Building Flood Resilience in Vulnerable Communities: A Framework for Integrating Physical Vulnerability Indicators with Adaptive Architectural Design

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Abstract

With the increasing frequency and severity of climate-related disasters, particularly floods, it is crucial to create adaptive strategies to minimize their impact on vulnerable communities and buildings. This paper introduces a conceptual framework to assess physical flood vulnerability indicators within the broader context of socio-ecological systems theory, aiming to help identify design approaches for reducing flood risk in residential neighborhoods. The paper adopts a semi-systematic review of literature involving theoretical perspectives, identifying themes and conceptualizing the key variables in developing the framework; which proposes that the identification of physical flood vulnerability indicators is a function of several factors: demographic and socio-economic characteristics, flood attributes, neighborhood and architectural context, and adaptive capacities, all of which reflects the extent of exposure, susceptibility and resilience to flood impacts. The paper suggests that the most effective adaptive architectural design techniques to reduce flood risk are based on key indicators that influence physical vulnerability to floods. The paper concludes by emphasizing the potential of this framework to guide decision-making in architectural design for flood-prone areas. By integrating offers a comprehensive method to develop adaptive design strategies that strengthen the resilience of at-risk communities

Keywords: Exposure, Flood Hazard, Physical Vulnerability Assessment, Resilience, Susceptibility

1. Introduction

Within the context of the built environment, physical vulnerability refers to the extent to which buildings, infrastructure, and other physical assets are susceptible to hazard (Nguyen-Trung & Forbes-Mewett, 2019; Hossain & Fahad, 2020). In other words, the tendency or propensity of assets to be negatively impacted by hazards is explained by the complex idea of vulnerability (Gu, 2019). In disaster management literature, vulnerability implies a potentially harmful condition which increases susceptibility to disasters (Bhattacharya-mis & Lamond, 2014; Stagrum et al., 2020; Slovic & Indvik, 2021). Generally, this condition causes damages to lives, property and livelihoods from any hazard or natural disaster. According to Kuriakose et al. (2009), the concept of vulnerability is too complex and diverse; as such, vulnerability analysis requires a qualitative, subjective, proportional and contextual approaches, as well as quantitative, objective, absolute and non-contextual approaches. Also, vulnerability is commonly perceived as the opposite of resilience, or as part of resilience (Bec et al., 2019); where, resilience is achieved by reducing vulnerability and improving adaptive capacity. Recognizing and understanding physical vulnerabilities and their underlying causes are critical in improving resilience and minimizing the impacts of hazards (Begoña et al., 2020).

Today, many coastal communities are vulnerable to flood hazard due to climate change impacts, economic and social consequences, and challenges in mitigation and adaptation (Satterthwaite et al., 2020; Rahman, Azad & Rahman, 2023). In Lagos, Nigeria, the physical and socio-economic impact of flooding is increasing in many areas because of the combined effects of growing populations and limited resources in high-risk areas. According to National Emergency Management Agency (NEMA) reports, over two million people in Lagos were impacted by flooding directly in 2020[1]. Same report highlights 158 fatalities, with over 200,000 residents affected in 2019. Prior to this time, about 17 to 25 deaths (although more than 100 deaths were mentioned in another report), displacement of around 5,000 people (although an IFRC report stated that 5,393 households were impacted, and it seems that several publications might have misidentified these figures with damages estimated to be around US$200–320 million) was documented (Adelekan, 2016). Also, drainage infrastructure in Lagos city suffers from overflowing during floods, leading to contamination and waterborne illnesses, although the actual prevalence of these diseases is uncertain (Lucas, 2021). Despite the difficulties involved, efforts to mitigate these risks and their consequences remains a challenge (Atufu & Holt, 2018).

