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Urbanization and Extreme Rainfall: A Systematic Review of Global Evidence from Developing and Developed Regions

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Author's contribution

The sole author designed, analyzed, interpreted and prepared the manuscript.

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ABSTRACT

Modern urbanization has become a dominant force in changing the environmental landscape and local climate systems. One of the most visible impacts of this process is the increase in extreme rainfall events in urban areas. This study presents a systematic review of nine academic studies that explicitly examine the relationship between urbanization and extreme rainfall intensity in various parts of the world, both in developed and developing countries. Using the PRISMA-based Systematic Literature Review (SLR) method, hundreds of articles were screened until only nine relevant high-quality studies were left. The results of the review show a consistent pattern that urbanization not only increases the frequency and intensity of extreme rainfall, but also modifies the temporal and spatial distribution of rainfall, strengthens the urban heat island effect, and exacerbates flood and drought risks. These findings emphasize the importance of integrating spatial

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planning, climate adaptation, and sustainable development policies to anticipate hydrometeorological impacts in urban areas. Further development is expected to consider environmental factors and ecosystem sustainability. This study also fills the gap in the literature by presenting a comprehensive cross-case synthesis as a theoretical and practical basis for future research and policy.

Keywords: Urbanization; extreme rainfall; urban heat island; hydrometeorological risk; systematic literature review (SLR).

1. INTRODUCTION

Urban area development cannot be separated from the contribution of human resources (HR) originating from rural areas (Ngoc and Tien, 2023; Surya et al., 2021). In the context of internal migration, the flow of people from rural to urban areas has become one of the main mechanisms for providing labor in strategic urban sectors, such as industry, services, and construction. This phenomenon reflects the structural relationship between rural areas as labor suppliers and urban areas as centers of capital accumulation and economic activity.

The city's dependence on rural labor also shows that urban development is basically not independent (Liu et al., 2022; Yang et al., 2021). This is the result of dynamics involving surrounding areas, especially villages, which provide cheap, flexible and often less institutionally protected labor. From a political economy perspective, this reflects a form of spatial inequality that is reproduced through the unequal allocation of roles between villages and cities in the national development system.

In addition to the role of villages as providers of human resources, the progress of urban areas is also a strong attraction for rural communities (Cattaneo et al., 2022; Lin et al., 2022). The transformation of cities as centers of economic growth, technological innovation, and access to better public services has created an image of cities as symbols of modernity and opportunity. This gives rise to what in migration literature is called the urban pull factor, namely the pulling power of cities that influences the decisions of individuals or households in villages to undertake spatial mobility.

Urban progress is often seen in the form of more advanced infrastructure, more diverse job opportunities, access to higher education, and better quality health services. For rural communities living in limited access and minimal facilities, this condition creates a sharp contrast and forms aspirations to improve their standard of living by moving to the city. Thus, the city is not only a physical space, but also a symbolic space that represents the hope for a better life.

In practice, urbanization does not only occur through planned legal channels, but also occurs non-legally and spontaneously (Abonyi and Udensi, 2023; Ibrahim, 2021). Legal urbanization usually involves administratively recorded population movements supported by adequate infrastructure and spatial planning policies. In contrast, illegal urbanization often occurs without clear planning, such as through migration of people to the city without official residence permits, the construction of illegal settlements, or unauthorized land use. This phenomenon shows that the flow of urbanization does not always go hand in hand with the institutional capacity of the city to manage it.

The consequences of this uncontrolled urbanization are very complex (Hossain and Huggins, 2021; Rahaman et al., 2023; Waseem and Talpur, 2021). One of the most obvious impacts is the emergence of informal settlements or slum areas that often develop on marginal lands such as riverbanks, railway lines, or disaster-prone areas. These types of settlements generally have minimal access to clean water, sanitation, and other basic services. This condition not only worsens the quality of life of the area's residents, but also burdens the city system as a whole—from infrastructure, public services, to environmental governance.

Furthermore, illegal urbanization also raises serious social challenges, such as increasing levels of disguised unemployment, income inequality, and social conflicts between native city dwellers and newcomers (Awasthi, 2021; Lipi and Hasan, 2021). Without integrative policies, migrant groups tend to experience social and economic exclusion, which in turn creates social fragmentation in urban spaces. In the long run, this fragmentation can disrupt social cohesion and weaken the foundations of inclusive and equitable urban development.

