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Climate Change and Flood Exposure in Settlements: Spatial Analysis of Geographical and Topographical Factors for Urban Resilience

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Abstract. Climate change has intensified the frequency and severity of floods, posing critical threats to urban settlements located in topographically vulnerable areas. This study examines climate change processes that contribute to flood exposure, identifies geographical and topographical factors—such as elevation, slope, proximity to water bodies, and landform configuration—that influence exposure, and analyzes settlement characteristics as spatial considerations for resilience planning. A systematic literature review of 31 peer-reviewed articles was conducted using the Scopus database. The findings indicate that low-lying elevations, flat slopes, and proximity to rivers or coastlines significantly amplify exposure, while anthropogenic factors such as unregulated urban expansion, artificial land modification, and insufficient drainage further exacerbate risks. Case studies from diverse contexts, including O‘ahu (Hawai‘i), Bekasi (Indonesia), and the Tanaro River Valley (Italy), demonstrate how physical geography interacts with climate-driven hazards. Unlike many studies that emphasize hazard intensity or socio-economic vulnerability, this research focuses narrowly on physical exposure as the foundational layer of flood risk. The results highlight the importance of integrating topographic analysis and nature-based solutions into spatial planning and urban design. By reframing exposure as an active spatial determinant, this study contributes conceptually to climate adaptation discourse and identifies research gaps, particularly the limited integration of settlement morphology in resilience strategies.

Keywords: climate change, flood exposure, geographical location, topography, settlement

1. Introduction

Flooding has become increasingly frequent and severe due to climate change, threatening the sustainability of urban settlements, particularly those with vulnerable topographic conditions. Limited understanding of how climate change processes contribute to flooding, as well as how geographical and topographic factors determine settlement exposure, often results in fragile and ineffective planning. Climate change, driven largely by anthropogenic greenhouse gas emissions, has altered precipitation patterns, intensified extreme rainfall events, and accelerated sea-level rise (Alfieri et al., 2017; Arku, 2013; Lane & Kay, 2021). Warmer atmospheric conditions enhance the hydrological cycle, increasing the likelihood of floods, droughts, and storms (Gribovszki et al., 2019). Consequently, floods have emerged as one of the most direct hydrometeorological impacts of climate change, affecting settlements worldwide. Figure 1.1 illustrates the pathways through which climate change intensifies flood hazards.

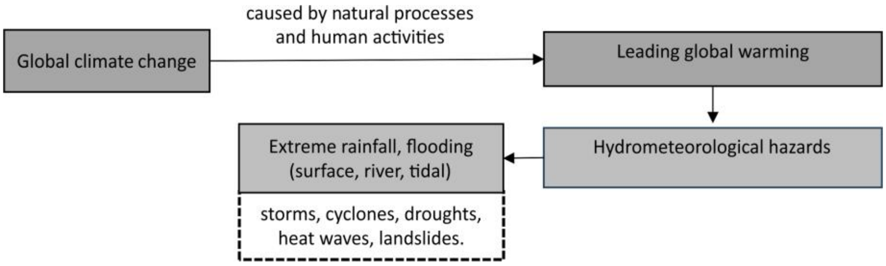

Figure 1.1. Pathways from climate change to hydrometeorological hazards (Authors, 2025)

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Flood exposure is shaped by the interplay of geographical location and topography, which influence hydrological processes and drainage performance. Low-lying coastal areas, floodplains, and river basins are naturally susceptible to flooding, while land-use changes and urban expansion can amplify these risks (Ali et al., 2018; Schober et al., 2020). Figure 1.2 presents the spatial framework linking exposure, geographic characteristics, and potential planning strategies.

