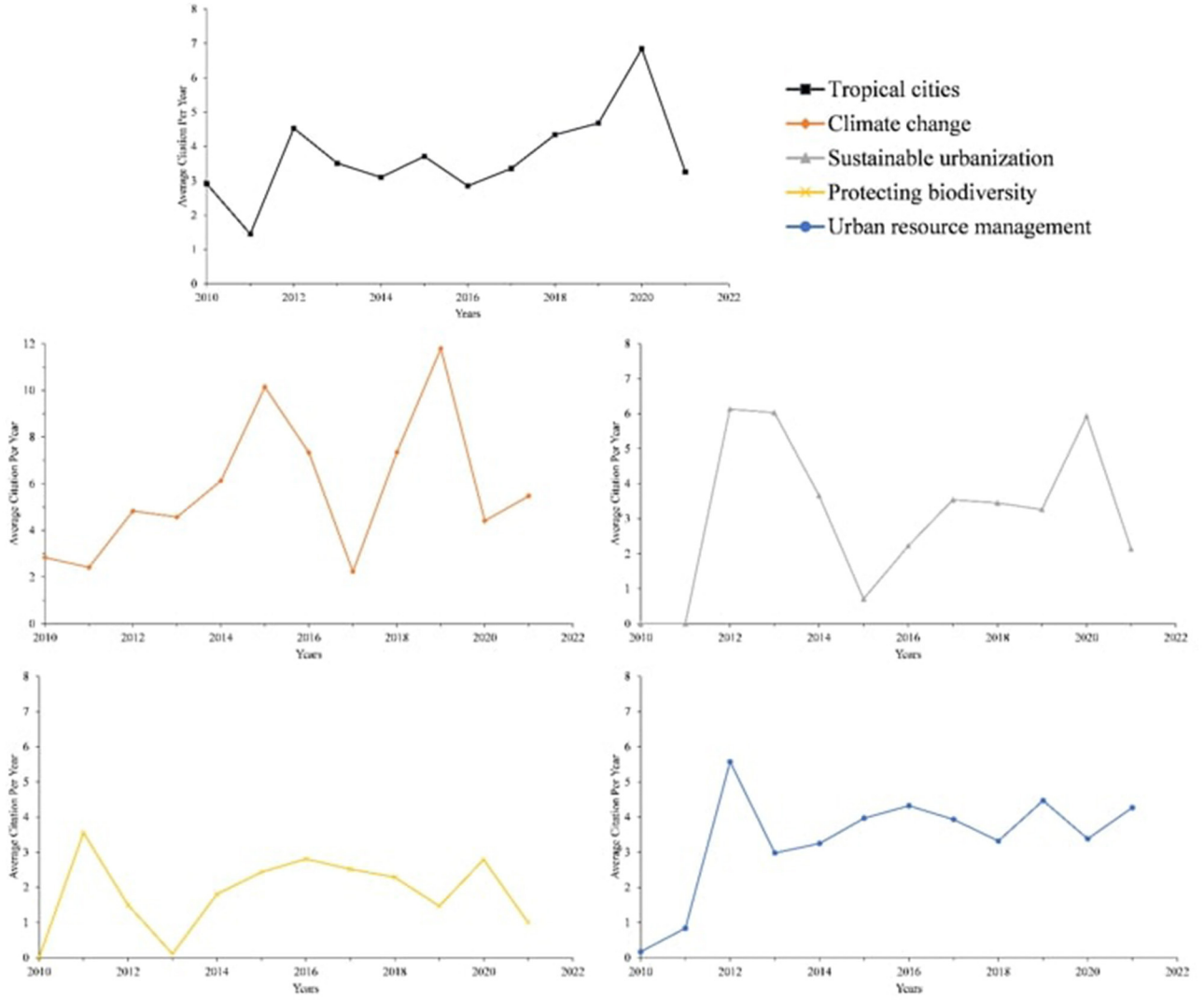

FIGURE 6
Average citation on tropical cities topic and subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management by year from 2010 to October 2022.

that, throughout the analyzed period, there were terms related to the quality of natural resources, such as air (e.g., "black carbon" and "aerosols and particles") and water (e.g., "water quality"). Particularly on water, it can be noted that at first (2014–2016), the median of the frequency of the related keywords represented greater concern with the availability and regime of this resource ("storm water" and "surface water"), and later (2018) with quality aspects ("water quality"). In addition, the keywords "biological invasions" and "pollination" presented median frequencies in 2018 and 2019, respectively. These terms reveal the interest in investigating biological aspects in the context of tropical cities, perhaps in parallel with the study of anthropogenic effects (another keyword, with a median of frequency in 2016) on the wide diversity of fauna and flora.

In addition, although different topics were addressed, from 2018 onwards there was constancy in the term "urban", which appeared in several keywords with median frequency during these years (e.g., "urban ecology," "urban environment," "urban forestry," "urban heat island," "urbanization," "urban planning," among others). This expressive increase in the number of keywords involved with the urban environment can be related to the accelerated urbanization of tropical cities in recent years, as well as the consequences of this rapid growth. Further, these keywords were related to environmental, social, and, naturally, urban planning aspects, which culminated in the appearance of the "ecosystem services" keyword with a median frequency later, in 2022.

Finally, over the period considered, there was an increase in the use of geoprocessing in the study of tropical cities, through the keywords "GIS" and "remote sensing", which presented the median of the frequency in 2016 and 2022, respectively. This later increase in the relevance of these words may indicate that remote sensing and geoprocessing started to be used as tools to evaluate the different aspects addressed in the other keywords.

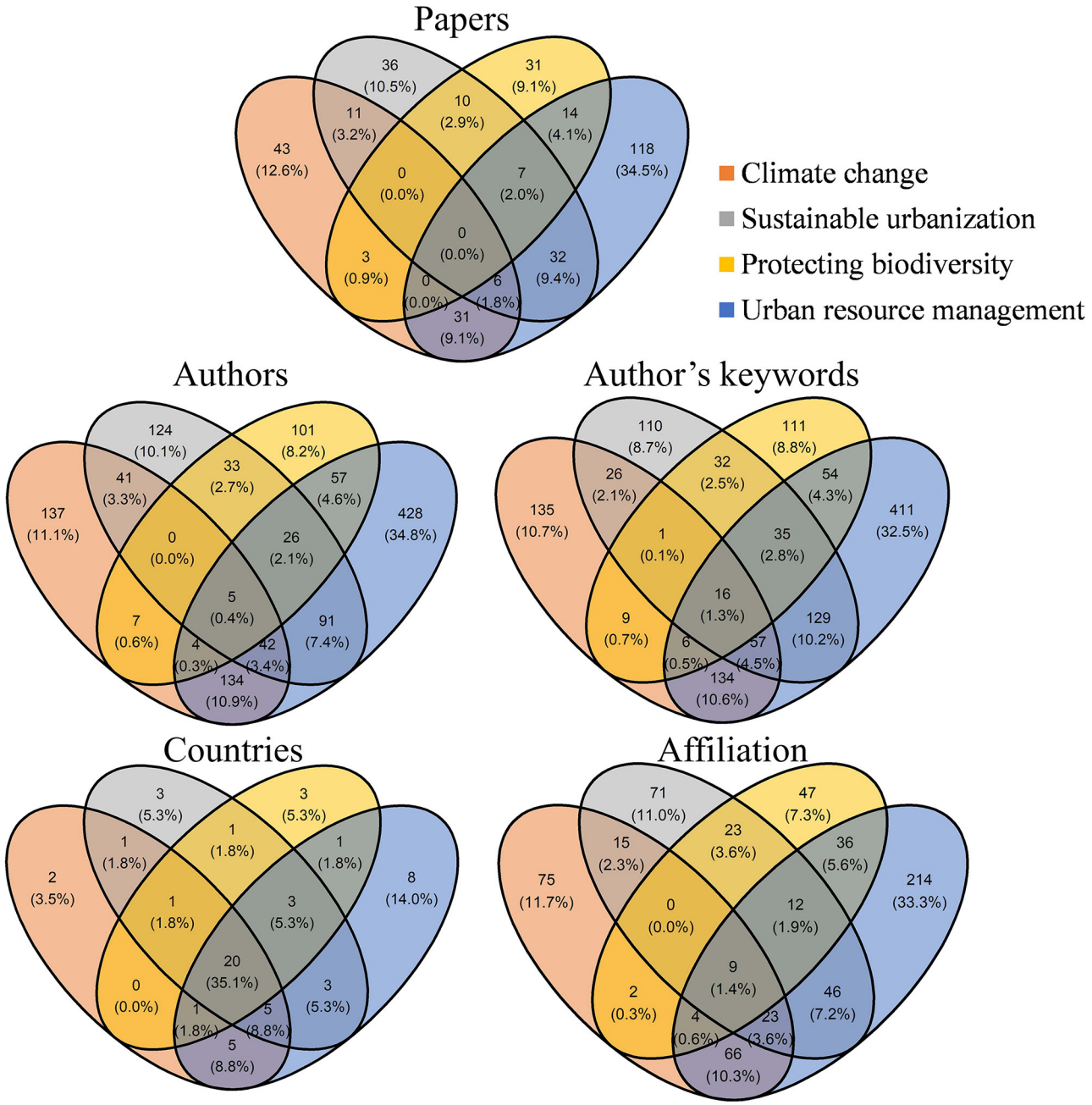

FIGURE 7
Venn diagram of the evaluated subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management by papers, authors, author's keywords, countries, and affiliations.

3.1. Assessment of risk of bias

To mitigate selection bias, a comprehensive search was conducted using the two largest article databases, Web of Science and Scopus. Furthermore, searches were performed across all fields within these databases, ensuring the inclusion of all relevant articles related to the topic in this analysis. While the choice of keywords may have introduced biases, the adherence test was employed to refine the final set of keywords and ensure accurate representation of the research areas, independent of the initial selection.

The data from both databases were merged into a single database containing 663 articles. To ensure data integrity, a visual inspection and the utilization of the R language were employed to confirm that no articles were erroneously excluded or duplicated. In order to minimize reporting bias, clear objectives were defined and utilized as a guide throughout the article selection process, which included reviewing titles, abstracts, and full texts. The stepwise approach of assessing alignment by title, then by abstract, and finally by reading the complete article was designed to establish a robust methodology suitable for large databases.

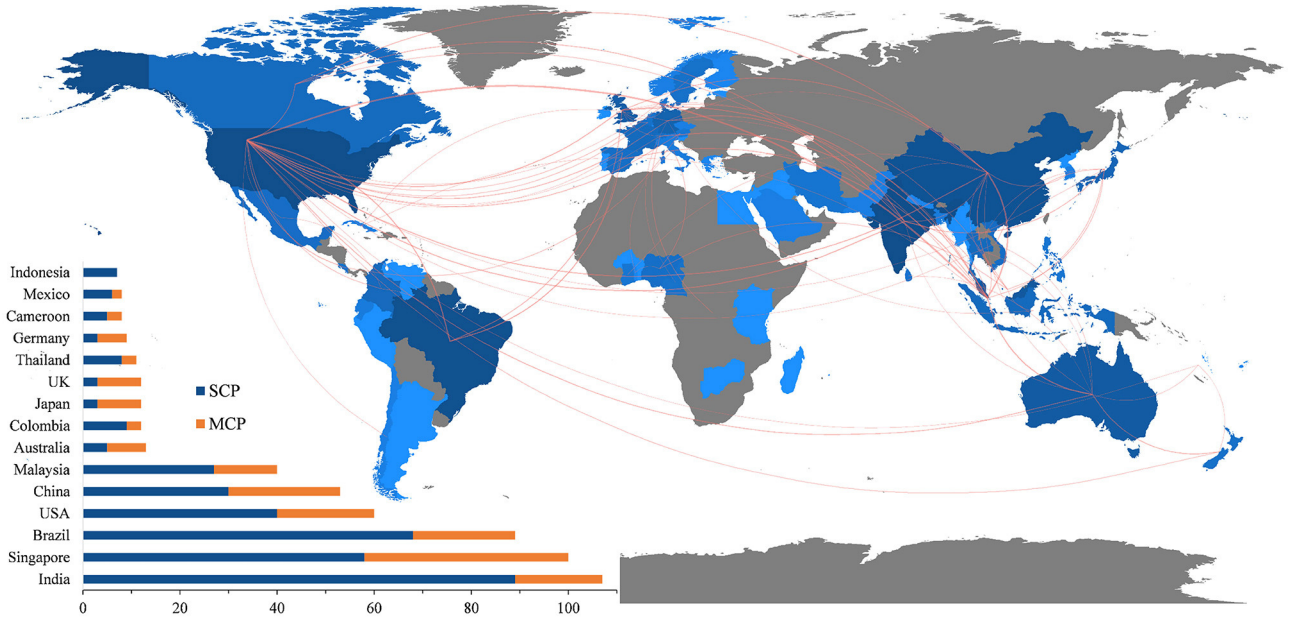

FIGURE 8
Collaboration world map on tropical cities field and top 15 countries per publication (SCP-single countries publications, MCP-multiple countries publications).

To mitigate publication and quality biases, the scientific significance of the articles was evaluated by considering their total citation count using the Pareto principle. Recently published articles, which may not have accumulated substantial citations yet, were included in the review. For articles with low citation counts and older publication dates, consultation with the authors was conducted to ascertain their quality.

These measures were implemented to minimize biases in the analysis. The flowcharts depicting the methodology, along with the availability of results at each step, demonstrate the robustness of this approach.

4. Discussion

The following section presents a detailed overview of the systematic review process, including a discussion of the results obtained from the bibliometric analysis. In addition, we will delve into geographical inequality in the publication output and discuss the concept of tropical cities. Furthermore, the subsequent sections will delve into each of the analyzed subtopics—climate change, sustainable urbanization, protecting biodiversity, and urban resource management—and provide a comprehensive review of the relevant literature. Finally, a summary of the main findings will be presented to conclude the review.

4.1. Geographical inequality in the publication output

The analysis presented in Figure 8 of our bibliometric study reveals significant geographical inequality in publication output. The systematic review further analyzes these inequalities in the studied subtopics. Within the climate change subtopic, the cities of Singapore, Colombo in Sri Lanka, and Kampala in Uganda emerged as the most extensively studied, with India emerging as the most studied country. In the sustainable urbanization subtopic, Singapore, San Juan in Puerto Rico, and Kuala Lumpur in Malaysia stood out as the most researched cities, while India remained the most studied country. In the biodiversity subtopic, Singapore, Delhi in India, and San Juan in Puerto Rico were the cities that garnered the most attention, with Brazil emerging as the most studied country. Regarding urban resource management, Singapore, Skudai, and Kuala Lumpur in Malaysia, and São Paulo in Brazil were the most extensively studied cities, with Brazil once again being the most studied country. For a comprehensive overview of the 68 cities and regions included in our systematic review, please refer to Figure 11, which was extracted from our systematic review database.