With the increasing threat of climate change impacts, especially the rising frequency and severity of flooding, the need for resilient architectural designs for flood-prone areas has become essential. In this context, developing a comprehensive conceptual framework to assess physical vulnerability indicators and create adaptive architectural design strategies is crucial for enhancing communities' ability to adapt to flood risks. This process requires a deep understanding of the various factors contributing to vulnerability (Munyai et al., 2019; Kaoje et al., 2021) and a recognition that design solutions must be tailored to each community's unique characteristics and needs (Petrosillo et al., 2015). To achieve this, a participatory approach like the socio-ecological systems (SES) theory is essential, acknowledging the interconnectedness of social, economic, and environmental factors that impact vulnerability to flooding and the efficacy of architectural interventions.

SES theory rooted in von Bertalanffy open systems concept highlights the complex interactions between components of a system and its environment (Bertalanffy, 1956). This theory, championed by scholars like Elinor Ostrom, asserts that social and ecological systems are interdependent and influence each other (Berkes, Folke, & Colding 2003; Ostrom, 2009; Flood, 2010; Petrosillo et al., 2015; Folke et al., 2016; Lai & Lin, 2017; Cabrera et al., 2021). In other words, societies and ecosystems are interconnected and co-evolve across scales. The theory further emphasizes the importance of understanding feedback loops, adaptive

[1] National Emergency Management Agency (NEMA), "Agency Reports," NEMA Nigeria, last modified 2023, https://nema.gov.ng/flood-forecasting-management-nema-provides-automatic-weather-observatories-to-nihsa/.

responses, and resilience within coupled systems (Folke et al., 2009). In retrospect, SES theory integrates social, economic, and environmental factors to study the interactions and feedback loops between human activities and the natural environment (Ostrom, 2009; Bodin & Prell, 2011; Folke et al., 2016), thereby offering a conceptual lens to understand the complex relationships between human activities and environmental factors. Hence, SES theory, as a participatory approach emphasizes the importance of involving various stakeholders, including local communities, in the planning and design process (Baldassarre et al., 2013).

Considering that this study seeks to inform the development of adaptive architectural design strategies for flood risk mitigation by understanding local context, it is imperative to consider and analyze all systems characteristics or factors which influence flood vulnerability. Given the above, this paper considers the basic components of physical vulnerability assessment from a systems perspective, and explores the important characteristics and criteria for developing a conceptual framework for assessing critical indicators that influence physical vulnerability to floods. This will guide in prioritizing areas for intervention and improvement.

2. Methods

The paper is based on a semi-systematic or narrative review of literature. The approach was selected because the review follows a methodological approach that can be used for detecting themes, theoretical perspectives, and identifying components of a theoretical concept (Snyder, 2019). The semi-systematic review approach thus serves as a strong evidence base and provides valuable insights for exploring methods in physical flood vulnerability assessment, and identifying components of flood vulnerability assessment in order to develop a testable conceptual framework for assessing physical flood vulnerability indicators to guide adaptive architectural design strategies for flood disaster risk reduction.

The paper adopted a research process that involved three (3) steps: identifying and searching a reliable research digital platform; inclusion and exclusion criteria; and data extraction and analysis.

2.1 Search strategy

The search started by identifying a reliable research digital platform that can provide a wider coverage of literatures from diverse disciplines. A thorough literature search was conducted via Litmaps digital platform. This platform was selected because it provides a valuable visual and interactive tool to explore and analyze existing literature from various regions, to allow for a diverse range of scope in a particular field of study across numerous academic databases[2]. The search initiated with documents that specifically address physical flood vulnerability assessment. The literatures discovered include research articles, conference papers, journal pre-proof, editorial journals, book chapters, and theses.

2.2 Inclusion and Exclusion Criteria

Since vulnerability is a complex concept considered to have multiple dimensions and components (Nguyen-trung & Forbes-mewett, 2019; Hossain & Fahad, 2020); these important components were further included as key terminologies in the search.