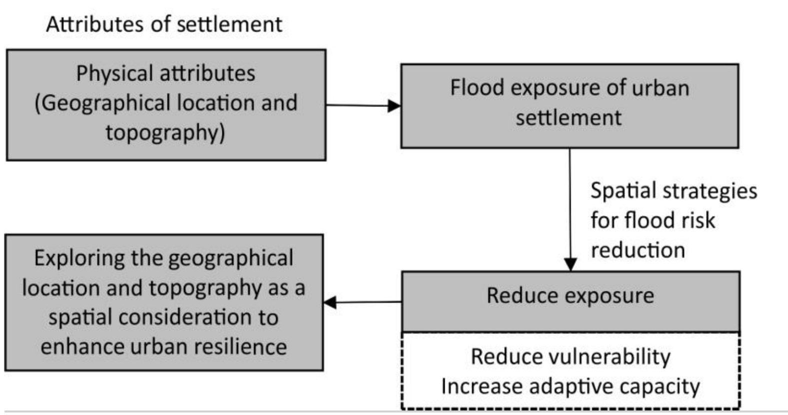

Figure 1.2. Spatial framework of flood exposure and reduction strategies in settlements (Authors, 2025)

1.1. Geographical Location and Topographical Attributes Related to Flood Exposure

Research shows that flood risk is closely linked to geographical features, with topography playing a direct role in influencing drainage and water accumulation patterns. As highlighted by Nikolova and Zlateva, understanding the physical-geographical environment is crucial for assessing flood vulnerability, which requires analyzing various components of the landscape and their interplay with socio-economic factors (Nikolova & Zlateva, 2017).
Low-lying terrain—defined by low elevation and gentle slopes—heightens flood vulnerability by slowing drainage and raising local relative sea level. Where subsidence coincides with sea-level rise, tidal flooding arrives earlier and spreads wider (Murray et al., 2025). In Semarang's north, elevations of 0–10 m with <2% slopes drive prolonged rob during heavy rain and high tide (Usman et al., 2025). More broadly, river-basin geometry (elevation gradients, valley and floodplain forms) governs how fluvial floods concentrate and propagate (Wuit Yee Kyaw & Pyai Tun, 2023).
Geographical location describes the position of a settlement on Earth, typically indicated by latitude and longitude, and encompasses proximity to water bodies, elevation, and climate zones. These attributes strongly influence flood exposure. (Ouedraogo & Mundler, 2019) emphasize that spatial proximity affects community access to resources and environmental vulnerability. Settlements near rivers or coastlines, for example, are more prone to flooding.

(Chakraborty et al., 2021) show that flood vulnerability often aligns with geographic boundaries, reinforcing how spatial inequalities shape exposure. (Azizat & Wan Mohd Sabki Wan Omar, 2018) further highlight that climate-related conditions—such as heavy rainfall—heighten flood risk. Thus, understanding both spatial positioning and climatic context is essential for targeted resilience strategies.

Topography encompasses land surface characteristics—elevation, slope, landforms, and soil types—that influence water flow and settlement sustainability. (Quinn, 2024) notes that terrain affects where communities settle, shaping exposure to hazards. Landforms determine water accumulation and runoff patterns, which are essential for planning flood-resilient settlements.

(Argyriou et al., 2017) link topographic variation to different urban forms and ecological conditions, underlining the role of landscape features in urban design. Elevation and slope influence flood dynamics: steep slopes cause fast runoff and potential flash floods, while flat areas retain water, increasing inundation risks (Kaspersen et al., 2017). (Dang & Kumar, 2017) stress the need for accurate flood hazard mapping, particularly in areas with poor drainage. Local topography—such as slopes and depressions—can significantly impact flood risk, especially in urban areas. (Arnous et al., 2022) and (Thannoun & Ismaeel, 2024) explain how terrain type dictates whether floods manifest as flash floods or prolonged inundation. (Alharbi & Mills, 2021) confirm that elevation and drainage capacity affect flash flood vulnerability in arid zones. Meanwhile, (Li et al., 2022) demonstrate the utility of remote sensing and high-resolution topographic data for mapping flood exposure and supporting effective flood management.

An integrated understanding of geographical location and topographical attributes is essential for assessing flood exposure. These interrelated factors shape hazard dynamics, inform risk assessments, and support the development of resilient urban policies and infrastructure.

1.2. Research Objectives and Gap

Accordingly, this study was guided by three objectives: to examine the climate change processes that contribute to flood events; to identify the geographical and topographical factors that influence settlement exposure; and to analyze settlement characteristics as spatial considerations for enhancing urban resilience.