In fact, tropical cities encompass a wide range of climates. For example, Singapore has a tropical rainforest climate (Af), Bangkok, Thailand has a tropical savannah climate (Aw), and Kerala, India has a tropical monsoon climate (Am) according to the Koppen classification (see Figure 11). Figure 8 sheds light on the current situation of countries that focus on publishing research about tropical cities, while Figure 11 illustrates the concentration of research areas within the four analyzed subtopics. Our findings indicate that India, Singapore, and Brazil were the most extensively studied regions out of the 29 countries/regions covered in our systematic review database.

Notably, a significant proportion of the studies analyzed in this review center around Singapore. This can be attributed

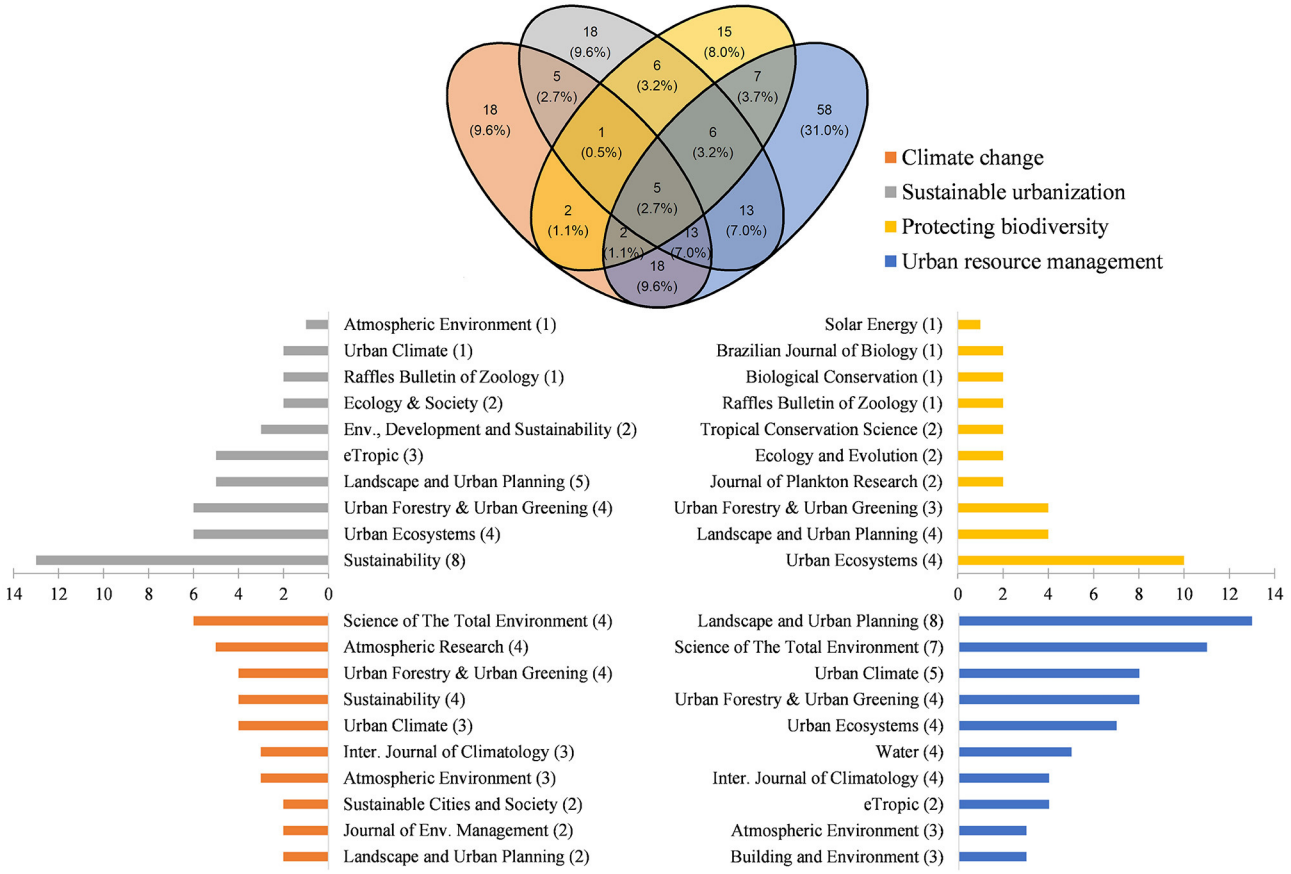

FIGURE 9
Venn diagram of the evaluated subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management by journals, and the top 10 by subtopic analyzed.

to the city-state's international recognition as a leader in urban greening. Singapore is renowned for having over 40% green areas within its city, as reported by Stefaner et al. (2021). The city has implemented notable programs such as the Active, Beautiful, Clean Waters Program (ABC) and Green Towns Program, which promote the adoption of nature-based solutions (Tan et al., 2021). However, it is important to acknowledge that Singapore's high number of international connections, as depicted in Figure 8, could offer opportunities for other tropical cities to establish partnerships or adapt similar programs based on Singapore's experiences.

It is crucial to highlight that both the bibliometric analysis and the systematic review are based on the keyword "tropical cities" and its variations. The definition of a city as tropical is determined by the authors of each study. Figure 11 indicates a divergence in the concept of tropical cities. While the majority of authors adhere to the Koppen classification, others define tropical cities based on the tropics lines. Additionally, a minority of studies self-identify as tropical despite not fitting into these classifications, as observed in the case of Wuhan in China, Varanasi and Delhi in India, and Florianópolis in Brazil.

4.2. Systematic review x bibliometric analysis

The bibliometric analysis was conducted with 663 articles, while systematic review was conducted with 30, 23, 30, and 85 articles in the climate change, sustainable urbanization and protecting biodiversity, urban resource management subtopics, respectively. In any case, both analyzes reveal an increasing trend in research on this topic, with a focus on the adaptation and application of methodologies used in temperate cities to the tropical context. The findings of the systematic review support the notion that publications on climate change often exhibit an international and interdisciplinary character. Notably, studies such as Velasco et al. (2016) and Manoli et al. (2019) exemplify this trend, as they employ a global study area or examine multiple tropical cities, respectively. Approximately 8% of the articles included in the review focused on a global scale, while an additional 8% examined multiple tropical cities. While publications on protecting biodiversity are more localized and specific to the area of study (e.g., Jain et al., 2018; Fragata et al., 2022). Additionally, the topic of urban resource management is the most comprehensive, with various studies covering different areas such as climate change, public health, and water resources quality (Lee M.-B. et al., 2019;

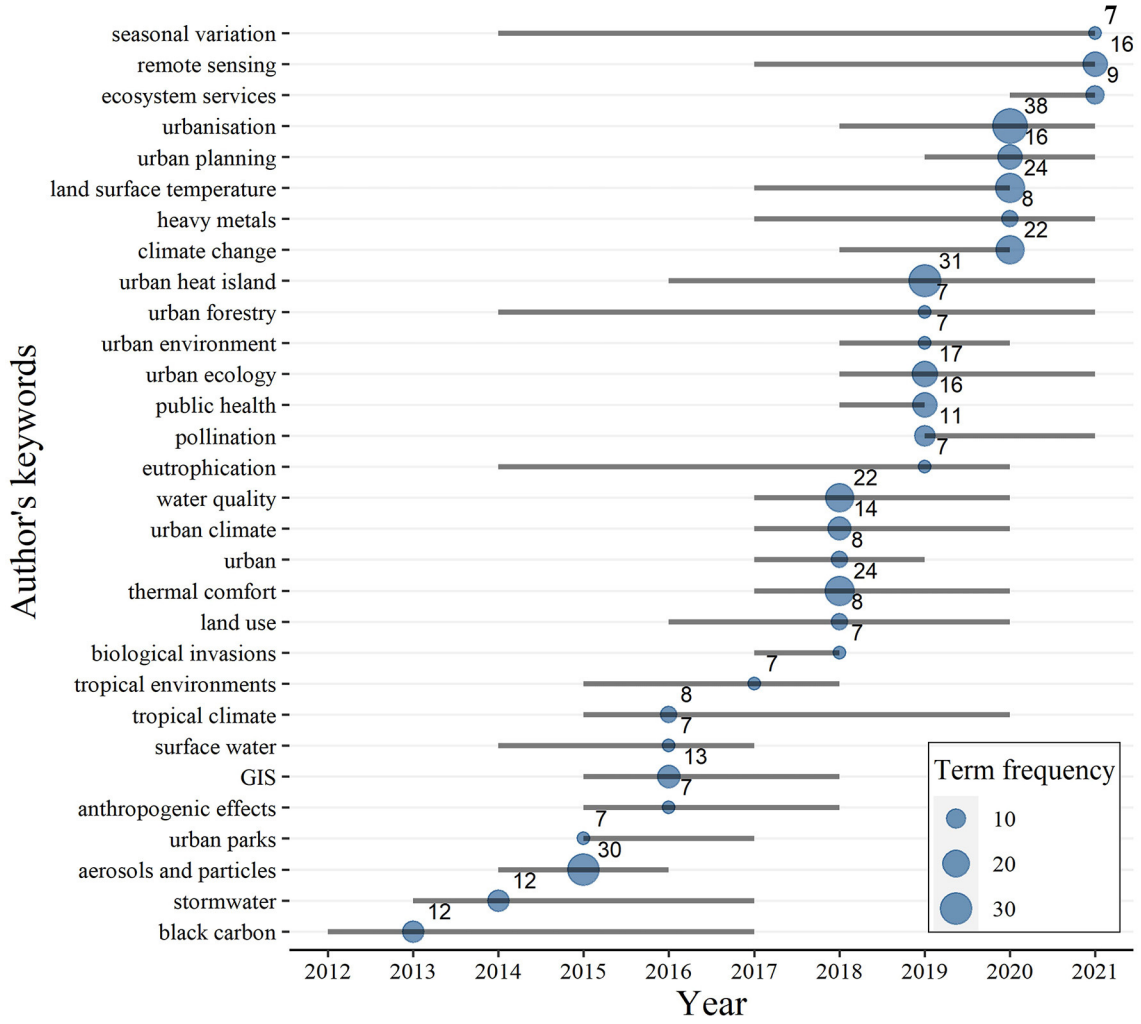

FIGURE 10
The trend of keywords by year on tropical cities field from 2010 to October 2022.

Stefaner et al., 2021; Bridhikitti et al., 2022) in line with the results of the bibliometric analysis.

Moreover, the bibliometric review aligns with the findings presented in Figure 7, highlighting the interdisciplinary nature of research on tropical cities. Of the 149 articles analyzed at this stage, 46 articles were in two categories, and 6 articles were in 3 categories. That is, a third of the articles were in at least two categories similar to the value found in the bibliometric analysis showed in Figure 7. The analysis of the articles suggests that studies in tropical cities need to consider multiple aspects, such as urban heat islands, outdoor thermal comfort, carbon footprint, and protecting biodiversity. Figure 9 demonstrates that several journals publish articles on multiple subtopics, which may facilitate future research on tropical cities.

Comparing the evolution of the study of tropical cities indicated through the keywords in Figure 10 with the systematic review, it can be said that previous decade saw limited use of remote sensing techniques in studies of tropical cities. However, there is a strong trend toward the use of these techniques in recent years, as demonstrated by the systematic review. For example, Mohan and Kandya (2015) used remote sensing data to examine the impact of urbanization and land use/land cover (LULC) in Delhi, India. Similarly, Arulbalaji et al. (2020) used remote sensing data to analyze changes in vegetation cover, urban growth, land surface temperature, and LULC in Kerala, India. This evolution in the use of techniques is important, since one of the challenges in applying urban climate knowledge to planning decisions in tropical cities is the scarcity of data. While simple classification methods such as the Local Climate Zone (LCZ) have been used to classify land use and occupancy in these regions (Chatterjee et al., 2019; Kabano et al., 2021), the complexity and rapid growth of tropical cities calls for more sophisticated systems (Perera and Emmanuel, 2018). To address this data gap, Van de Walle et al. (2021) proposed a low-cost fieldwork approach using a cost-effective methodology to gather relevant parameters that effectively capture urban heterogeneity in terms of morphology and building materials. This approach is particularly useful for urban climate studies utilizing Local Climate Zones (LCZ) in small and medium-sized cities. The increasing utilization of remote sensing techniques in tropical cities may be attributed to these studies and others like them.

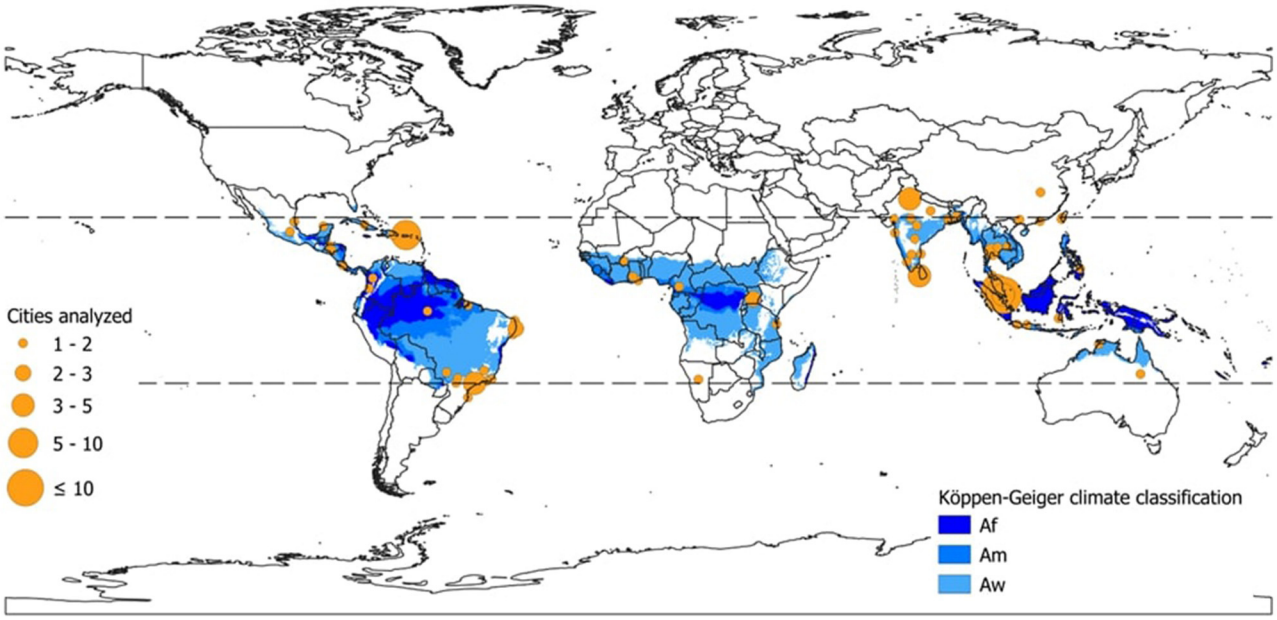

FIGURE 11
Cities/regions studied in the database used for the systematic review. In yellow the frequency of study of cities/regions and the tropical regions of the world according to Köppen-Geiger climate classification (Beck et al., 2018): Af, tropical rainforest; Am, tropical monsoon; Aw, tropical savannah.