The current issue that is increasingly relevant in the context of urbanization is the increasing frequency and intensity of extreme rainfall. Global climate change has accelerated the dynamics of extreme weather, including high rainfall in a short time that has a significant impact on urban areas. Large cities, as the epicenter of population growth due to urbanization, are becoming increasingly vulnerable to hydrometeorological risks due to increasing environmental pressures.

Massive urbanization is often not accompanied by adequate spatial planning and drainage infrastructure. The increase in the area of covered land due to the construction of settlements, roads, and commercial areas has reduced the soil's ability to absorb rainwater. As a result, even extreme rainfall with a short duration can cause widespread inundation or flooding. In many developing cities, existing drainage systems are not designed to handle such large volumes of water, especially when combined with garbage that clogs the water flow.

In addition to technical issues, the relationship between urbanization and extreme rainfall also reflects the dimensions of social inequality. Low-income communities living in dense, informal, or flood-prone areas are the most affected. Flooding disasters caused by extreme rainfall are not only an environmental issue, but also a matter of spatial justice: who is most vulnerable, who is least protected by policy, and who is slowest to recover after a disaster.

Although there have been many studies that have addressed certain issues separately and limited to specific areas, most of these studies tend to be partial and lack integration of findings across locations and approaches (Rajeswari et al., 2021; Wang et al., 2021). The dominance of sectoral and fragmented approaches in previous studies has made it difficult to form a holistic understanding of the phenomena studied. As a result, there is no comprehensive synthesis that links previous research results to build a more systemic analytical framework.

The absence of an integrative approach creates a gap in the literature, especially in understanding the interrelationships between factors across regions, temporally, and conceptually. This is a crucial problem because many social, economic, and environmental phenomena are multidimensional and interrelated, and therefore cannot be adequately understood through isolated studies. Thus, a study is needed that not only summarizes the existing literature but also develops an interpretive framework that is able to bridge the various findings systematically and interconnectedly.

2. METHODOLOGY

This study uses the Systematic Literature Review (SLR) method as the main approach in answering the formulated research questions. SLR was chosen because it is able to present a systematic, transparent, and replicable knowledge mapping of literature relevant to the research topic. This approach not only aims to summarize the results of previous studies, but also to identify patterns, gaps, and potential directions for future research (Torkayesh et al., 2023; Van Dinter et al., 2021).

In this study, literature searches were conducted through a number of reputable academic databases, such as Scopus, Web of Science, and Google Scholar, using a combination of keywords tailored to the main topic of the study. Furthermore, an initial screening process was carried out based on the title and abstract, followed by a full content review to determine suitability with the focus of the study. The literature that passed the selection was then analyzed using qualitative content analysis and/or bibliometric mapping techniques, depending on the needs of thematic analysis or research trends.

The use of the SLR method not only contributes to developing a strong theoretical and conceptual framework, but also strengthens the position of this research in a broader academic context. By systematically integrating various findings from previous studies, this study aims to present a scientific synthesis that can be a basis for further empirical research and as input for policy makers in relevant fields.

The article selection process in this study follows the Systematic Literature Review (SLR) approach that refers to the PRISMA standard. From a total of 625 articles identified through the Scopus database, the initial selection stage was carried out by excluding 295 articles published in low-reputation journals (Q3 and Q4) or not scientifically indexed. This step aims to ensure that only literature with high academic quality is analyzed further.