While numerous studies have examined flood hazards and socio-economic vulnerability, fewer have explicitly focused on exposure as a spatial condition shaped by geography and topography. Even fewer have integrated settlement morphology and spatial attributes into resilience planning. This research seeks to address that gap by reframing exposure not as a passive outcome but as an active spatial determinant in understanding and reducing flood risk.

2. Methods

This study employs a systematic literature review (SLR) to synthesize current knowledge on the relationship between geographical and topographical factors and flood exposure in human settlements. The SLR followed explicit steps—problem identification, literature search, screening, data extraction, and synthesis—ensuring transparency and replicability (Massaro et al., 2016; Xiao & Watson, 2017).

The search was conducted on May 31, 2025 using the Scopus database with advanced Boolean queries. The core term *“flood exposure”* was combined with keywords such as *“spatial,” “settlement,” “climate change,” “vulnerability,” “flood,”* and *“risk”* within titles, abstracts, and keywords. The initial search retrieved 6,385 records, which were reduced to 700 after removing unrelated studies. Further screening excluded non-journal publications (conference papers, book chapters, reviews) and non-English articles.

An inclusion criterion was open-access availability, resulting in a final selection of 31 peer-reviewed articles that provide empirical and conceptual insights into spatial and topographical determinants of flood exposure. The emphasis on open-access sources ensured transparency and accessibility; however, this is acknowledged as a methodological limitation, as high-quality studies in subscription-only databases (e.g., Web of Science, Scopus closed access) were excluded. While this may limit comprehensiveness, the selected dataset remains representative for identifying spatial trends and settlement characteristics.

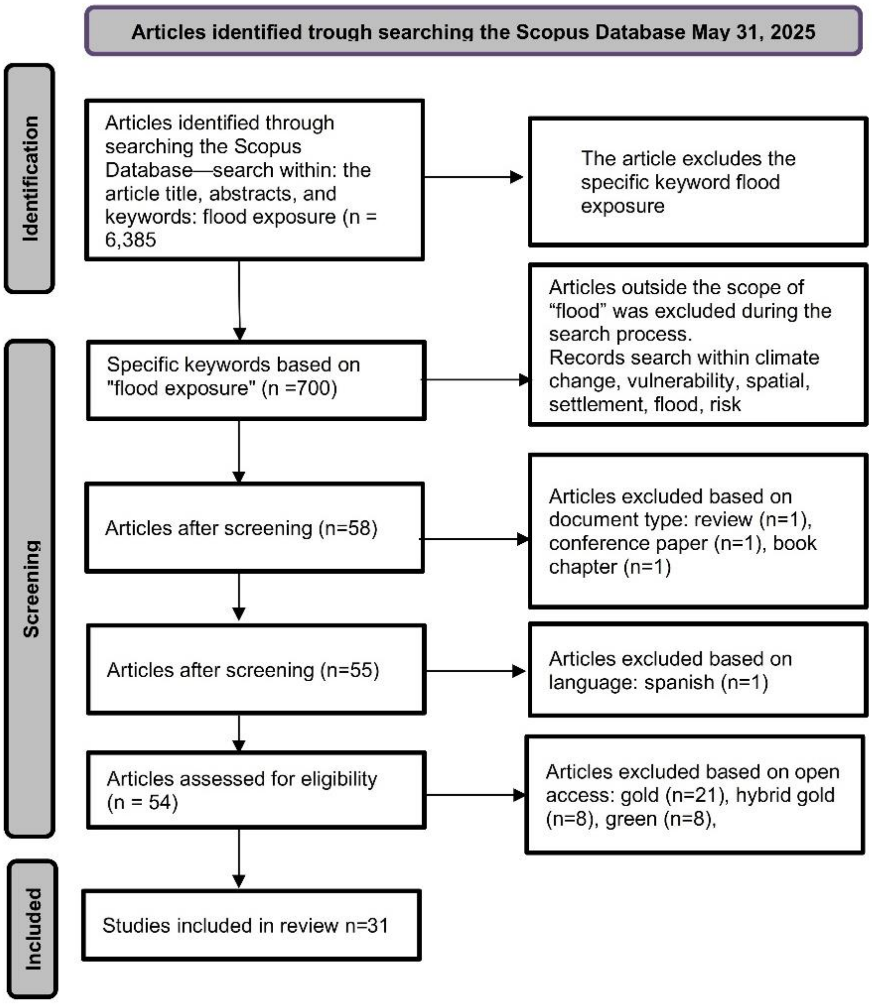

Figure 2.1. Article selection flowchart for the systematic literature review, resulting in 31 included studies (Authors, 2025)