Further, the main focus of climatological research on tropical cities from 1996 to 2006 was on issues related to air quality (Roth, 2007). However, current research on tropical cities has become more diverse, and keywords such as "black carbon" and "aerosol and particles" have now a median in 2013 and 2015 respectively as indicated in Figure 10. The review of articles in our database on the subtopic of climate change showed that only one dealt specifically with this topic. Badarinath et al. (2010) found that aerosols contribute to a continuous solar dimming effect over Hyderabad, India. However, other articles in the category of urban resource management addressed this issue. Indicating the tendency of the study of tropical cities to become broader and involve more than one area of knowledge.

Again, in the protecting biodiversity subtopic, the word pollinators in Figure 10 is also in line with the systematic review where it was found that pollinators in tropical cities revealed important information about the impacts of urbanization on biodiversity. Also, in the urban resource management subtopics, some research support the design of urban environments that are sensitive to climate is crucial for human health and comfort. This is in line with the bibliometric analysis that demonstrated a growing trend of keywords related to this topic, such as "public health" and "urban planning" in recent studies (see Figure 10). These trends will be discussed in more detail in subsequent sections of the paper.

In addition, research has shown that tropical regions are lagging behind in terms of urban resource management when compared to temperate regions, as noted by Jochner et al. (2013). This can be attributed to the greater presence of developing countries and lack of political and economic incentives in tropical cities. However, in the past decade, there has been a notable increase in research on this topic, as evidenced by the upward trend in publications (see Figure 5).

4.3. Climate change

Forecasting future climates in urban areas is crucial for the implementation of effective mitigation and adaptation strategies. However, limited research has been conducted on future temperature projections in tropical cities. To address this gap, He et al. (2022) utilized a statistical method to downscale global climate modeling results to the city scale and employed an urban morphological approach to estimate the impact of urbanization on air temperature in Singapore. Conducting such studies in tropical cities can significantly enhance our understanding of the dynamics of global climate change. Furthermore, investigating climate change in tropical cities is of paramount importance because the effects of climate change can extend beyond the boundaries of a specific location and impact the region and the world as a whole, so the unplanned rapid expansion of tropical cities is not a local problem (Roth, 2007).

Moreover, despite its crucial relevance for water resource management, flood risk reduction, drought mitigation, and the design of ecologically sustainable cities, research on precipitation spell characteristics in tropical urban areas remains limited (Lo and Koralegedara, 2015; Li et al., 2016). Given the complex precipitation patterns exhibited by tropical cities, access to spatial and temporal precipitation data is indispensable for effective water resource management. However, financial constraints often hinder the availability of high-resolution data in many regions. Combining spatial downscaling and temporal disaggregation techniques can offer valuable projections of high-resolution rainfall data. Unfortunately, only a few studies of this nature have been conducted in tropical cities, with one example being the study conducted by Lu and Qin (2014) in Singapore.

Examining the influence of urbanization-driven land-use changes on local hydrometeorological processes, Pathirana et al. (2014) observed an increase in local extreme rainfall with the growth of urban areas in Mumbai, India. However, the relationship between urbanization and rainfall is non-linear and depends on various localized factors such as topography, surrounding land use, and local/seasonal climate patterns. For instance, Li et al. (2017) investigated long-term trends in extreme precipitation in Singapore and found that the impact of local factors on precipitation extremes outweighs the effect of global warming. Consequently, further studies on this topic are necessary to gain a comprehensive understanding of the complex interplay between urbanization and rainfall patterns.

Anthropogenic activities have a significant impact on the urban microclimate, particularly through the urban heat island (UHI) phenomenon, where urban areas exhibit higher temperatures compared to surrounding regions, exacerbating heat waves. Marcotullio et al. (2021) conducted a study on 270 tropical cities globally and found that all cities in the tropics have experienced warmer conditions. Notably, cities in rainforest and monsoonal zones have witnessed an intensified UHI effect, resulting in increased urban warming. In addition, Chew et al. (2021) conducted research in Singapore during a heatwave and found no amplification of UHI intensity, which differs from studies conducted in temperate cities showing a positive correlation between heatwaves and UHI. Although studies focusing on heat waves in tropical cities are relatively scarce, they are essential for enhancing our understanding of UHI dynamics and heat wave impacts.

Mitigating the effects of UHIs in tropical cities, is widely acknowledged as necessary. However, Roth and Chow (2012) highlighted the limited availability of information regarding the environmental benefits of proposed greening options and the lack of data on current climate interventions employed in Singapore. Despite these limitations, some progress has been made in understanding the impacts of various strategies to mitigate UHI in tropical cities. For instance, Benrazavi et al. (2016) analyzed the effect of pavement materials on surface temperatures in Putrajaya, Malaysia. Herath et al. (2018) demonstrated that trees on curbsides, green roofs, and green walls can influence microclimatic conditions and potentially mitigate UHI in Colombo, Sri Lanka. Chatterjee et al. (2019) conducted simulations to assess the effectiveness of different mitigation strategies, such as cool pavements, cool roofs, and increased urban vegetation, in reducing UHI intensity in Kolkata, India. Koranteng et al. (2021) suggested that green roofs may be a viable solution to alleviate indoor thermal discomfort in Kumasi, Ghana. Gamero-Salinas et al. (2021) found that passive cooling design strategies, including natural ventilation, wall absorptance, and wall thermal transmittance, can significantly reduce the risk of overheating in Tegucigalpa and San Pedro Sula, Honduras. Additionally, Dayathilake et al. (2021) demonstrated the high carbon storage potential of urban freshwater wetlands in Colombo, Sri Lanka. However, further research is necessary to enhance our understanding of the effectiveness of different mitigation strategies in tropical cities and their associated environmental benefits.

In the context of climate change, it is crucial for tropical cities to adapt their policies to mitigate its impacts. While traditional solutions such as transitioning away from outdated technologies and promoting public transportation have been extensively discussed in the literature, innovative approaches like nature-based solutions have received limited attention in tropical cities, particularly within South America (Reynolds et al., 2017). Several studies have indicated the potential environmental benefits of street trees in reducing air temperature, humidity, and air pollution, as demonstrated by Vailshery et al. (2013) in Bangalore, India. Similarly, research by Morris et al. (2017) in Klang Valley, Malaysia, highlighted the role of urban vegetation in mitigating the formation of UHI. However, Velasco et al. (2016) found that the impact of urban vegetation on directly reducing greenhouse gas (GHG) emissions through carbon sequestration is limited or negligible, even in tropical cities.

Moreover, there exists a gap in our understanding of the phenology of individual trees or specific tree species in tropical cities (Jochner et al., 2013; Kabano et al., 2020, 2021), which is crucial for urban tree management as phenological observations in urban areas can help assess microclimatic conditions. Furthermore, the complex interactions between the built environment and vegetation make it challenging to evaluate the contribution of vegetation to a city's radiative budget. Recent studies by Dissegna et al. (2019) have suggested the potential of physically-based radiation transfer models, such as the Discrete Anisotropic Radiative Transfer model, for neighborhood-scale analysis and scenario testing with different surface materials and vegetation properties, providing a better understanding of UHI dynamics in tropical contexts.

Furthermore, gaining a deeper understanding of the ecosystem services and economic values associated with urban forests is essential for the implementation of effective urban forest management policies (Jim and Chen, 2009). Implementing nature-based solutions requires multidisciplinary studies that encompass various aspects relevant to tropical cities.

Additionally, the effectiveness of different cooling solutions is influenced by the nonlinear interactions between the local climate, vegetation characteristics, and the built environment. Research by Manoli et al. (2019) revealed that increasing green cover and albedo are more effective in dry regions, while tropical cities require more innovative solutions. Consequently, UHI mitigation strategies commonly employed in temperate cities need to be adapted to the tropical context, considering that the energy balance mechanisms in the tropics differ from those in mid-latitudes (Chatterjee et al., 2019).

Moreover, the impacts of climate change on tropical cities can have significant social and economic consequences. Méndez-Lázaro et al. (2016) highlighted the increased effect of high temperatures on mortality, particularly from stroke and cardiovascular disease, in Puerto Rico. Ramsay et al. (2021) demonstrated that heat stress approached the upper limits of human thermoregulatory capacity in informal settlements in Makassar, Indonesia. Furthermore, Upadhyay et al. (2021) indicated that variations in soil temperature and moisture conditions under climate change scenarios may hinder future soil carbon dynamics by mediating soil nutrient availability in

urban soils in Varanasi city, India. Understanding the effects of climate change on urban tropical areas is also crucial for addressing issues like eutrophication and pollution (Silva et al., 2019) and for flood damage estimation and mitigation (Tabucanon et al., 2021). Therefore, when planning for sustainable, biodiverse, and resource-efficient tropical cities, it is essential to consider these social and economic impacts.

Finally, climate change is compelling city governments to adopt innovative and creative approaches to urban planning as traditional practices have reached their limits (Yulia and Arlianda, 2020). Biswas et al. (2022) found that the holistic implementation of climate change adaptation for water resources is rare and still in its early stages due to a lack of quantifiable implementation frameworks or audit processes. This is likely to be the case for many tropical cities in different regions, which often face challenges such as poor data availability and limited access to financial resources. Currently, there is a gap in standards that can assist tropical cities in adapting to climate change. However, considering the dynamic and uncertain nature of climate change, it is more beneficial to develop plans that can be adapted as the future unfolds, such as the development of dynamically robust plans (Manocha and Babovic, 2018).

4.4. Sustainable urbanization

Many studies in this subtopic focus on characterizing the urban heat island (UHI), effects similar to the previous subtopic, but here they aim to build cities suitable for the well-being of human beings and the environment. For instance, Souto and Cohen (2021) utilized satellite images from 2003 to 2018 to examine the relationship between increased land surface temperature and dense urbanized areas, as well as their surroundings in the metropolitan region of Belém, Brazil. In a study conducted in Singapore, Jin et al. (2018) found that the building plot ratio (the ratio of total floor area to total land area) and sky view factor were the most significant parameters influencing daytime air temperature. Similarly, Kotharkar et al. (2019) identified the distance from the central business district, surface albedo, aspect ratio, and vegetation density ratio as major factors contributing to UHI occurrence in Nagpur, India.

In addition to investigating UHI phenomena, sustainable urbanization research often explores outdoor thermal comfort (OTC). Rajan and Amirtham (2021) emphasize the close link between UHI and OTC, highlighting how proper urban planning can mitigate the UHI effect and enhance OTC through the creation of vegetated parks and the preservation of forested areas, especially those with large, dense canopies. Haddad et al. (2020) proposed a holistic approach to mitigate UHI effects and improve OTC in tropical cities, demonstrating that a combination of cool materials, shading, and greenery in urban areas effectively reduces temperatures and enhances thermal comfort in Darwin, Australia. However, there is limited research specifically focused on users' perception of OTC. Das et al. (2020) conducted a study in Eastern India that associated field measurements of thermal indices with questionnaire surveys to evaluate the subjective thermal sensation of outdoor spaces. Their findings revealed a strong correlation between objective and subjective parameters related to OTC.

While adopting mitigation strategies is crucial for achieving sustainability in urban areas, it is important to plan these strategies carefully to avoid resource misuse and ensure their success. For example, Lin and Tsai (2017) conducted a study in Taiwan, demonstrating that planting appropriate tree species can improve OTC in tropical climates. Acero et al. (2019) investigated the impact of vertical green systems (VGS) on pedestrian thermal comfort in Singapore and found that benefits are not expected to be noticed at a distance >3 m from the facade with its geographical orientation also influencing its thermal performance. Furthermore, Zaki et al. (2020) demonstrated the influence of roadside tree orientation on outdoor air temperature in Kuala Lumpur, Malaysia. Vailshery et al. (2013) highlighted the positive effects of tree plantation along roads, including reduced air and road temperatures, as well as lower air pollution in Bangalore, India. These findings underscore the need for multidisciplinary strategies that consider various factors to effectively address the challenges of UHI and OTC in tropical cities.

Moreover, the consideration of carbon footprint and offset is crucial in the pursuit of sustainable urban environments. Reynolds et al. (2017) compared different carbon offset techniques and found that public trees are a competitive option in a Colombian metropolitan area, outperforming alternatives such as cable car public transportation. Nadeeshani et al. (2021) evaluated the life cycle carbon footprint of conventional building roofs vs. green roofs in Colombo, Sri Lanka, and discovered an 85% reduction in carbon footprint with the implementation of green roofs.

In addition to green roofs, other sustainable drainage systems have been studied as well. Chui and Trinh (2016) found that converting 5% of a Singapore catchment area into bioretention systems would enhance infiltration and groundwater recharge. Other strategies such as protecting remaining forests, planting multi-layered vegetation, and restoring urban soils have also been proposed to help with flood regulation and carbon sequestration (Fung et al., 2021).

Several studies have evaluated the adoption of green strategies at the yard and indoor levels, providing valuable insights for urban planners in terms of urban zoning and the implementation of incentive policies. Meléndez-Ackerman et al. (2014) found strong associations between yard characteristics and household demographic profiles in Puerto Rico, with yard size emerging as the most important factor influencing vegetation diversity and quality. Oh et al. (2018) conducted a study in Singapore and discovered that corridor and building design significantly influenced the abundance and diversity of vertical greenery, emphasizing the importance of incorporating plant requirements into urban space design to enhance the synergy between humans and flora.

Thus, the synergy between urbanization and ecosystem services provision is a key aspect of sustainable urbanization. Tan et al. (2021) conducted a case study in Singapore and demonstrated that the consistent application of nature-based solutions across all elements of urban development significantly enhances urban ecosystem services. In fact, Singapore serves as a long-term case study for tropical urban ecosystem services, with evidence of these services being present in the city-state since the nineteenth century.

Further, case study of Singapore serves as a model to other cities across the tropics, considering its experience with the urban-green continuous conflicts (Friess, 2016).

To summarize, the reviewed literature on this subtopic provides valuable technical information on urbanization in tropical regions. Local study areas were utilized to explore the challenges associated with urban growth and evaluate strategies for minimizing these issues. However, there is a limited exploration of the effects of urbanization and mitigation strategies beyond the microscale. Additionally, there is a lack of studies evaluating the relationship between knowledge generation and its practical application. Achieving sustainable strategies in tropical urban environments requires not only scientific advances but also effective management of the politics and visions arising from complex governance systems. In this sense, the use of knowledge-action systems could be useful to enhance the ability of decision-makers, scientists, and planners to work together in the aim to achieve sustainable strategies within the tropical urban environment (Muñoz-Erickson, 2014).

4.5. Protecting biodiversity

The articles selected for this subtopic demonstrate investigations into various species and aspects, which aligns with the diversity of fauna and flora in tropical regions. However, birds and avian species are the most studied animal group, as their observation in urban areas is relatively simple and accessible. In terms of human presence and disturbance, Wolff et al. (2018) and Lee M.-B. et al. (2019) evaluated how local-scale features of an urban tropical city can affect the richness and occupancy of avian species, specifically in the San Juan Metropolitan Area, Puerto Rico and Nanning, China, respectively. They found that noise, population density, building height and proportion of commercial buildings have negative impacts on bird presence. Additionally, Estela et al. (2021) examined how the nocturnal activity of birds in the tropical city of Cali, Colombia changed during the COVID-19 pandemic lockdown and found that there was an increase in bird activity during the strict circulation period, highlighting the impacts of changes in human activity on urban biodiversity.