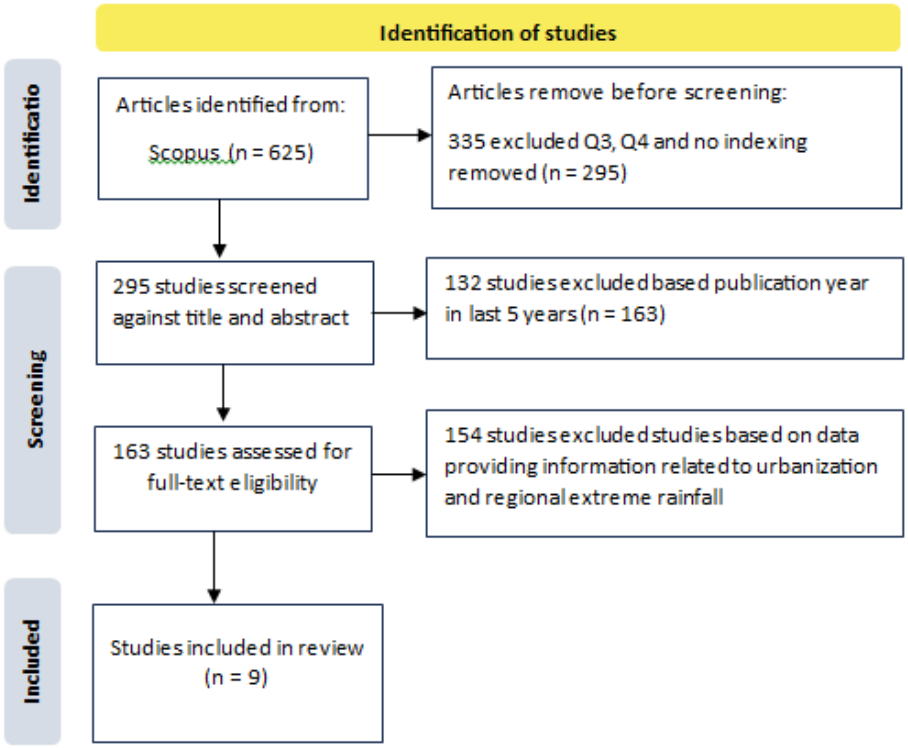

Fig. 1. PRISMA Diagram of Article Selection

After initial screening, 295 articles were left, which were then further reviewed based on title and abstract. At this stage, 132 articles were again eliminated because they did not meet the publication time limit criteria, which was the last five years. This time-based selection was carried out to ensure that the literature analysis was up-to-date and relevant to the context of the contemporary issues being studied, especially related to the phenomena of urbanization and extreme rainfall.

From the screening results, 163 articles were then thoroughly analyzed through full-text reading to assess the suitability of the content substance to the research focus. However, most of them—153 articles—did not meet the criteria because they did not contain information that explicitly linked the two important elements that were the focus of this study: urbanization and extreme rainfall on a regional scale. This shows that although many studies discuss each of these issues separately, very few examine their relationship directly and integratively.

Finally, only 9 articles passed all stages of selection and were deemed worthy of inclusion in the systematic review. This very limited number actually confirms the existence of a significant literature gap. In other words, there are not many studies that seriously and integratedly explore the relationship between urbanization dynamics and the intensification of extreme rainfall events at the regional level. This gap is the basis and urgency of this research to present a comprehensive and contextual conceptual synthesis.

3. RESULTS AND DISCUSSION

Urbanization is a global phenomenon that not only changes the physical landscape of an area, but also has a significant impact on local climate systems, especially rainfall patterns. Various studies from several countries have shown that urban growth is closely correlated with increased frequency, intensity, and uncertainty of extreme rainfall events.

One important finding emerged from the study of Yang et al. (2024), which shows that compact urban development patterns tend to increase extreme rainfall events compared to rural areas. This phenomenon is not only found in one region, but is also consistently observed in various regions of the world. For example, in Bhubaneswar, India, urbanization not only

increases rainfall intensity, but also shifts the timing of rainfall to a later period of the day (Swain et al., 2023). This indicates that urbanization is capable of modifying local weather systems, creating new dynamics in the temporal distribution of rainfall.

Table 1. The influence of urbanization on changes in rainfall according to several researchers