The literature search was conducted on May 31, 2025, using the Scopus database with an advanced query interface. The search strategy employed a combination of specific keywords and Boolean operators. The core term "flood exposure" was targeted within the article title, abstract, and keyword fields to ensure thematic consistency. This term was combined using the operator AND with other relevant keywords, including "spatial," "settlement," "climate change," "vulnerability," "flood," and "risk", to expand the search scope and capture studies addressing related topics.

An initial pool of 6,385 documents was retrieved. From this, records unrelated to flood exposure were excluded, narrowing the results to 700 entries. Further screening removed non-journal publications such as conference papers, book chapters, and review articles, followed by the exclusion of one article written in Spanish to retain only English-language sources.

A key inclusion criterion was open-access availability to ensure transparency and accessibility; therefore, gold, hybrid gold, and green open-access articles with restricted access were excluded. After applying all inclusion and exclusion criteria, a final set of 31 journal articles was selected for analysis. These selected articles form the empirical foundation of this systematic literature review, offering insights into how spatial and topographical attributes contribute to urban flood exposure in the context of climate change.

3. Discussion

The bibliometric overview highlights the diversity of authors, institutions, and disciplines engaging with flood exposure studies (Figure 3.1). This dispersed authorship pattern indicates broad scholarly interest rather than concentration in a few research clusters. It also underscores the interdisciplinary nature of the field, bridging environmental science, earth sciences, social science, and applied disciplines such as engineering and urban planning.

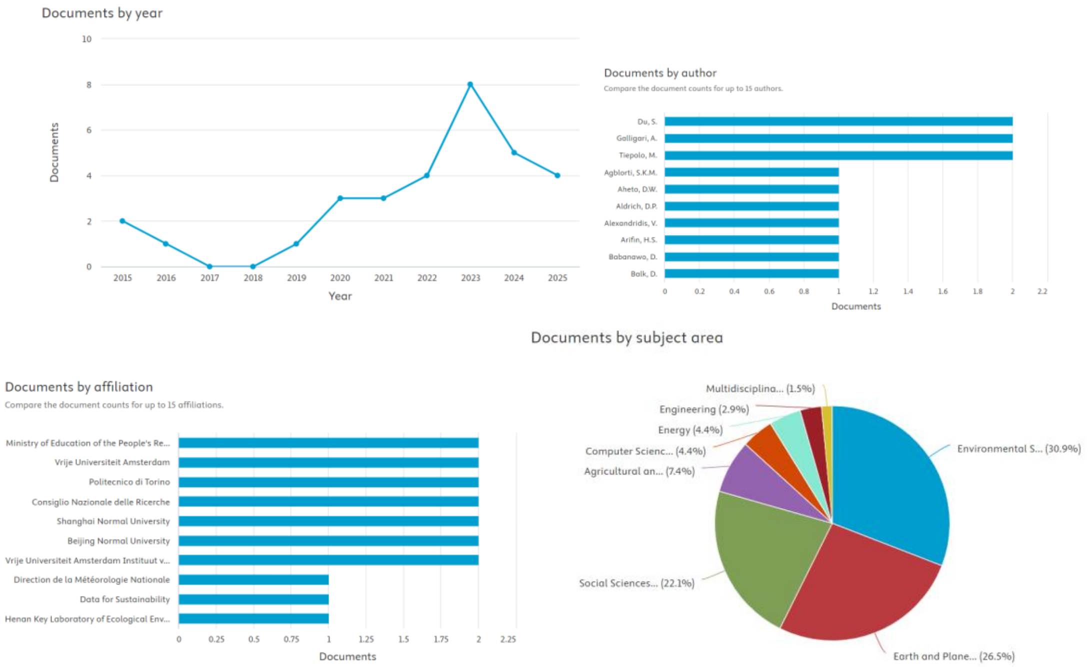

Figure 3.1. Bibliometric summary of publications on flood exposure and urban spatial characteristics (2015–2025) (Scopus.com, 2025)