Furthermore, Dri et al. (2021) developed a model that combines historical aerial imagery and current species distribution data to examine the effects of urbanization on habitat loss and isolation in birds in Florianópolis, Brazil. Their findings indicate that habitat loss is the primary cause of species extinction in urban areas, and that cities can rapidly promote biodiversity by preserving or restoring forest cover. Fragata et al. (2022) studied the patterns of diversity and abundance of parrots in the tropical city of Manaus, Brazil and revealed that the quantity of green areas in the city is a major driver of parrot diversity and composition, linked to the urbanization process of the city. Sultana et al. (2022) investigated the effects of urban land cover and socioeconomic factors on resident bird species richness and abundance in the tropical megacity of Dhaka, Bangladesh. They found that increasing impervious areas result in low bird richness, while bird abundance is increased in areas with high habitat heterogeneity and near green areas, and that regions with rising poverty decrease birds' abundance. Tang et al. (2015) studied the population genetics of a bird species affected by urbanization in Singapore and discovered high genetic diversity and evidence of population growth, suggesting that conservation of bird species may be possible despite the fragmentation of green areas.

Besides, some studies have investigated strategies to ensure bird biodiversity in tropical cities. Thaweepworadej and Evans (2022) found that urban woodlands can moderate the negative impacts of urbanization on avian species richness in Bangkok, Thailand, suggesting strategies to design such woodlands to maximize biodiversity protection and conservation benefits. Rawal et al. (2021a) evaluated winter bird's abundance, species richness and functional guild composition in ponds of a major tropical city Delhi, India. In the same study area, Rawal et al. (2021b) investigated the bird diversity in the ponds and its relationship with site-level (pond size, water quality, shoreline heterogeneity, wetland vegetation, and others) and landscape variables (impervious surface, proximity of local ponds, extent of wetlands and others). Their findings highlight the importance of preserving ponds, as they are a refuge to hundreds of birds in tropical megacities. However, further research is needed to fully understand the impacts of these strategies, particularly in regard to the effects on bird molting and the role of urban resource planning in biodiversity conservation. Therefore, the literature on the impact of urbanization on bird biodiversity in tropical cities underscores the complexity of the issue and the need for interdisciplinary research.

The studies of butterflies and pollinators in tropical cities have revealed important insights into the impacts of urbanization on biodiversity. Jain et al. (2018) examined the temporal trends of butterfly extirpations and discoveries in Singapore, highlighting the rapid urbanization of this tropical city. Gupta et al. (2019) evaluated the changes in butterfly diversity in urban tropical areas, specifically examining the effects of temperature and humidity changes in Delhi, India. Their findings indicated that temperature gradients can greatly influence urban landscapes and their biodiversity. Oliveira et al. (2018) studied how an urban reserve affects the diversity of butterflies in public squares in Natal, Brazil. They observed a notable difference between the butterfly communities in the reserve and those in the public squares, suggesting limited dispersal from the reserve to the surrounding areas, despite the presence of green cover and resources. Similarly, May-Itzá et al. (2021) identified differences in bee communities between urban and rural areas, likely attributed to resource limitations and mating conditions in Merida, Mexico.

Furthermore, Nascimento et al. (2020) conducted a systematic review of 86 studies on urban plant-pollinator interactions in Brazil, aiming to understand the role of urban green spaces in preserving pollinator diversity in tropical cities. The authors found that despite the negative impacts of urbanization, tropical urban areas can support a diverse array of pollinator species. Cézar et al. (2022) also highlighted the importance of considering changes in pollinator communities and their impact on fruit production, emphasizing that the relationship between pollinators and plants must be considered in conservation efforts. These findings demonstrate the need for an effective pollinator conservation plan that considers these multiple factors.

In addition to the species mentioned above, several other studies have explored different facets of biodiversity in tropical urban environments. Ganci et al. (2021) investigated frog species richness and composition, Lippert et al. (2020) studied communities of protozoans in a tropical urban stream, Andrade (2019) focused on lagartixas, a common lizard found in Brazil, de Jesús-Crespo and Ramírez (2011) examined macroinvertebrate assemblages, Izuddin et al. (2019) explored orchid mycorrhizal fungi found in trees within urban environments, and Alves-de-Souza et al. (2017) analyzed eukaryotic phytoplankton in coastal lagoons. These studies collectively emphasize the importance of considering biodiversity as an indicator of the impact of human expansion on the environment and highlight the need to incorporate biodiversity considerations into conservation and management strategies.

In the context of conservation of plants and trees in tropical cities, some studies have highlighted that despite the importance of urban green spaces, the presence of exotic species is common due to lack of proper management. For example, Silva et al. (2020) evaluated the species of trees planted in green spaces of tropical urban areas in northeastern Brazil. They found a high proportion of exotic plants, which could negatively impact native species in terms of pollination and colonization. Similarly, Oliveira et al. (2020) investigated the role of urban green spaces as repositories of natural forests and found that the dominance of exotic plants limited their ability to serve as biodiversity repositories in Recife, Brazil. These findings underscore the need for proper management to mitigate the negative impacts of exotic species and enhance the conservation value of urban green spaces.

Additionally, research have also examined the relationship between species and the urban environment, highlighting how the implementation of green spaces in different locations can contribute to biodiversity protection and conservation. For instance, Jim (2013) evaluated the abiotic and biotic conditions for tree growth on stone walls in Hong Kong, while Wang et al. (2017) observed bird and butterfly visitors at a tropical roof garden in Singapore, both indicating the importance of proper dimensions and design for these spaces to attract wildlife.

Besides, Oh et al. (2018) presented an in-depth analysis of the presence and distribution of greenery along high-rise residential corridors in Singapore, highlighting the potential of these green urban areas as refuges for native species, providers of ecosystem services, and facilitators of human-nature interactions. Belcher and Chisholm (2018) quantified the economic value placed on vegetation areas by homebuyers in proximity to residential areas in Singapore. They determined that homebuyers placed higher value on managed vegetation, such as parks and street trees, compared to spontaneous or natural areas. Overall, these studies emphasize the importance of careful planning and management of urban green spaces in tropical cities to ensure their effectiveness in promoting sustainability and conserving biodiversity.

4.6. Urban resource management

The analyzed studies in this subtopic reveal a lack of urban resource planning, consistent with the trends highlighted in previous topics. Changes in LULC, particularly the expansion of impermeable areas with reduced ecosystem functions (Tan et al., 2021), have led to air quality degradation (Ooi et al., 2019; Nipen et al., 2022), temperature changes (Aktas et al., 2020; Meili et al., 2021), and increased sensible heat absorption, exacerbating UHIs (Li et al., 2013; Carrillo-Niquete et al., 2022). In fact, UHIs can be influenced by multiple factors, including climate, society, and the economy (Li et al., 2020), and can have various impacts on both people and the environment, as previously discussed (Kotharkar et al., 2020; Acero et al., 2021; Kabano et al., 2021). Therefore, understanding this phenomenon within the context of each tropical city is crucial to assist in urban resource management (Amorim, 2018; Isa et al., 2020).

Enhancing the ability of tropical cities to adapt to UHIs and climate effects requires multidisciplinary planning of urban resources. One approach is to mitigate damage through technical guidance for building features in high-density urban areas (Chen et al., 2010; Rodríguez-Algeciras et al., 2018; Bartorila and Rosas Lusett, 2021) and increasing green areas to enhance their benefits, such as microclimate control (Ali and Patnaik, 2019). For instance, highly urbanized landscapes without tree cover can absorb up to four times more heat compared to densely vegetated natural landscapes (Dissegna et al., 2019). Thus, implementing green building and environmental initiatives, such as replacing existing roof structures with green roofs, is another viable strategy (Ali and Li, 2018). Other strategy can involve utilizing available radiation as an opportunity for solar energy generation in different urban topologies, as demonstrated in studies conducted in Brazil (Martins et al., 2014) and Tanzania (Lau et al., 2017).

Appropriate management of urban resources, including sustainable planning of LULC and conscious expansion of green areas and water bodies, can enhance ecosystem functions (Fung et al., 2021; Olivero-Lora et al., 2022). This, in turn, leads to higher biodiversity (Abendroth et al., 2012; Chang and Lee, 2015; Barbosa et al., 2020; Hwang et al., 2021), improved pollination processes (Albuquerque-Lima et al., 2022), and effective control of illness-vector mosquitoes (Skovmand et al., 2011; Lee J. M. et al., 2019).

Green areas also play a role in storm water interception (Nytch et al., 2018), and when implemented on green roofs, they can remove pollutants and heavy metals (Lim et al., 2021) while mitigating diffuse pollution effects through bioretention basins (Chui and Trinh, 2016). However, it is important to note that the choice of soil and substrate used can impact nutrient levels in water and become a water quality issue if not managed properly (Lim et al., 2021).

Moreover, these green spaces can have economic implications for tropical cities. For instance, Belcher and Chisholm (2018) demonstrated that vegetation has positive effects on property selling prices in Singapore. However, it is important to acknowledge that not all tropical cities have the same resources for implementing green infrastructure. Oliveira and Ahmed (2021) highlighted the challenges faced in Ghana and other African countries, such as a lack of trained professionals, financial incentives, and effective public policy management, which hinder the realization of environmental and socioeconomic benefits from green and blue infrastructure.

Besides, considering the historical context of tropical cities, understanding past actions and their consequences is important

for supporting future decision-makers (Scarborough and Isendahl, 2020; Evans et al., 2021). Historical research has highlighted the benefits of sustainable adaptations and connectivity in tropical urban cities (Scarborough and Isendahl, 2020), as well as the soil security achieved by ancient societies such as the Maya (Evans et al., 2021). These studies demonstrate that preserving green areas increases environmental awareness and a sense of belonging to space. Similar investigations can be conducted to characterize social and environmental dynamics in other historical civilizations in the tropics.

Extreme hydrological events, such as inundation, pose significant risks that can be better understood through hydrodynamic simulations. These simulations aid in risk mitigation by controlling peak discharges, facilitating communication with society and water managers (Tabucanon et al., 2021; Chitwatkulsiri et al., 2022; Mattos et al., 2022), and assisting in the design of water management systems (Manocha and Babovic, 2018).

In fact, water resources play a crucial role in the development of urban resource policies (Biswas et al., 2022). Understanding water quality impacts, including their origin, is addressed through various monitoring studies (Chow et al., 2013a,b; Chow and Yusop, 2014). Some studies have explored the relationship between eutrophic tropical reservoirs and greenhouse gas emissions (de Mello et al., 2017; Pierangeli et al., 2021), while others emphasize the importance of studying eutrophic reservoirs for public health assurance (You et al., 2015; López-Doval et al., 2017; Silva et al., 2019; Malta et al., 2022).

Spatial and temporal assessment of surface water quality provides valuable information for formulating evidence-based water resource management strategies by local governments (Othman et al., 2012; Mena-Rivera et al., 2017; Bridhikitti et al., 2022; Marinho et al., 2022). Additionally, studies focused on water treatment have explored the use of different algae species for pollutant removal via phytoremediation (Anne et al., 2021), while the separation of yellow water, brown water, and gray water shows promise in improving the management of domestic wastewater in a sustainable manner (Zhang et al., 2013; Ng et al., 2014). In addition, in situ monitoring research and computational hydrodynamic simulations are essential for sustainable development in tropical cities, as the quantitative and qualitative aspects significantly impact the environment (Chow et al., 2012; Hasan et al., 2019).

Furthermore, studies conducted on this subtopic have investigated atmospheric composition and air quality by examining photochemical processes (Soni et al., 2022), wet deposition of secondary atmospheric pollutants like nitrate (Villalobos-Forbes et al., 2021), ozone and particulate matter (PM) measurements (Barima et al., 2014; Salvador et al., 2022), the impact of biomass burning on PM composition (Yang et al., 2013), and the effects of peat-forest burning on PM (Lan et al., 2021).

In summary, effective urban resource planning in tropical cities requires a comprehensive and multidisciplinary approach. This approach should consider socio-economic factors, for example, the morphological and chemical characteristics of the soil, the impacts of extreme weather events, and the potential use of solid waste for energy generation and cooling (Udomsri et al., 2011; Upadhyay et al., 2021; Olivero-Lora et al., 2022). Additionally, it is crucial to ensure that urban resource planning concepts are equitable and accessible to all, regardless of education or economic power (Muñoz-Erickson et al., 2014; Martinuzzi et al., 2021; Takakura and Massi, 2021).

4.7. Summary of main findings

The research conducted on tropical cities in relation to climate change underscores the importance of understanding the impacts of this phenomenon on urban areas. The social and economic consequences of climate change in tropical cities extend beyond local boundaries, making it a global concern. Additionally, the unique climatic dynamics in tropical cities can provide valuable insights into several themes, such as the association between extreme events and urbanization. Furthermore, investigating the influence of urbanization-driven land-use changes on local hydrometeorological processes and forecasting future climates in tropical urban areas can significantly enhance our comprehension of the dynamics of global climate change.

Further, limited research has been conducted on future temperature projections and precipitation spell characteristics in tropical cities, highlighting the need for further studies in these areas. Studies have shown a correlation between increase in urban tropical areas and extreme urban rainfall, however, this relationship is complex and influenced by factors such as local topography, surrounding land use, and specific climate patterns. Since the management of water resources and extreme events are essential for sustainable development in tropical cities, more research is needed in this area to fully understand the dynamics of precipitation in tropical urban areas.

Many studies on sustainable urbanization, climate change, and urban resource management in tropical cities have focused on characterizing the effects of the UHI phenomenon. These studies suggest that addressing UHI needs a multidisciplinary effort that must consider both climate and urban planning factors. However, there are gaps in understanding this phenomenon, such as the dynamics of UHI and heatwaves in urban tropical regions. Understanding the complex interactions between the built environment, vegetation, and climate is crucial for effective UHI mitigation and adaptation strategies.

Various strategies have been employed in tropical cities to mitigate the effects of climate change on the UHI phenomenon, such as cool pavements, cool roofs, green walls, and passive cooling design strategies. However, challenges remain in implementing these strategies effectively. Firstly, limited availability of information regarding the environmental benefits of proposed greening options and insufficient data on current climate interventions hinder progress. Secondly, the nonlinear interactions between local climate, vegetation characteristics, and the built environment further complicate the effectiveness of these strategies. Hence, innovative solutions specifically tailored to the tropical context are necessary, i.e. global and multi-scale understanding, linking physical-chemical processes, transport and thermodynamics approaches with optimization, like deep learning and numerical simulation.