Therefore, the search further mapped literature on physical flood vulnerability,

[2] Litmaps, Your Literature Review Assistant, last modified 2024, https://www.litmaps.com/

flood hazard, exposure, susceptibility, and resilience (see Figure 1). In addition, attempt was made to focus on both empirical studies and theoretical frameworks that directly address the key terminologies. However, article collections published before year 2000 were excluded from the review. This was done ensure that the review reflects the most relevant and current literature in the field. A total of 68 full text articles deemed relevant were included and used.

2.3 Methods used for data extraction and analysis

Data extraction and analysis in a systematic review helps to identify the relevant information from the included studies and synthesize the findings to develop a testable conceptual framework (Chong et al., 2022). In this review, data on the specific components of physical flood vulnerability (flood *hazard, exposure, susceptibility and resilience)* was extracted; with a view to identify common themes or patterns for which the identified components would be measured, thereby offering insights that can inform the development of a testable conceptual framework.

Table 1: Breakdown of Digital Platform and Databases, Key Terminologies and Journals used for the review

Digital Platform	Searched Terminologies	Journals assessed
Litmaps	Physical Flood Vulnerability	City and Environment Interactions
	Hazard	Climate
	Exposure	Economy of Ukraine
	Susceptibility	Environmental science pollution research
	Resilience	Frontiers in Water
		Hydrol. Earth Syst. Sci.,
		International Journal of Disaster Risk Management
		International Journal of Disaster Risk Science
		International Journal of Environment and Climate Change
		IOP Conf. Series: Earth and Environmental Science
		Journal of Biodiversity and Endangered Species
		Jàmbá - Journal of Disaster Risk Studies
		Journal of Flood Risk Management
		Journal of Hydrology
		Journal of Research and Rural Planning
		Nature Communications
		Natural Hazards
		Natural Hazards Review
		Natural Hazards and Earth System Sciences
		OECD/IEA
		Remote Sensing
		Sustainable and Resilient Infrastructure
		Sustainability
		Spatial planning and Sustainable development
		Water