3.1. Flood Risk Under Climate Change

The reviewed literature confirms that climate change intensifies hydrometeorological hazards through altered rainfall patterns, sea-level rise, and drainage disruption, with disproportionate effects on low-lying and riverine settlements (Gómez et al., 2019; Shampa et al., 2022; Wing et al., 2018). Impervious urban surfaces further exacerbate runoff. Studies in O‘ahu, Hawai‘i, show that land subsidence combined with artificial fill increases exposure by up to 53% by 2050 (Murray et al., 2025) Similar findings in North Jakarta and Semarang also highlight how land subsidence interacts with sea-level rise to accelerate coastal flood risks (Rukayah et al., 2023, 2025). These examples demonstrate how climate-driven hazards are amplified by both natural and anthropogenic processes.

3.2. Geographical and Topographical Determinants of Exposure

From the 31 reviewed articles, 11 focus on coastal settlements, 13 on riverine or floodplain areas, and 7 in mixed or unspecified contexts. Tables 3.1 and 3.2 classify the main types of flood-prone geographies and topographies. Coastal lowlands, deltas, and river basins consistently emerge as the most exposed settlement environments, characterized by low elevation, flat terrain, and direct proximity to water bodies (Fitriyati et al., 2024; Kouakou et al., 2023).

Urban case studies provide further evidence of how topography interacts with development pressures. In Bekasi, Indonesia, flat slopes (0–2%) combined with rapid expansion and inadequate drainage increase inundation frequency (Fitriyati et al., 2024). In Istanbul's Pendik District, artificial fill and constrained river systems amplify flood risks (Pala et al., 2025). These findings demonstrate that settlement exposure is not only determined by physical geography but also by land-use patterns and infrastructure modifications.

Table 3.1. Geographical Types of Flood-Exposed Areas (Authors, 2025)

No	Geographical Type	Geographical Sub-Type	Representative References
1	Coastal Lowlands & Deltas	Hawai'i (southern coast of O'ahu, Maunalua); Coastal zone of China (15 provinces); Port-Bouët Bay (Côte d'Ivoire); Bangladesh; India (megacities, coastal lowlands); Ghana (Ketu South); Global scale (coastal lowlands, delta regions)	Murray et al., 2025; Kouakou et al., 2023; Fitriyati et al., 2024; Schober et al., 2020
2	River Basins and Floodplains	Bengawan Solo River Basin (Indonesia); Pendik District, Istanbul; Bekasi City (Indonesia); China (9 river basins); Tanaro River (Italy); Hawkesbury-Nepean (Australia)	Shrestha et al., 2025; Pala et al., 2025; Fitriyati et al., 2024; Mandarino et al., 2023; Kelly et al., 2023

Table 3.2. Topographical Types of Flood-Exposed Settlement Areas (Authors, 2025)

No	Topography	Topographical Variations	Representative References
1	Low-Lying Coastal Plains & Zones	Hawai'i (reef deposits); Istanbul (Pendik District); Coastal China; Bekasi (11–81 m, slope 0–2%); Port-Bouët (<8 m); East Coast US; Sicily; India (LECZ); Ghana (deltaic plains); Bangladesh	Murray et al., 2025; Fitriyati et al., 2024; Kouakou et al., 2023; Schober et al., 2020
2	River Systems & Floodplains	Bengawan Solo (Indonesia); Slovakia (Roma communities); Italy (Tanaro River); Australia (Hawkesbury-Nepean); Niger (floodplain towns); Global river floodplains	Shrestha et al., 2025; Jančovič & Kidová, 2024; Mandarino et al., 2023; Kelly et al., 2023