The implementation of cooling solutions in tropical cities requires careful consideration of local climate and vegetation characteristics. Simply applying solutions from temperate cities may not yield the desired results. Due to the complexity and diversity of tropical cities, strategies must be tailored to each specific location. To ensure the success of these solutions, research must be conducted across a range of different tropical cities. However, unfortunately, there is a lack of guidelines or standards to assist these cities that are particularly vulnerable to the effects of climate change. Another challenge lies in the absence of quantifiable implementation frameworks or audit processes. The lack of standards that can guide tropical cities in adapting to climate change exacerbates this issue.

Nature-based solutions, such as urban trees and green infrastructure, hold promise for mitigating climate impacts in tropical cities. Their implementation in tropical cities aligns with the United Nations' Sustainable Development Goal 11 to create inclusive, safe, resilient, and sustainable cities (United Nations General Assembly, 2015). However, a knowledge gap remains concerning the phenology of individual trees or specific tree species in tropical cities, which is crucial for effective urban tree management. For example, policies for the implementation and conservation of urban trees should consider environmental factors, the species' ability to adapt to the local environment, their ability to combat climate change, and their impact on local biodiversity. It's important to note that the conservation efforts should be well-performed and substantiated to avoid the introduction of exotic species into tropical cities and potential ecological impacts. Furthermore, understanding the ecosystem services and economic values associated with urban forests is essential for the implementation of effective urban forest management policies. Comprehensive multidisciplinary studies addressing these aspects are crucial for effective implementation of Nature-based solutions.

Moreover, the studies on the sustainable urbanization subtopic explore the relationship between urbanization and UHI, the influence of factors like vegetation, building design, and geographical orientation on outdoor temperature and thermal comfort, and the potential of green infrastructure such as green roofs and bioretention systems to mitigate climate impacts. Furthermore, the studies discuss the importance of considering carbon offset and reduction strategies, such as public trees and green roofs, and highlights the benefits of sustainable drainage systems and the preservation of forests for flood regulation and carbon sequestration. It also touches upon the significance of incorporating nature-based solutions into urban development.

In addition, studies have revealed the effectiveness of mitigation strategies such as utilizing vertical green systems and considering road orientation in addressing climate change and urban resource management in tropical cities. However, it is important to note that these strategies must be carefully planned and implemented to avoid the misuse of resources and ensure their success. In addition, these strategies need to consider social and economic aspects to ensure that such measures are beneficial to the entire population. Some findings suggest that incorporating plant requirements into the design of urban spaces can improve the synergy between human and flora.

Regarding the subtopic protecting biodiversity, these studies explore the impact of urbanization on biodiversity in tropical cities, focusing on various animal groups and aspects. Studies demonstrate how the expansion of cities and associated human activities affect various species and ecosystems within urban environments. In general, urbanization can lead to habitat loss, fragmentation, and degradation, resulting in declines in species richness and abundance. Other negative impacts include noise pollution, changes in land use patterns, loss of green spaces, and alteration of natural habitats.

Moreover, studies suggest that conservation efforts can be successful despite the fragmentation of green areas. Strategies such as urban woodlands and preserving ponds are found to protect bird biodiversity in tropical cities. Urban green spaces in tropical cities can support diverse pollinator species, and conservation efforts need to consider the relationship between pollinators and plants. The presence of exotic species in urban green spaces highlights the need for proper management to protect native species. The location and design of green spaces influence their attractiveness to wildlife.

These findings emphasize the importance of understanding these impacts to develop effective strategies for biodiversity conservation and sustainable urban development in tropical cities, where unique contexts for studying the interactions between urban environments and biodiversity are found, due to the specific challenges and opportunities presented by tropical climates, landscapes, and urbanization patterns. Given the increasing rate of urbanization in tropical cities, it is essential to conduct further research to ensure the preservation of biodiversity.

The research on tropical cities in relation to urban resource management highlight the lack of urban resource planning, which has led to various negative impacts such as air quality degradation, temperature changes, and UHI effects. To address these issues, multidisciplinary planning is necessary, such as including technical guidance for building features and increasing green areas. Proper management of urban resources can enhance ecosystem functions, biodiversity, and control illness-vector mosquitoes. Green areas also play a role in storm water interception and pollutant removal. Economic implications of green infrastructure are noted, but challenges in implementing such initiatives in some tropical cities are acknowledged. Water resource management strategies should be evidence-based and consider spatial and temporal assessments. Studies on atmospheric composition and air quality are also important. In summary, effective urban resource planning requires a multidisciplinary approach that considers socio-economic factors and ensures equitable access for all.

However, these studies analyzed in our study also acknowledge some limitations, including the lack of research beyond the microscale and the need for more comprehensive studies on the practical application of knowledge generation. It emphasizes the importance of effective governance systems and collaboration between decision-makers, scientists, and planners to achieve sustainable strategies in tropical urban environments. These studies provide valuable insights into the challenges of climate change in tropical cities and offer various strategies and case studies for sustainable urbanization, protecting biodiversity

and management urban resources. It underscores the need for multidisciplinary approaches and emphasizes the role of governance and collaboration in implementing effective solutions.

4.8. Limitations

Despite its strengths, the bibliometric review methodology employed in this study does have certain limitations that should be acknowledged. Firstly, our analysis focused exclusively on articles published in English within the international review literature in the Web of Science and Scopus databases, using a specific set of keywords. This approach inherently excludes articles in other languages, as well as those in different document formats such as books and technical reports. Additionally, articles pertaining to tropical cities that do not contain any of the keywords examined in this study were not considered. This selection bias may have restricted the inclusivity of our analysis.

Another limitation arises from the qualitative analysis involved in the systematic review. The subjective aspects in determining the alignment of the analyzed documents with the study objectives, as well as the presentation of results, introduce a level of subjectivity. Furthermore, given the evolving nature of the topic of tropical cities, the temporal scope of this analysis may become outdated as new research emerges.

It is also important to note that only a limited number of the selected articles addressed the institutional and cultural challenges associated with the implementation of new techniques or practices in tropical cities. Although the work by Emmanuel (2018) highlighted some institutional and cultural challenges in implementing passive climate-sensitive design strategies in tropical regions, further research is needed to comprehensively address these aspects.

Other aspects relevant to the topic of tropical cities, including energy management, technologies for renewable energy sources, and agricultural prospects, were not discussed in this study. This omission is primarily due to the absence of these topics in our database or their limited prominence in the analyzed studies.

Additionally, while certain mitigation practices such as nature-based solutions were discussed across the four analyzed subtopics, the interdisciplinary and innovative exploration of these solutions requires additional studies using alternative frameworks.

Furthermore, our research provides a broad overview of trends across tropical cities in subtopics of climate change, sustainable urbanization, protecting biodiversity, and urban resource management. However, to determine the practical applicability of these trends in specific city contexts, more specific studies are necessary.

Notwithstanding these limitations, it is important to highlight that the proposed methodology recognizes and accounts for these limitations, taking proactive steps to mitigate potential biases as discussed in the assessment of risk of bias topic.

5. Conclusions

After conducting a comprehensive bibliometric analysis and systematic literature review, this study has yielded significant findings regarding the exploration of tropical cities. The results highlight a growing interest in this field and reveal key subjects that have been investigated. The analysis examined the growth of publications, citations, and prevalent keywords from 2010 to 2022, shedding light on the interconnectedness of subtopics climate change, sustainable urbanization, protecting biodiversity, and urban resource management within the realm of tropical cities.

The systematic literature review successfully addressed the four objectives guiding the analysis and demonstrated that studies within each subtopic contribute to the overarching theme of tropical cities. These studies offer valuable elements that can enhance the inclusivity, safety, resilience, and sustainability of tropical cities. Additionally, the research on tropical cities also contributes to broader subjects like global climate change and biodiversity protection. The evaluation of various studies showcased strategies for climate change adaptation through sustainable practices and effective urban resource management.

However, it is crucial to acknowledge the complexities inherent in studying tropical cities, including limited data availability, insufficient models, and financial constraints, which present significant obstacles to conducting comprehensive research. The effectiveness of mitigation strategies varies depending on local conditions, and it is essential to consider social and economic aspects to ensure equitable distribution of benefits among the population. Thus, comprehensive research, effective management, and interdisciplinary approaches are paramount for sustainable development in tropical cities.

While the employed methodology offered notable advantages, it is imperative to develop new frameworks that evaluate overarching themes present across all subtopics, such as Nature-based solutions. Furthermore, the bibliometric analysis, encompassing 663 articles, and the systematic literature review, covering 149 articles, indicated a geographical inequality in the publication output of tropical cities. This disparity can introduce bias in the study of tropical cities. Nevertheless, well-studied regions like Singapore can serve as models for other tropical cities, considering their unique characteristics.

To conclude, the research analyzed in this study has provided valuable insights into the intricate interactions among urban environments, biodiversity, urban resource management, and climate change within tropical cities. These findings underscore the multidisciplinary nature of addressing climate change in such environments and emphasize the necessity of sustained research and collaborative efforts to achieve effective and sustainable solutions. By continuously expanding our knowledge and fostering cooperation, we can strive toward

a more resilient and prosperous future for tropical cities and beyond.

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

JU, EW, and EM developed the concept. JU and LB performed the bibliometric analyses. JU, LB, MS, and AR performed the systematic review analysis and wrote the paper. EM addressed the interdisciplinary comments throughout the paper. EW and EM supervised the project and provided institutional support and financial acquisition. All authors contributed to the article and approved the submitted version.

Funding

JU thanks CAPES, Brazil (Grant 88887.683601/2022) for supported part of this study. EM thanks Univ Montpellier I-SITE Excellence Program & Campus France (Grant 139529Q/3281199) and INCT Climate Change - Water Security FAPESP # 14/50848-9.

Acknowledgments

The authors of this study would like to thank all reviewers for their helpful remarks. EM thanks Univ Montpellier Dr. H. Khaizourane, Prof. D. Cornu, Prof. P. Miele, and CNRS Prof. R. Pellenq.

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/frsc.2023.1154667/full#supplementary-material

References

Abendroth, S., Kowarik, I., Müller, N., and von der Lippe, M. (2012). The Green Colonial Heritage: woody plants in parks of Bandung, Indonesia. *Landsc. Urban Plan.* 106, 12–22. doi: 10.1016/j.landurbplan.2011.12.006

Acero, J. A., Koh, E. J., Li, X. X., Ruefenacht, L. A., Pignatta, G., and Norford, L. K. (2019). Thermal impact of the orientation and height of vertical greenery on pedestrians in a tropical area. *Build. Simul.* 12, 973–984. doi: 10.1007/s12273-019-0537-1

Acero, J. A., Koh, E. J. Y., Ruefenacht, L. A., and Norford, L. K. (2021). Modelling the influence of high-rise urban geometry on outdoor thermal comfort in Singapore. *Urban Climate* 36, 100775. doi: 10.1016/j.uclim.2021.100775

Aghamohammadi, N., Fong, C. S., Mohd Idrus, M. H., Ramakreshnan, L., and Haque, U. (2021). Outdoor thermal comfort and somatic symptoms among students in a Tropical City. *Sustain. Cities Soc.* 72, 103015. doi: 10.1016/j.scs.2021.103015

Akbari, H., Cartalis, C., Kolokotsa, D., Muscio, A., Pisello, A. L., Rossi, F., et al. (2015). Local climate change and urban heat island mitigation techniques – the state of the art. *J. Civil Eng. Manage.* 22, 1–16. doi: 10.3846/13923730.2015.1111934

Aktas, Y. D., Wang, K., Zhou, Y., Othman, M., Stocker, J., Jackson, M., et al. (2020). Outdoor thermal comfort and building energy use potential in different land-use areas in tropical cities: case of Kuala Lumpur. *Atmosphere* 11, 652. doi: 10.3390/atmos11060652

Albuquerque-Lima, S., Diniz, U. M., and Machado, I. C. S. (2022). A nectar oasis for urban glossophaginae bats: temporal resource dynamics of the chiropterophilous crescentia cujete (bignoniaceae). *Urban Forestry Urban Green.* 67, 127412. doi: 10.1016/j.ufug.2021.127412

Ali, S. B., and Li, B. (2018). Evaluating the impact of the morphological transformation of urban sites on the urban thermal microenvironment. *Buildings* 8, 182. doi: 10.3390/buildings8120182

Ali, S. B., and Patnaik, S. (2019). Assessment of the impact of urban tree canopy on microclimate in Bhopal: a devised low-cost traverse methodology. *Urban Clim.* 27, 430–445. doi: 10.1016/j.uclim.2019.01.004

Alue, B. A., Salleh Hudin, N., Mohamed, F., Mat Said, Z., and Ismail, K. (2022). Plant diversity along an urbanization gradient of a Tropical City. *Diversity* 14, 1024. doi: 10.3390/d14121024

Alves-de-Souza, C., Benevides, T. S., Santos, J. B., Von Dassow, P., Guillou, L., and Menezes, M. (2017). Does environmental heterogeneity explain temporal β diversity of small eukaryotic phytoplankton? Example from a tropical eutrophic Coastal Lagoon. *J. Plank. Res.* 39, 698–714. doi: 10.1093/plankt/fbx026

Amorim, M. C. (2018). Spatial variability and intensity frequency of Surface Heat Island in a Brazilian city with continental tropical climate through remote sensing. *Rem. Sens. Appl.* 9, 10–16. doi: 10.1016/j.rsase.2017.11.001

Andrade, A. C. (2019). Metropolitan lizards? Urbanization gradient and the density of lagartixas (*Tropidurus hispidus*) in a Tropical City. *Ecol. Evol.* 10, 1740–1750. doi: 10.1002/ece3.5518

Anne, A., Ebenezer, S. K., Guy Valerie, D. W., Pierre, N., Cédric, D. C., Annie Stephanie, N., et al. (2021). Floristic surveys of some lowlands polluted of a tropical urban area: the case of yaounde, cameroon. *Int. J. Phytoremed.* 23, 1191–1202. doi: 10.1080/15226514.2021.1884183

Aria, M., and Cuccurullo, C. (2017). Bibliometrix: an R-tool for comprehensive science mapping analysis. *J. Informetr.* 11, 959–975. doi: 10.1016/j.joi.2017.08.007

Arulbalaji, P., Padmalal, D., and Maya, K. (2020). Impact of urbanization and land surface temperature changes in a coastal town in Kerala, India. *Environ. Earth Sci.* 79, 400. doi: 10.1007/s12665-020-09120-1

Badarinath, K. V., Sharma, A. R., Kaskaoutis, D. G., Kharol, S. K., and Kambezidis, H. D. (2010). Solar dimming over the tropical urban region of Hyderabad, India: effect of increased cloudiness and increased anthropogenic aerosols. *J. Geophys. Res.* 115, D21208. doi: 10.1029/2009jd013694

Barbosa, K. V., Rodewald, A. D., Ribeiro, M. C., and Jahn, A. E. (2020). Noise level and water distance drive resident and migratory bird species

richness within a neotropical megacity. *Landsc. Urban Plan.* 197, 103769. doi: 10.1016/j.landurbplan.2020.103769