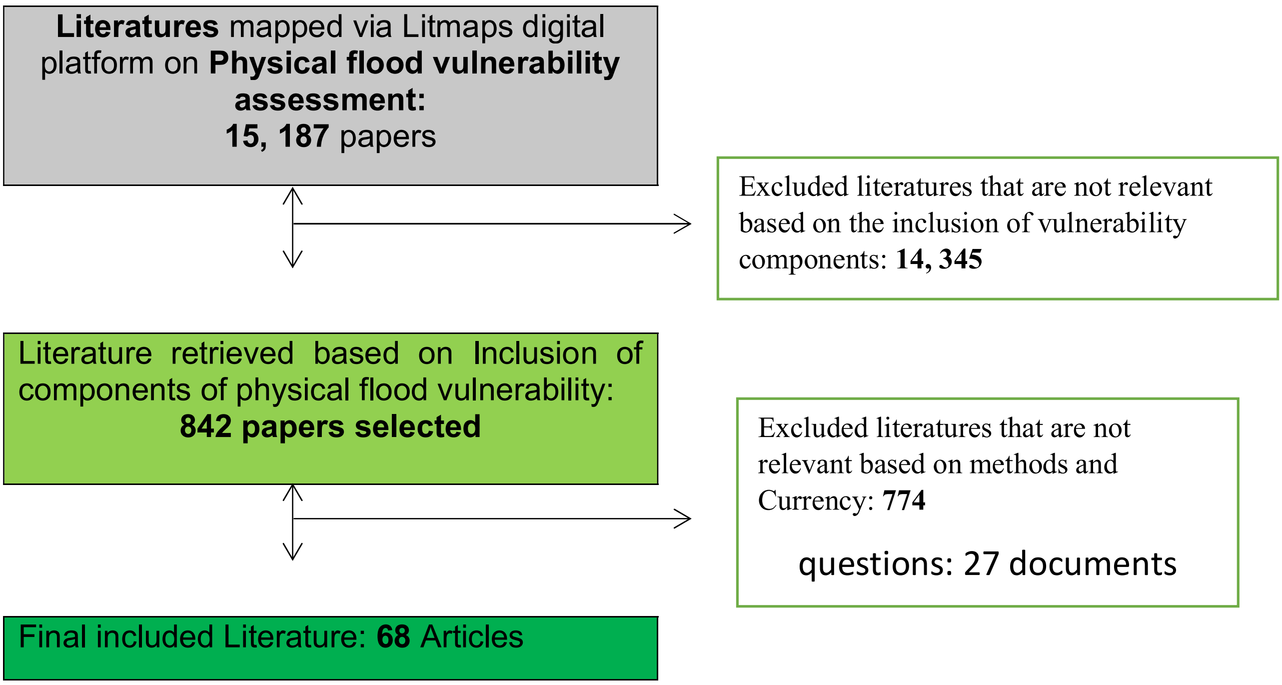

Figure 1: Criteria for Inclusion and Exclusion

3. Results and Discussion

3.1 Methods used in Physical Flood Vulnerability Assessment

Physical vulnerability assessment is a critical component of risk analysis and disaster management, providing valuable insights into the susceptibility of physical assets to various hazards. Analyses of mapped articles shows a number of methods have been used in literature to determine physical flood vulnerability. Many of the articles employed quantitative methods, such as vulnerability indices, statistical models, and GIS-based analyses to assess physical vulnerability (Aktar et al., 2021; Hernández-Atencia et al., 2023; Thi et al., 2022; Miranda et al., 2023; Papathoma-k et al., 2022). These methods often involve the use of spatial data, vulnerability curves, and flood damage models to quantify the potential impacts of hazards on physical assets. Flood damage models generally rely on complex mathematical algorithms to estimate the potential economic losses associated with flooding, based on factors such as water depth, velocity and duration. However, these models can be difficult to validate and may not accurately reflect local conditions or full range of impacts associated with flooding.

Other articles reviewed utilized qualitative methods, such as participatory assessments, expert judgment, and, interviews in physical vulnerability assessment (Begoña et al., 2020; Ferrari et al., 2019). A typical example is the MOVE framework (Methods for the Improvement of Vulnerability Assessment in Europe), which provides valuable insights into the social and contextual aspects of physical vulnerability. For example, Hamidi et al., (2020) utilized the MOVE framework to evaluate physical flood vulnerability for the purpose of developing strategies to reduce vulnerability and increase capacity to cope with future flood events. However, due to increasing complexity of risks facing physical assets, researchers are exploring multi-hazard methods to assess physical vulnerability. Sammonds et al. (2023) for instance adopted a modified expression of disaster risk for the multi-hazard hurricane risk assessment in Dominica using Multi-hazard susceptibility analysis (*covering flood susceptibility, hurricane susceptibility, landslide susceptibility*) and demographic vulnerability analysis. The assumption is that by integrating multiple hazards and climate change impacts, a more comprehensive understanding of vulnerability patterns can be attained.

It thus implies that quantitative, qualitative and multi-hazard analysis each provides numerical assessments, contextual understanding of vulnerabilities, and combined impact of multiple hazards on physical vulnerability respectively. Furthermore, evidence from the literature review shows that indicator-based methods have also been used in vulnerability assessment (Sahraei et al., 2023; Hamidi et al., 2022; Leal et al., 2021; Malgwi et al., 2020). The method generally involves the use of specific indicators or metrics which can be integrated into quantitative, qualitative and multi-hazard analysis to quantify and measure different dimensions of vulnerability in a systematic and structured manner for data collection, analysis and interpretation (Rasch, 2015). These indicators are typically selected based on their relevance to the specific context and dimensions of vulnerability being assessed (Kaoje et al., 2021). The outcome of the indicator-based approach is indexed and represents the level of vulnerability on a scale assigned by expert judgment to reflect policy priorities or theoretical data (G. Wang et al., 2020). Also, by considering a range of indicators and dimensions, the robustness and reliability of vulnerability assessments can be enhanced; thus leading to informed decision-making and targeted interventions to enhance resilience and reduce risk (Begoña et al., 2020).