No.	Title and Author	Research Area	Findings
1.	Urban development pattern's influence on extreme rainfall occurrences. (Yang et al., 2024)	Global (with specific simulation in central China)	Compact urban development patterns are associated with increased extreme rainfall frequency in cities compared to rural areas.
2.	Delay in timing and spatial reorganization of rainfall due to urbanization- analysis over India's smart city Bhubaneswar. (Swain et al., 2023)	India	Increasing urbanization in Bhubaneswar, India is correlated with changes in rainfall patterns, including increased intensity and a shift to later in the day.
3.	Urbanization Amplified Asymmetrical Changes of Rainfall and Exacerbated Drought: Analysis Over Five Urban Agglomerations in the Yangtze River Basin, China. (Huang et al., 2023)	China	Urbanization in the Yangtze River Basin of China has increased heavy rainfall and decreased light rainfall, and made urban regions more prone to drought.
4.	Urbanization-induced changes in extreme climate indices in Thailand during 1970–2019. (Pimonsree et al., 2022)	Thailand	Urbanization in Thailand has led to increases in temperature and rainfall extremes.
5.	Intensification of sub-daily rainfall extremes in a low-rise urban area. (Huang et al., 2022)	United States (Arizona)	Urbanization in a low-rise metropolitan area is correlated with intensification of sub-daily rainfall extremes compared to rural surroundings.
6.	Urbanization Further Intensifies Short-Duration Rainfall Extremes in a Warmer Climate. (Yan et al., 2024)	China	Urbanization increases short-duration rainfall extremes more than longer-duration rainfall in a warming climate.
7.	Advanced statistical analyses of urbanization impacts on heavy rainfall in the Beijing metropolitan area. (Chang et al., 2021)	Beijing metropolitan area, China	Increasing urbanization in the Beijing metropolitan area is correlated with changes in heavy rainfall patterns, including higher variability and intensity.
8.	Changes in rainfall rates and increased number of extreme rainfall events in Rio de Janeiro city. (Regueira and Wanderley, 2022)	Brazil	Increased urbanization in Rio de Janeiro is correlated with changes in rainfall patterns, including increased intensity and frequency of extreme rainfall events.
9.	Assessing the Effects of Urban Canopy on Extreme Rainfall over the Lake Victoria Basin in East Africa Using the WRF Model. (Birungi et al., 2024)	Lake Victoria Basin in East Africa (encompassing parts of Burundi, Rwanda, Kenya, Tanzania, and Uganda)	Increasing urbanization in the Lake Victoria basin in East Africa amplifies the intensity and duration of extreme rainfall events.

In the Yangtze River basin, China, urbanization has even more complex impacts. A study by S. Huang et al. (2023) noted that increasing urban development has led to a surge in heavy rainfall, but has reduced light rainfall. This imbalance makes urban areas not only vulnerable to flooding but also to drought. Similar findings were found in Thailand, where extreme changes in temperature and rainfall have become more pronounced over the past five decades (Pimonsree et al., 2022).

In other parts of the world such as the United States and Brazil, urbanization has also had a significant impact. In Arizona, J. Huang et al. (2022) noted that low-rise metropolitan areas experienced an increase in extreme rainfall on a sub-daily scale. Meanwhile, in Rio de Janeiro, research by Regueira and Wanderley (2022) found an increase in the frequency and intensity of extreme rainfall events due to rapid urban growth.

Not only that, in the context of global climate change, urbanization appears to amplify the impact of global warming on rainfall patterns. Yan et al. (2024) showed that in a warming climate, urban development exacerbates short-term rainfall intensity. Meanwhile, in the Lake Victoria region of East Africa, Birungi et al. (2024) found that the presence of urban canopies lengthens the duration and amplifies the intensity of extreme rainfall in areas that previously tended to be more stable.

Overall, these results show a consistent pattern that urbanization amplifies extreme dynamics in the hydrometeorological system (Deng et al., 2024; El Kenawy, 2024). The change in land surface from vegetation to hard infrastructure such as concrete and asphalt causes an increase in local temperature and changes in air circulation, which ultimately accelerates the convection process and the formation of rain clouds. This phenomenon is known as the urban heat island effect, and plays an important role in creating atmospheric conditions that are more likely to trigger heavy rainfall. This study still has shortcomings in terms of the number of relevant papers to be analyzed (n=9). Further research is expected to analyze more relevant papers so that the conclusions produced can be more comprehensive.

The implications of these findings are far-reaching, especially in the context of urban planning and management. Cities around the world need to design evidence-based adaptation strategies that take into account future climate risks. Drainage infrastructure, green open spaces, and environmentally oriented spatial planning are essential elements in addressing these challenges. (Castelo et al., 2023; Corgo et al., 2024; D. Wang et al., 2024).

4. CONCLUSION

Globally, urbanization has been shown to have a significant impact on increasing the frequency, intensity, and unpredictability of extreme rainfall events in urban areas. Through a systematic review of nine cross-country studies, this study shows that the process of urbanization triggers microclimate changes through the urban heat island effect and land-use modification, which ultimately increases the risk of floods and droughts at the same time. These findings emphasize the need for integration between climate-adaptive urban planning and sustainable development policies, so that urbanization does not become a source of new vulnerabilities, but rather an opportunity to create cities that are resilient and responsive to increasingly extreme environmental dynamics.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

COMPETING INTERESTS

Author has declared that no competing interests exist.

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