Barima, Y. S., Angaman, D. M., N'Gouran, K. P., Koffi, N. A., Kardel, F., De Cannière, C., et al. (2014). Assessing atmospheric particulate matter distribution based on saturation isothermal remanent magnetization of herbaceous and tree leaves in a tropical urban environment. *Sci. Total Environ.* 470, 975–982. doi: 10.1016/j.scitotenv.2013.10.082

Bartorila, M. A., and Rosas Lusett, M. A. (2021). Biodiversidad y ordenamiento territorial. *Contexto* 15, 71–88. doi: 10.29105/contexto15.23-286

Beck, H. E., Zimmermann, N. E., McVicar, T. R., Vergopolan, N., Berg, A., and Wood, E. F. (2018). Present and future Köppen-Geiger climate classification maps at 1-km resolution. *Sci. Data* 5, 214. doi: 10.1038/sdata.2018.214

Belcher, R. N., and Chisholm, R. A. (2018). Tropical vegetation and residential property value: a hedonic pricing analysis in Singapore. *Ecol. Econ.* 149, 149–159. doi: 10.1016/j.ecolecon.2018.03.012

Benrazavi, R. S., Binti Dola, K., Ujang, N., and Sadat Benrazavi, N. (2016). Effect of pavement materials on surface temperatures in tropical environment. *Sustain. Cities Soc.* 22, 94–103. doi: 10.1016/j.scs.2016.01.011

Bertrand, G. F., de Paiva, A. L., de Araújo Freitas, J. B., da Silva Pereira Cabral, J. J., Veras Albuquerque, T. B., and de Carvalho Filho, J. A. (2021). River bank filtration in tropical metropoles: integrated evaluation of physical, geochemical and Biochemical Interactions in Recife, NE Brazil. *Int. J. Environ. Sci. Technol.* 19, 5803–5818. doi: 10.1007/s13762-021-03558-x

Biswas, R. R., Sharma, R., and Gyasi-Agyei, Y. (2022). Adaptation to climate change: a study on regional urban water management and Planning Practice. *J. Clean. Prod.* 355, 131643. doi: 10.1016/j.jclepro.2022.131643

Bridhikitti, A., Pumkaew, M., Prabamroong, T., Yu, G.-A., and Liu, G. (2022). Processes governing nutrient dynamics in tropical urban-agriculture rivers, NE Thailand. *Sustain. Water Resour. Manage.* 8, 750. doi: 10.1007/s40899-022-00750-w

Burkart, K., Schneider, A., Breitner, S., Khan, M. H., Krämer, A., and Endlicher, W. (2011). The effect of atmospheric thermal conditions and urban thermal pollution on all-cause and cardiovascular mortality in Bangladesh. *Environ. Pollut.* 159, 2035–2043. doi: 10.1016/j.envpol.2011.02.005

Carrillo-Niquete, G., Andrade, J., Valdez-Lazalde, J., Reyes-Garcia, C., and Hernandez-Stefanoni, J. (2022). Characterizing spatial and temporal deforestation and its effects on surface urban heat islands in a tropical city using Landsat time series. *Landsc. Urban Plan.* 217, 104280. doi: 10.1016/j.landurbplan.2021.104280

Cézar, K., Franklin, E., and Pinto, C. E. (2022). Temporal variation in pollinators' visitation of *Lantana camara* in a tropical urban landscape: does butterfly abundance and richness drive the fruit set? *Ekológia* 41, 46–56. doi: 10.2478/eko-2022-0006

Chang, H.-Y., and Lee, Y.-F. (2015). Effects of area size, heterogeneity, isolation, and disturbances on urban park avifauna in a highly populated tropical city. *Urban Ecosyst.* 19, 257–274. doi: 10.1007/s11252-015-0481-5

Chatterjee, S., Khan, A., Dinda, A., Mithun, S., Khatun, R., Akbari, H., et al. (2019). Simulating micro-scale thermal interactions in different building environments for mitigating Urban Heat Islands. *Sci. Total Environ.* 663, 610–631. doi: 10.1016/j.scitotenv.2019.01.299

Chen, L., Ng, E., An, X., Ren, C., Lee, M., Wang, U., et al. (2010). Sky view factor analysis of street canyons and its implications for daytime intra-urban air temperature differentials in high-rise, high-density urban areas of Hong Kong: a GIS-based simulation approach. *Int. J. Climatol.* 32, 121–136. doi: 10.1002/joc.2243

Chew, L. W., Liu, X., Li, X. -X., and Norford, L. K. (2021). Interaction between heat wave and urban heat island: A case study in a tropical coastal city, Singapore. *Atmos. Res.* 247, 105134. doi: 10.1016/j.atmosres.2020.105134

Chitwatkulsiri, D., Miyamoto, H., Irvine, K. N., Pilailar, S., and Loc, H. H. (2022). Development and application of a real-time flood forecasting system (RTFlood system) in a tropical urban area: a case study of ramkhamhaeng polder, Bangkok, Thailand. *Water* 14, 1641. doi: 10.3390/w14101641

Chow, M. F., and Yusop, Z. (2013). Characterization and source identification of stormwater runoff in tropical urban catchments. *Water Sci. Technol.* 69, 244–252. doi: 10.2166/wst.2013.574

Chow, M. F., and Yusop, Z. (2014). Sizing first flush pollutant loading of stormwater runoff in tropical urban catchments. *Environ. Earth Sci.* 72, 4047–4058. doi: 10.1007/s12665-014-3294-6

Chow, M. F., Yusop, Z., and Shirazi, S. M. (2013a). Storm runoff quality and pollutant loading from commercial, residential, and industrial catchments in the tropic. *Environ. Monit. Assess.* 185, 8321–8331. doi: 10.1007/s10661-013-3175-6

Chow, M. F., Yusop, Z., and Toriman, M. E. (2012). Modelling runoff quantity and quality in tropical urban catchments using Storm water management model. *Int. J. Environ. Sci. and Technol.* 9, 737–748. doi: 10.1007/s13762-012-0092-0

Chow, M. F., Yusop, Z., and Toriman, M. E. (2013b). Level and transport pattern of faecal coliform bacteria from tropical urban catchments. *Water Sci. Technol.* 67, 1822–1831. doi: 10.2166/wst.2013.048

Chui, T. F., and Trinh, D. H. (2016). Modelling infiltration enhancement in a tropical urban catchment for improved stormwater management. *Hydrol. Process.* 30, 4405–4419. doi: 10.1002/hyp.10926

Coccolo, S., Kämpf, J., Scartezzini, J.-L., and Pearlmutter, D. (2016). Outdoor human comfort and thermal stress: a comprehensive review on models and standards. *Urban Clim.* 18, 33–57. doi: 10.1016/j.uclim.2016.08.004

Das, M., Das, A., and Mandal, S. (2020). Outdoor thermal comfort in different settings of a tropical planning region: a study on sriniketan-santiniketan planning area (SSPA), Eastern India. *Sustain. Cities Soc.* 63, 102433. doi: 10.1016/j.scs.2020.102433

Dayathilake, D. D. T. L., Lokupitiya, E., and Wijeratne, V. P. I. S. (2021). Estimation of soil carbon stocks of urban freshwater wetlands in the Colombo Ramsar Wetland City and their potential role in climate change mitigation. *Wetlands* 41, 29. doi: 10.1007/s13157-021-01424-7

de Jesús-Crespo, R., and Ramírez, A. (2011). Effects of urbanization on stream physicochemistry and macroinvertebrate assemblages in a tropical urban watershed in Puerto Rico. *J. North Am. Benthol. Soc.* 30, 739–750. doi: 10.1899/10-081.1

de Mello, N. A., Brighenti, L. S., Barbosa, F. A., Staehr, P. A., and Bezerra Neto, J. F. (2017). Spatial variability of methane (CH4) ebullition in a tropical hypereutrophic reservoir: silted areas as a Bubble hot spot. *Lake Reserv. Manag.* 34, 105–114. doi: 10.1080/10402381.2017.1390018

Dissegna, M. A., Yin, T., Wei, S., Richards, D., and Grêt-Regamey, A. (2019). 3-D reconstruction of an urban landscape to assess the influence of vegetation in the radiative budget. *Forests* 10, 700. doi: 10.3390/f10080700

Donthu, N., Kumar, S., Mukherjee, D., Pandey, N., and Lim, W. M. (2021). How to conduct a bibliometric analysis: an overview and guidelines. *J. Bus. Res.* 133, 285–296. doi: 10.1016/j.jbusres.2021.04.070

Dri, G. F., Fontana, C. S., and de Dambros, C. (2021). Estimating the impacts of habitat loss induced by urbanization on bird local extinctions. *Biol. Conserv.* 256, 109064. doi: 10.1016/j.biocon.2021.109064

Eccles, R., Zhang, H., and Hamilton, D. (2019). A review of the effects of climate change on riverine flooding in subtropical and tropical regions. *J. Water Clim. Change* 10, 687–707. doi: 10.2166/wcc.2019.175

Emmanuel, R. (2018). Performance standard for tropical outdoors: a critique of current impasse and a proposal for way forward. *Urban Clim.* 23, 250–259. doi: 10.1016/j.uclim.2017.01.002

Ensslin, L., Ensslin, S. R., Lacerda, R. T. O., and Tasca, J. E. (2010). *ProKnow-C, Knowledge Development Process-Construtivist. Processo tecnico com patente de registro pendente junto ao Instituto Nacional da Propriedade Industrial - INPI*. Brazil.

Estela, F. A., Sánchez–Sarria, C. E., Arbeláez–Cortés, E., Ocampo, D., García–Arroyo, M., Perlaza–Gamboa, A., et al. (2021). Changes in the nocturnal activity of birds during the COVID−19 pandemic lockdown in a Neotropical City. *Anim. Biodivers. Conserv.* 213–217. doi: 10.32800/abc.2021.44.0213

Evans, D. L., Vis, B. N., Dunning, N. P., Graham, E., and Isendahl, C. (2021). Buried solutions: how maya urban life substantiates soil connectivity. *Geoderma* 387, 114925. doi: 10.1016/j.geoderma.2020.114925

Fragata, M. M., Baccaro, F., Gonçalves, A. L., and Borges, S. H. (2022). Living in a tropical concrete jungle: diversity and abundance variation in a parrot assemblage (Aves, Psittacidae) of a major Amazonian City. *Urban Ecosyst.* 25, 977–987. doi: 10.1007/s11252-022-01209-8

Friess, D. A. (2016). Singapore as a long-term case study for Tropical Urban Ecosystem Services. *Urban Ecosyst.* 20, 277–291. doi: 10.1007/s11252-016-0592-7

Fung, T. K., Richards, D. R., Leong, R. A., Ghosh, S., Tan, C. W., Drillet, Z., et al. (2021). Litter decomposition and infiltration capacities in soils of different tropical urban land covers. *Urban Ecosyst.* 25, 21–34. doi: 10.1007/s11252-021-01126-2

Gamero-Salinas, J., Monge-Barrio, A., Kishnani, N., López-Fidalgo, J., and Sánchez-Ostiz, A. (2021). Passive cooling design strategies as adaptation measures for lowering the indoor overheating risk in tropical climates. *Energy Build.* 252, 111417. doi: 10.1016/j.enbuild.2021.111417

Ganci, C. C., Provete, D. B., Püttker, T., Lindenmayer, D., and Almeida-Gomes, M. (2021). High species turnover shapes Anuran community composition in ponds along an urban-rural gradient. *Urban Ecosyst.* 25, 633–642. doi: 10.1007/s11252-021-01174-8

Grêt-Regamey, A., Galleguillos-Torres, M., Dissegna, A., and Weibel, B. (2020). How urban densification influences ecosystem services—a comparison between a temperate and a tropical city. *Environ. Res. Lett.* 15, 075001. doi: 10.1088/1748-9326/ab7acf

Grullón-Penkova, I. F., Zimmerman, J. K., and González, G. (2020). Green roofs in the tropics: design considerations and vegetation dynamics. *Heliyon* 6, e04712. doi: 10.1016/j.heliyon.2020.e04712

Gupta, H., Tiwari, C., and Diwakar, S. (2019). Butterfly diversity and effect of temperature and humidity gradients on butterfly assemblages in a sub-tropical urban landscape. *Trop. Ecol.* 60, 150–158. doi: 10.1007/s42965-019-00019-y

Haddad, S., Paolini, R., Ulpiani, G., Synnefa, A., Hatvani-Kovacs, G., Garshasbi, S., et al. (2020). Holistic approach to assess co-benefits of local climate mitigation in a hot humid region of Australia. *Sci. Rep.* 10, 14216. doi: 10.1038/s41598-020-71148-x

Harding, S., Bird, G., Losos, E., Aderolili, R., and Hotez, P. (2016). international day of the tropics: towards a better global future. *ETropic* 15, 3538. doi: 10.25120/etropic.15.2.2016.3538

Hasan, H. H., Mohd Razali, S. F., Ahmad Zaki, A. Z., and Mohamad Hamzah, F. (2019). Integrated hydrological-hydraulic model for flood simulation in tropical urban catchment. *Sustainability* 11, 6700. doi: 10.3390/su11236700

He, W., Zhang, L., and Yuan, C. (2022). Future air temperature projection in high-density tropical cities based on global climate change and urbanization – a study in Singapore. *Urban Clim.* 42, 101115. doi: 10.1016/j.uclim.2022.101115

Herath, H. M. P. I. K., Halwatura, R. U., and Jayasinghe, G. Y. (2018). Evaluation of green infrastructure effects on tropical Sri Lankan urban context as an urban heat island adaptation strategy. *Urban Forestry Urban Green.* 29, 212–222. doi: 10.1016/j.ufug.2017.11.013

Hwang, Y. H., See, S. C., and Patil, M. A. (2021). Short-term vegetation changes in tropical urban parks: patterns and design-management implications. *Urban Forestry Urban Green.* 64, 127240. doi: 10.1016/j.ufug.2021.127240

IPCC (2014). *Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Geneva: IPCC.

Isa, N. A., Wanmohd, W. M., Salleh, S. A., Gee Ooi, M. C., and Chan, A. (2020). Land cover impacts towards thermal variation in the kuala Lumpur City. *J. Urban Reg. Anal.* 12, 91–111. doi: 10.37043/jura.2020.12.1.6

Izuddin, M., Srivathsan, A., Lee, A. L., Yam, T. W., and Webb, E. L. (2019). Availability of orchid mycorrhizal fungi on roadside trees in a tropical urban landscape. *Sci. Rep*. 9, 19528. doi: 10.1038/s41598-019-56049-y

Jain, A., Khoon, K. S., Gan, C. W., and Webb, E. L. (2018). Butterfly extirpations, discoveries and rediscoveries in Singapore over 28 years. *Raffles Bullet. Zool.* 66, 217–257.