Flood exposure arises from the convergence of natural processes and anthropogenic alterations. Natural factors include topography (e.g., elevation, slope) and hydrology, while human-induced changes—such as land reclamation, artificial fill, and infrastructure on floodplains—amplify risk (Mandarino et al., 2023; Murray et al., 2025). Artificial fill, as in Mapunapuna (O'ahu), leads to subsidence and loss of land integrity over time. Similarly, river valleys in Italy's Tanaro region demonstrate increased exposure due to steep slopes, narrow floodplains, and expanding settlements (Mandarino et al., 2023; Shrestha et al., 2025).
Building upon the identified geographical and topographical categories, this section synthesizes flood exposure levels across selected coastal and riverine settlements. Table 3.3. presents representative case studies to illustrate how specific physical attributes, when combined with contextual factors, result in consistently high levels of flood exposure.

3.3. Settlement Characteristics and Flood Exposure

Beyond location and topography, settlement morphology significantly shapes flood exposure. Dense and unplanned urban forms on floodplains—such as in Bekasi or the Tanaro River valleys in Italy—reduce infiltration capacity and obstruct natural flow channels (Mandarino et al., 2023). Informal settlements in low-lying deltas, including coastal Ghana and Bangladesh, also show how settlement typologies interact with terrain to intensify risks. In Indonesia, heritage districts in Semarang and North Jakarta highlight how compact urban fabric and historical building stock situated on subsiding land are repeatedly affected by tidal floods, illustrating how physical terrain and settlement form jointly compound exposure (Rukayah et al., 2023, 2025).

Table 3.3 synthesizes these findings by linking specific settlement settings, physical attributes, and amplifying factors. Across both coastal and riverine cases, exposure is consistently high when low elevation and flat or unstable topography converge with anthropogenic pressures such as drainage alteration, land reclamation, or settlement densification.

Table 3.3. Inferred Flood Exposure Based on Coastal and Riverine Physical Attributes (Authors, 2025)

Geographical Setting	Key Physical Characteristics	Amplifying Factors	Exposure Level	Representative References
Coastal	Artificial fill; low-lying; subsiding land	Sea-level rise, land instability	High	Murray et al., 2025
Coastal	<8 m elevation; unprotected shoreline	Urban growth, lack of natural barriers	High	Kouakou et al., 2023; Fitriyati et al., 2024
River Basin	Floodplain; low elevation; flat slope	Urban expansion, drainage alteration	High	Fitriyati et al., 2024; Shrestha et al., 2025
River Basin	Narrow valleys; steep slope; confined riverbed	Erosion, floodplain encroachment	High	Mandarino et al., 2023; Pala et al., 2025
River Basin	Wide floodplain; dense settlement	Increased rainfall, limited flood control	High	Kelly et al., 2023; Jančovič & Kidová, 2024

3.4. Implications for Urban Planning and Resilience

Physically grounded planning must integrate elevation and slope mapping (Wu et al., 2024), monitoring of anthropogenic modifications (Jančovič & Kidová, 2024), and improved hydrological modeling (Kelly et al., 2023). Hybrid approaches that combine engineered infrastructure with nature-based solutions—such as wetland restoration, infiltration zones, and ecological river rehabilitation—can reduce exposure in vulnerable settlements (Pappalardo & La Rosa, 2023; Stefanidis et al., 2022).

Importantly, settlement-scale interventions need to account for morphology and density patterns. For instance, retrofitting drainage in compact informal settlements or restricting new construction in subsiding coastal areas should be prioritized. These strategies emphasize that flood exposure is shaped as much by the form and growth of settlements as by natural topography.

4. Conclusion

This study shows that climate change processes—sea-level rise, intensified rainfall, and land subsidence—amplify settlement flood risk; that geographical and topographical conditions, especially low elevation, flat slopes, and proximity to water bodies, consistently determine exposure across coastal and riverine settings; and that settlement characteristics, including dense morphology, unregulated growth, and artificial land modification, further compound risk by disrupting natural hydrological pathways. Reframing exposure as an active spatial determinant advances urban climate-adaptation theory and supports planning that integrates topographic assessment with nature-based and regulatory measures. Future research should pair high-resolution spatial analyses with field evidence to better capture how settlement form interacts with physical geography in shaping flood exposure.

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