Jim, C. Y. (2013). Ecology and conservation of strangler figs in urban wall habitats. *Urban Ecosyst.* 17, 405–426. doi: 10.1007/s11252-013-0322-3

Jim, C. Y., and Chen, W. Y. (2009). Ecosystem services and valuation of urban forests in China. *Cities* 26, 187–194. doi: 10.1016/j.cities.2009.03.003

Jin, H., Cui, P., Wong, N., and Ignatius, M. (2018). Assessing the effects of urban morphology parameters on microclimate in Singapore to control the urban heat island effect. *Sustainability* 10, 206. doi: 10.3390/su10010206

Jochner, S., Alves-Eigenheer, M., Menzel, A., and Morellato, L. P. (2013). Using phenology to assess urban heat islands in tropical and temperate regions. *Int. J. Climatol.* 33, 3141–3151. doi: 10.1002/joc.3651

Kabano, P., Harris, A., and Lindley, S. (2020). Sensitivity of canopy phenology to local urban environmental characteristics in a tropical city. *Ecosystems* 24, 1110–1124. doi: 10.1007/s10021-020-00571-y

Kabano, P., Lindley, S., and Harris, A. (2021). Evidence of urban heat island impacts on the vegetation growing season length in a tropical city. *Landsc. Urban Plan.* 206, 103989. doi: 10.1016/j.landurbplan.2020.103989

Koranteng, C., Simons, B., and andamp; Nyame-Tawiah, D. (2021). Simulation-based analysis of the effect of green roofs on thermal performance of buildings in a tropical landscape. *J. Innovat. Sustain.* 12, 45–56. doi: 10.23925/2179-3565.2021v12i1p45-56

Kotharkar, R., Bagade, A., and Ramesh, A. (2019). Assessing urban drivers of canopy layer urban heat island: a numerical modeling approach. *Landsc. Urban Plan.* 190, 103586. doi: 10.1016/j.landurbplan.2019.05.017

Kotharkar, R., Bagade, A., and Singh, P. R. (2020). A systematic approach for urban heat island mitigation strategies in critical local climate zones of an Indian city. *Urban Clim.* 34, 100701. doi: 10.1016/j.uclim.2020.100701

Lan, Y., Tham, J., Jia, S., Sarkar, S., Fan, W. H., Reid, J. S., et al. (2021). Peat-forest burning smoke in maritime continent: impacts on receptor PM2.5 and implications at Emission Sources. *Environ. Pollut.* 275, 116626. doi: 10.1016/j.envpol.2021.116626

Lau, K. K.-L., Lindberg, F., Johansson, E., Rasmussen, M. I., and Thorsson, S. (2017). Investigating solar energy potential in tropical urban environment: a case study of dar es salaam, Tanzania. *Sustain. Cities Soc.* 30, 118–127. doi: 10.1016/j.scs.2017.01.010

Lee, J. M., Wasserman, R. J., Gan, J. Y., Wilson, R. F., Rahman, S., and Yek, S. H. (2019). Human activities attract harmful mosquitoes in a tropical urban landscape. *Ecohealth* 17, 52–63. doi: 10.1007/s10393-019-01457-9

Lee, M.-B., Peabotuwage, I., Gu, H., Zhou, W., and Goodale, E. (2019). Factors affecting avian species richness and occupancy in a tropical city in southern China: importance of human disturbance and open green space. *Basic Appl. Ecol.* 39, 48–56. doi: 10.1016/j.baae.2019.08.003

Li, X., Meshgi, A., and Babovic, V. (2016). Spatio-temporal variation of wet and dry spell characteristics of tropical precipitation in Singapore and its association with enso. *Int. J. Climatol.* 36, 4831–4846. doi: 10.1002/joc.4672

Li, X., Wang, X., and Babovic, V. (2017). Analysis of variability and trends of precipitation extremes in Singapore during 1980-2013. *Int. J. Climatol.* 38, 125–141. doi: 10.1002/joc.5165

Li, X.-X., Koh, T.-Y., Entekhabi, D., Roth, M., Panda, J., and Norford, L. K. (2013). A multi-resolution ensemble study of a tropical urban environment and its interactions with the background regional atmosphere. *J. Geophys. Res.* 118, 9804–9818. doi: 10.1002/jgrd.50795

Li, Y., Sun, Y., Li, J., and Gao, C. (2020). Socioeconomic drivers of urban heat island effect: empirical evidence from major Chinese cities. *Sustain. Cities Soc.* 63, 102425. doi: 10.1016/j.scs.2020.102425

Lim, H. S., Segovia, E., and Ziegler, A. D. (2021). Water quality impacts of young green roofs in a tropical city: a case study from Singapore. *Blue-Green Syst.* 3, 145–163. doi: 10.2166/bgs.2021.007

Lin, Y.-H., and Tsai, K.-T. (2017). Screening of tree species for improving outdoor human thermal comfort in a Taiwanese City. *Sustainability* 9, 340. doi: 10.3390/su9030340

Lippert, M. A., Lansac-Tôha, F. M., Meira, B. R., Velho, L. F., and Lansac-Toha, F. A. (2020). Structure and dynamics of the Protoplankton community in an environmentally protected urban stream. *Brazil. J. Biol.* 80, 844–859. doi: 10.1590/1519-6984.222607

Lo, K., and Koralegedara, S. (2015). Effects of climate change on urban rainwater harvesting in Colombo city, Sri Lanka. *Environments* 2, 105–124. doi: 10.3390/environments2010105

López-Doval, J. C., Montagner, C. C., de Alburquerque, A. F., Moschini-Carlos, V., Umbuzeiro, G., and Pompêo, M. (2017). Nutrients, emerging pollutants and pesticides in a tropical urban reservoir: spatial distributions and risk assessment. *Sci. Total Environ.* 575, 1307–1324. doi: 10.1016/j.scitotenv.2016.09.210

Lu, Y., and Qin, X. S. (2014). Multisite rainfall downscaling and disaggregation in a tropical urban area. *J. Hydrol.* 509, 55–65. doi: 10.1016/j.jhydrol.2013.11.027

Macedo, M. B., Mendiondo, E. M., Razzolini, M. T., Goel, N. K., Arya, D. S., Kurian, M., et al. (2022). Multi-stage resilience analysis of the nexus flood-sanitation-public health in urban environments: a theoretical framework. *Urban Water J.* 1–18. doi: 10.1080/1573062x.2022.2047737

Malta, J. F., Nardocci, A. C., Razzolini, M. T., Diniz, V., and Cunha, D. G. (2022). Exposure to microcystin-LR in tropical reservoirs for water supply poses high risks for children and adults. *Environ. Monit. Assess.* 194, 253. doi: 10.1007/s10661-022-09875-z

Manocha, N., and Babovic, V. (2018). Real options, multi-objective optimization and the development of dynamically robust adaptive pathways. *Environ. Sci. Policy* 90, 11–18. doi: 10.1016/j.envsci.2018.09.012

Manoli, G., Fatichi, S., Schläpfer, M., Yu, K., Crowther, T. W., Meili, N., et al. (2019). Magnitude of urban heat islands largely explained by climate and population. *Nature* 573, 55–60. doi: 10.1038/s41586-019-1512-9

Marcotullio, P. J., Keßler, C., Quintero Gonzalez, R., and Schmeltz, M. (2021). Urban growth and heat in tropical climates. *Front. Ecol. Evol.* 9, 616626. doi: 10.3389/fevo.2021.616626

Marinho, C. C., Breves, A., Rocha, A., de, Silva, E. C., van Weerelt, M. D., Gutemberg, A. C., et al. (2022). Long-term changes in sanitary conditions and zooplankton community in the Imboassica Lagoon (rio de janeiro, Brazil): effects of sandbar openings. *Oecol. Austr.* 26, 239–254. doi: 10.4257/oeco.2022.2602.12

Martins, T. A. L., Adolphe, L., and Bastos, E. G. L. (2014). From solar constraints to urban design opportunities: optimization of built form typologies in a Brazilian tropical city. *Energy Build.* 76, 43–56. doi: 10.1016/j.enbuild.2014.02.056

Martinuzzi, S., Locke, D. H., Ramos-González, O., Sanchez, M., Grove, J. M., Muñoz-Erickson, T. A., et al. (2021). Exploring the relationships between tree canopy cover and socioeconomic characteristics in tropical urban systems: the case of santo domingo, Dominican Republic. *Urban Forestry Urban Green.* 62, 127125. doi: 10.1016/j.ufug.2021.127125

Mattos, T. S., Oliveira, P. T., Bruno, L., de, Carvalho, G. A., Pereira, R. B., Crivellaro, L. L., et al. (2022). Towards reducing flood risk disasters in a tropical urban basin by the development of flood alert web application. *Environ. Model. Softw.* 151, 105367. doi: 10.1016/j.envsoft.2022.105367

May-Itzá, W. J., de Araujo-Freitas, C., Paxton, R. J., Moo-Valle, H., Medina-Medina, L. A., and Quezada-Euán, J. J. (2021). Stingless Bees in urban areas: low body size and high frequency of diploid males at mating congregations of Nannotrigona perilampoides (hymenoptera: Meliponini) in Mérida, Yucatán, México. *Apidologie* 52, 755–766. doi: 10.1007/s13592-021-00862-w

Meili, N., Acero, J. A., Peleg, N., Manoli, G., Burlando, P., and Fatichi, S. (2021). Vegetation cover and plant-trait effects on outdoor thermal comfort in a tropical city. *Build. Environ.* 195, 107733. doi: 10.1016/j.buildenv.2021.107733

Meléndez-Ackerman, E. J., Santiago-Bartolomei, R., Vila-Ruiz, C. P., Santiago, L. E., García-Montiel, D., Verdejo-Ortiz, J. C., et al. (2014). Socioeconomic drivers of yard sustainable practices in a tropical city. *Ecol. Soc.* 19, 20. doi: 10.5751/es-06563-190320

Mena-Rivera, L., Salgado-Silva, V., Benavides-Benavides, C., Coto-Campos, J., and Swinscoe, T. (2017). Spatial and seasonal surface water quality assessment in a tropical urban catchment: Burío River, Costa Rica. *Water* 9, 558. doi: 10.3390/w9080558

Méndez-Lázaro, P. A., Pérez-Cardona, C. M., Rodríguez, E., Martínez, O., Taboas, M., Bocanegra, A., et al. (2016). Climate change, heat, and mortality in

the tropical urban area of San Juan, Puerto Rico. *Int. J. Biometeorol.* 62, 699–707. doi: 10.1007/s00484-016-1291-z

Mohan, M., and Kandya, A. (2015). Impact of urbanization and land-use/land-cover change on diurnal temperature range: a case study of tropical urban airshed of India using remote sensing data. *Sci. Total Environ.* 506, 453–465. doi: 10.1016/j.scitotenv.2014.11.006

Morakinyo, T. E., Ouyang, W., Lau, K. K.-L., Ren, C., and Ng, E. (2020). Right tree, right place (urban canyon): tree species selection approach for optimum urban heat mitigation - development and evaluation. *Sci. Total Environ.* 719, 137461. doi: 10.1016/j.scitotenv.2020.137461

Morris, K. I., Chan, A., Morris, K. J., Ooi, M. C. G., Oozeer, M. Y., Abakr, Y. A., et al. (2017). Urbanisation and urban climate of a tropical conurbation, Klang Valley, Malaysia. *Urban Clim.* 19, 54–71. doi: 10.1016/j.uclim.2016.12.002

Mukim, M., and Roberts, M. (editors). (2023). *Thriving: Making Cities Green, Resilient, and Inclusive in a Changing Climate*. Washington, DC: World Bank. doi: 10.1596/978-1-4648-1935-3

Muñoz-Erickson, T. A. (2014). Co-production of knowledge–action systems in urban sustainable governance: the Kasa Approach. *Environ. Sci. Policy* 37, 182–191. doi: 10.1016/j.envsci.2013.09.014

Muñoz-Erickson, T. A., Lugo, A. E., and Quintero, B. (2014). Emerging synthesis themes from the study of social-ecological systems of a tropical city. *Ecol. Soc.* 19, 23. doi: 10.5751/es-06385-190323

Nadeeshani, M., Ramachandra, T., Gunatilake, S., and Zainudeen, N. (2021). Carbon footprint of green roofing: a case study from Sri Lankan Construction Industry. *Sustainability* 13, 6745. doi: 10.3390/su13126745

Nascimento, V. T., Agostini, K., Souza, C. S., and Maruyama, P. K. (2020). Tropical urban areas support highly diverse plant-pollinator interactions: an assessment from Brazil. *Landsc. Urban Plan.* 198, 103801. doi: 10.1016/j.landurbplan.2020.103801

Ng, B. J. H., Zhou, J., Giannis, A., Chang, V. W.-C., and Wang, J.-Y. (2014). Environmental life cycle assessment of different domestic wastewater streams: policy effectiveness in a tropical urban environment. *J. Environ. Manage.* 140, 60–68. doi: 10.1016/j.jenvman.2014.01.052

Nipen, M., Vogt, R. D., Bohlin-Nizzetto, P., Borg,å, K., Mwakalapa, E. B., Borgen, A. R., et al. (2022). Spatial trends of chlorinated paraffins and dechloranes in air and soil in a tropical urban, suburban, and rural environment. *Environ. Pollut.* 292, 118298. doi: 10.1016/j.envpol.2021.118298

Nytch, C. J., Meléndez-Ackerman, E. J., Pérez, M.-E., and Ortiz-Zayas, J. R. (2018). Rainfall interception by six urban trees in San Juan, Puerto Rico. *Urban Ecosyst.* 22, 103–115. doi: 10.1007/s11252-018-0768-4

Oh, R. R. Y., Richards, D. R., and Yee, A. T. K. (2018). Community-driven Skyrise Greenery in a dense tropical city provides biodiversity and ecosystem service benefits. *Landsc. Urban Plan.* 169, 115–123. doi: 10.1016/j.landurbplan.2017.08.014

Oliveira, I. F., Lion, M. B., and Cardoso, M. Z. (2018). A plaza too far: high contrast in butterfly biodiversity patterns between plazas and an urban reserve in Brazil. *Landsc. Urban Plan.* 180, 207–216. doi: 10.1016/j.landurbplan.2018.09.002

Oliveira, J. A. P., and Ahmed, A. (2021). Assessment and mitigation of tangible flood damages driven: gaps and opportunities for innovation in Accra, Ghana. *J. Clean. Prod.* 312, 127730. doi: 10.1016/j.jclepro.2021.127730

Oliveira, M. T. P., Silva, J. L. S., Cruz-Neto, O., Borges, L. A., Girão, L. C., Tabarelli, M., et al. (2020). Urban green areas retain just a small fraction of tree reproductive diversity of the Atlantic forest. *Urban Forestry Urban Green.* 54, 126779. doi: 10.1016/j.ufug.2020.126779

Olivero-Lora, S., Meléndez-Ackerman, E., Santiago, L., Santiago-Bartolomei, R., and García-Montiel, D. (2019). Attitudes toward residential trees and awareness of tree services and disservices in a tropical city. *Sustainability* 12, 117. doi: 10.3390/su12010117

Olivero-Lora, S., Rojas-Sandoval, J., Meléndez-Ackerman, E. J., and Orengo-Rolón, J. L. (2022). Hurricane driven changes in vegetation structure and ecosystem services in tropical urban yards: a study case in San Juan, Puerto Rico. *Urban Ecosyst.* 25, 1431–1444. doi: 10.1007/s11252-022-01236-5

Ooi, M. C. G., Chan, A., Ashfold, M. J., Oozeer, M. Y., Morris, K. I., and Kong, S. S. K. (2019). The role of land use on the local climate and air quality during calm inter-monsoon in a tropical city. *Geosci. Front.* 10, 405–415. doi: 10.1016/j.gsf.2018.04.005

Othman, F., M. E., A. E., and Mohamed, I. (2012). Trend analysis of a tropical urban river water quality in Malaysia. *J. Environ. Monitor.* 14, 3164. doi: 10.1039/c2em30676j

Page, M. J., McKenzie, J., Bossuyt, P., Boutron, I., Hoffmann, T., mulrow, cindy, Shamseer, L., et al. (2020). The Prisma 2020 statement: an updated guideline for reporting systematic reviews. *BMJ* 372, n71 doi: 10.31222/osf.io/v7gm2

Palafox-Juárez, E. B., López-Martínez, J. O., Hernández-Stefanoni, J. L., and Hernández-Nuñez, H. (2021). Impact of urban land-cover changes on the spatial-temporal land surface temperature in a tropical city of Mexico. *Int. J. Geo Informat.* 10, 76. doi: 10.3390/ijgi10020076

Pathirana, A., Denekew, H. B., Veerbeek, W., Zevenbergen, C., and Banda, A. T. (2014). Impact of urban growth-driven landuse change on microclimate and extreme precipitation — a sensitivity study. *Atmos. Res.* 138, 59–72. doi: 10.1016/j.atmosres.2013.10.005

Perera, N. G. R., and Emmanuel, R. (2018). A "local climate zone" based approach to urban planning in Colombo, Sri Lanka. *Urban Clim.* 23, 188–203. doi: 10.1016/j.uclim.2016.11.006

Pérez-Villalona, H., Cornwell, J. C., Ortiz-Zayas, J. R., and andamp; Cuevas, E. (2015). Sediment denitrification and nutrient fluxes in the San José Lagoon, a tropical lagoon in the highly urbanized San Juan Bay Estuary, Puerto Rico. *Estuar. Coasts* 38, 2259–2278. doi: 10.1007/s12237-015-9953-3

Pierangeli, G. M., Domingues, M. R., Jesus, T. A., Coelho, L. H., Hanisch, W. S., Pompêo, M. L., et al. (2021). Higher abundance of sediment methanogens and methanotrophs do not predict the atmospheric methane and carbon dioxide flows in eutrophic tropical freshwater reservoirs. *Front. Microbiol.* 12, 647921. doi: 10.3389/fmicb.2021.647921

Rajan, E. H., and Amirtham, L. R. (2021). Urban heat island intensity and evaluation of outdoor thermal comfort in Chennai, India. *Environ. Devel. Sustain.* 23, 16304–16324. doi: 10.1007/s10668-021-01344-w

Ramsay, E. E., Duffy, G. A., Burge, K., Taruc, R. R., Fleming, G. M., Faber, P. A., et al. (2022). Spatio-temporal development of the urban heat island in a socioeconomically diverse tropical city. *bioRxiv* doi: 10.1101/2022.07.07.499124

Ramsay, E. E., Fleming, G. M., Faber, P. A., Barker, S. F., Sweeney, R., Taruc, R. R., et al. (2021). Chronic heat stress in tropical urban informal settlements. *IScience* 24, 103248. doi: 10.1016/j.isci.2021.103248

Rawal, P., Kittur, S., Chatakonda, M. K., and Sundar, K. S. (2021a). Winter bird abundance, species richness and functional guild composition at Delhi's ponds: does time of day and wetland extent matter? *J. Urban Ecol.* 7, juab001. doi: 10.1093/jue/juab001

Rawal, P., Kittur, S., Chatakonda, M. K., and Sundar, K. S. G. (2021b). Capital ponds: site-level habitat heterogeneity and management interventions at ponds regulate high landscape-scale bird diversity across a mega-city. *Biol. Conserv.* 260, 109215. doi: 10.1016/j.biocon.2021.109215

Reynolds, C., Escobedo, F., Clerici, N., and Zea-Camaño, J. (2017). Does "greening" of neotropical cities considerably mitigate carbon dioxide emissions? The case of Medellin, Colombia. *Sustainability* 9, 785. doi: 10.3390/su9050785

Richards, D. R., and Friess, D. A. (2017). Characterizing coastal ecosystem service trade-offs with future urban development in a tropical city. *Environ. Manage.* 60, 961–973. doi: 10.1007/s00267-017-0924-2

Rodríguez-Algeciras, J., Tablada, A., Chaos-Yeras, M., De la Paz, G., and Matzarakis, A. (2018). Influence of aspect ratio and orientation on large courtyard thermal conditions in the historical centre of Camagüey-cuba. *Renew. Energy* 125, 840–856. doi: 10.1016/j.renene.2018.01.082

Roth, M. (2007). Review of Urban Climate Research in (sub)tropical regions. *Int. J. Climatol.* 27, 1859–1873. doi: 10.1002/joc.1591

Roth, M., and Chow, W. T. L. (2012). A historical review and assessment of urban heat island research in Singapore. *Singap. J. Trop. Geogr.* 33, 381–397. doi: 10.1111/sjtg.12003

Salvador, C. M., Alindajao, A. D., Burdeos, K. B., Lavapiez, M. A., Yee, J. R., Bautista, V. I. I., et al. (2022). Assessment of impact of meteorology and precursor in long-term trends of PM and ozone in a tropical city. *Aerosol Air Qual. Res.* 22, 210269. doi: 10.4209/aaqr.210269

Sari, D. P. (2021). A review of how building mitigates the urban heat island in Indonesia and Tropical Cities. *Earth.* 2, 653–666. doi: 10.3390/earth2030038

Scarborough, V. L., and Isendahl, C. (2020). Distributed urban network systems in the tropical archaeological record: toward a model for urban sustainability in the era of climate change. *Anthrop. Rev.* 7, 208–230. doi: 10.1177/2053019620919242

Secretariat of the Convention on Biological Diversity (2012). *Cities and Biodiversity Outlook*. Montreal, QC.

Silva, J. L., Oliveira, M. T., Oliveira, W., Borges, L. A., Cruz-Neto, O., and Lopes, A. V. (2020). High richness of exotic trees in tropical urban green spaces: reproductive systems, fruiting and associated risks to native species. *Urban Forestry Urban Green.* 50, 126659. doi: 10.1016/j.ufug.2020.126659

Silva, T. F., Vinçon-Leite, B., Lemaire, B. J., Petrucci, G., Giani, A., Figueredo, C. C., et al. (2019). Impact of urban stormwater runoff on cyanobacteria dynamics in a tropical urban lake. *Water* 11, 946. doi: 10.3390/w110 50946

Skovmand, O., Ouedraogo, T. D., Sanogo, E., Samuelsen, H., To,é, L. P., Bosselmann, R., et al. (2011). Cost of integrated vector control with improved sanitation and road infrastructure coupled with the use of slow-release bacillus sphaericus granules in a tropical urban setting. *J. Med. Entomol.* 48, 813–821. doi: 10.1603/me10041

Soni, M., Girach, I., Sahu, L. K., and Ojha, N. (2022). Photochemical evolution of air in a tropical urban environment of India: a model-based study. *Chemosphere* 297, 134070. doi: 10.1016/j.chemosphere.2022.134070

Souto, J. I., and Cohen, J. C. (2021). Spatiotemporal variability of urban heat island: influence of urbanization on seasonal pattern of land surface temperature in the Metropolitan Region of Belém, Brazil. *Urbe. Revista Brasileira De Gestão Urbana* 13. doi: 10.1590/2175-3369.013.e20200260

Stefaner, K., Ghosh, S., Mohd Yusof, M. L., Ibrahim, H., Leitgeb, E., Schindlbacher, A., et al. (2021). Soil greenhouse gas fluxes from a humid tropical forest and differently managed urban parkland in Singapore. *Sci. Total Environ.* 786, 147305. doi: 10.1016/j.scitotenv.2021.147305

Sultana, M., Storch, I., Naser, M. N., and Uddin, M. (2022). Land cover and socioeconomic factors explain avian diversity in a tropical megacity. *Ecol. Soc.* 27, 19. doi: 10.5751/es-12905-270119

Tabucanon, A. S., Kurisu, K., and Hanaki, K. (2021). Assessment and mitigation of tangible flood damages driven by climate change in a tropical city: hat yai municipality, Southern Thailand. *Sci. Total Environ.* 789, 147983. doi: 10.1016/j.scitotenv.2021.147983

Takakura, M., and Massi, K. G. (2021). Wealth and education influences on spatial pattern of tree planting in a tropical metropolis in Brazil. *Environ. Manage.* 69, 169–178. doi: 10.1007/s00267-021-01542-2

Tan, B. A., Gaw, L. Y.-F., Masoudi, M., and Richards, D. R. (2021). Nature-based solutions for urban sustainability: an ecosystem services assessment of plans for Singapore's first "Forest town." *Front. Environ. Sci.* 9, 610155. doi: 10.3389/fenvs.2021.610155

Tan, Y. H., Tham, J. K., Paul, A., Rana, U., Ang, H. P., Nguyen, N. T., et al. (2022). Remote sensing mapping of the regeneration of coastal natural habitats in Singapore: implications for marine conservation in tropical cities. *Singap. J. Trop. Geogr.* 44, 130–148. doi: 10.1111/sjtg.12454

Tang, G. S., Sadanandan, K. R., and Rheindt, F. E. (2015). Population genetics of the olive-winged bulbul (*Pycnonotus plumosus*) in a tropical urban-fragmented landscape. *Ecol. Evol.* 6, 78–90. doi: 10.1002/ece3.1832

Thaweepworadej, P., and Evans, K. L. (2022). Avian species richness and tropical urbanization gradients: effects of woodland retention and human disturbance. *Ecol. Appl.* 32, e2586. doi: 10.1002/eap.2586

Udomsri, S., Martin, A. R., and Martin, V. (2011). Thermally driven cooling coupled with municipal solid waste-fired power plant: application of combined heat, cooling and power in tropical urban areas. *Appl. Energy* 88, 1532–1542. doi: 10.1016/j.apenergy.2010.12.020

United Nations (2012). *Un System Task Team on the Post-2015 un Development Agenda*. Available online at: https://www.un.org/millenniumgoals/pdf/Think%20Pieces/18_urbanization.pdf (accessed March 19, 2023).

United Nations (2015). *Ecosystems and Biodiversity The Role of Cities: Involvement Influence Implementation*. Available online at: https://www.uncclearn.org/wp-content/uploads/library/unhab40.pdf (accessed March 19, 2023).

United Nations (2023). *What Is Climate Change?* United Nations. Available online at: https://www.un.org/en/climatechange/what-is-climate-change#:~:text=Climate%20change%20refers%20to%20longin%20temperatures%20and%20weather%20patterns (accessed March 18, 2023).

United Nations General Assembly. (2015). *Transforming Our World: The 2030 Agenda for Sustainable Development*. London: United Nations General Assembly. p. 35.

Upadhyay, S., Singh, R., Verma, P., and Raghubanshi, A. S. (2021). Spatio-temporal variability in soil CO_2 efflux and regulatory physicochemical parameters from the tropical urban natural and anthropogenic land use classes. *J. Environ. Manage.* 295, 113141. doi: 10.1016/j.jenvman.2021.113141

Vailshery, L. S., Jaganmohan, M., and Nagendra, H. (2013). Effect of street trees on microclimate and air pollution in a tropical city. *Urban Forestry Urban Green.* 12, 408–415. doi: 10.1016/j.ufug.2013.03.002

Van de Walle, J., Brousse, O., Arnalsteen, L., Byarugaba, D., Ddumba, D. S., Demuzere, M., et al. (2021). Can local fieldwork help to represent intra-urban variability of canopy parameters relevant for tropical african climate studies? *Theor. Appl. Climatol.* 146, 457–474. doi: 10.1007/s00704-021-03733-7

Velasco, E., Roth, M., Norford, L., and Molina, L. T. (2016). Does urban vegetation enhance carbon sequestration? *Landsc. Urban Plan.* 148, 99–107. doi: 10.1016/j.landurbplan.2015.12.003

Villalobos-Forbes, M., Esquivel-Hernández, G., Sánchez-Murillo, R., Sánchez-Gutiérrez, R., and Matiatos, I. (2021). Stable isotopic characterization of nitrate wet deposition in the tropical urban atmosphere of Costa Rica. *Environ. Sci. Pollut. Res.* 28, 67577–67592. doi: 10.1007/s11356-021-15327-x

Wang, J. W., Poh, C. H., Tan, C. Y., Lee, V. N., Jain, A., and Webb, E. L. (2017). Building biodiversity: drivers of bird and butterfly diversity on tropical urban roof gardens. *Ecosphere* 8, 1905. doi: 10.1002/ecs2.1905

Wolff, P. J., DeGregorio, B. A., Rodriguez-Cruz, V., Mulero-Oliveras, E., and Sperry, J. H. (2018). Bird community assemblage and distribution in a tropical, urban ecosystem of Puerto Rico. *Tropical Conserv. Sci.* 11, 75477. doi: 10.1177/1940082918754777

Yang, L., Nguyen, D. M., Jia, S., Reid, J. S., and Yu, L. E. (2013). Impacts of biomass burning smoke on the distributions and concentrations of C2–C5 dicarboxylic acids and dicarboxylates in a tropical urban environment. *Atmos. Environ.* 78, 211–218. doi: 10.1016/j.atmosenv.2012.03.049

You, L., Nguyen, V. T., Pal, A., Chen, H., He, Y., Reinhard, M., et al. (2015). Investigation of pharmaceuticals, personal care products and endocrine disrupting chemicals in a tropical urban catchment and the influence of environmental factors. *Sci. Total Environ.* 536, 955–963. doi: 10.1016/j.scitotenv.2015.06.041

Yulia, Y., and Arlianda, R. (2020). Climate resilience and policy transfer in Semarang City, Indonesia. *ETropic* 19, 143–171. doi: 10.25120/etropic.19.2.2020.3767

Zaki, S. A., Toh, H. J., Yakub, F., Mohd Saudi, A. S., Ardila-Rey, J. A., and Muhammad-Sukki, F. (2020). Effects of roadside trees and road orientation on thermal environment in a tropical city. *Sustainability* 12, 1053. doi: 10.3390/su12031053

Zhang, J., Giannis, A., Chang, V. W. C., Ng, B. J. H., and Wang, J.-Y. (2013). Adaptation of urine source separation in tropical cities: process optimization and odor mitigation. *J. Air Waste Manage. Assoc.* 63, 472–481. doi: 10.1080/10962247.2013.763306

Zucaro, A., Maselli, G., and Ulgiati, S. (2022). Insights in urban resource management: A comprehensive understanding of unexplored patterns. *Front. Sustain. Cities.* 3, 807735. doi: 10.3389/frsc.2021.807735