3.2 Components of Physical Flood Vulnerability Assessment

Previously published studies highlighted three main components of vulnerability, namely: exposure, susceptibility and resilience (Ajijola & Adedire, 2023; Abid et al., 2021; Aktar et al., 2021; Hossain & Fahad, 2020; Salami et al., 2017; Qasim et al., 2017). On one hand, it was deduced that exposure implies the proximity of people and/or physical assets to flood damage (Hamidi et al., 2022). It also means the identification of elements in areas where flood hazard events may occur (Gu, 2019). Further analysis shows that exposure is dynamic and its influencing factors vary widely depending on the hazard situation, the stage of the disaster, as well as the demographic and socio-economic characteristics of the affected population (Hamidi et al., 2022; Rentschler et al., 2022). On the other hand, researchers described susceptibility as the inherent characteristics or qualities of a system that make it more or less vulnerable to hazard (Swain et al., 2020; Sahraei et al., 2023). It is obvious from the literatures reviewed that there are no specific sets of geomorphometric standards for identifying flood susceptibility zones, however, studies focusing on urban physical vulnerability assessment often explore the interconnectedness of built environment elements and their susceptibility to hazards. Kometa et al. (2021) argued that building characteristics such as building elevation, foundation type, and building materials, also influence physical susceptibility to flood damage. In addition, neighborhoods characteristics, such as the spatial pattern, drainage systems, proximity to water sources, landscaping and vegetation, were also found to influence flood proneness (Chen et al., 2020). Resilience, as the third component implies the adaptive capacity to cope with flood impacts, and it was found to be a function of pre-disaster preparedness, coping capacity during flood events and post disaster intervention (Ajijola & Adedire, 2023; Bixler et al., 2021; Norris, et al., 2008).

Thus, an inference may be drawn that exposure explains the link between the social system and hazards (demographics, socio-economic characteristics and hazard attributes), and susceptibility explains the interaction between human conditions (for example, physical elements and neighborhood conditions within the built-environment), and resilience entails coping and adaptive capacities. According to studies, demographics and socioeconomic status of a community as evident in the quality of the social capital, household composition, and livelihood pattern determines the ability to access resources, implement preparedness measures, and respond effectively to flood events (Partelow, 2021; Hallegatte et al., 2020; ADB, 2016; Tunstall et al., 2013). Also, hazard attributes, for instance the flood pattern, causes of flooding and its influencing factors, as well as flood impacts play a significant role in determining flood vulnerability (Kaoje et al., 2021; Fu et al., 2020). Furthermore, Miranda et al., (2023) and Ajijola et al., (2024) argued that built environment factors at the neighborhood and building scale are both influential in reducing flood susceptibility. Wang et al. (2019) also hinted that specific strategies and measures for disaster risk reduction are embedded within the physical dimensions of an urban community. Similarly, reduction of flood risk in a vulnerable community lies in their capacity for resilience and ability to adapt (Ajijola & Adedire, 2023; Liao, 2018; Brooks, 2017).

Thus, this paper views flood hazard, exposure, susceptibility and resilience as major components of physical flood vulnerability, particularly in flood-prone neighborhoods where vulnerability of houses and occupants to flood risk result from multiple factors such as the nature of the hazard experienced, neighborhood context and building design characteristics as well as issues surrounding socio-demographic characteristics and adaptive capacity of individuals and households.

Table 1: Summary of basic Components of Physical Vulnerability assessment

Components of Physical Flood Vulnerability	**Exposure**		**Susceptibility**	**Resilience**
Themes	Flood hazard	People at Risk of flood disaster	Physical elements that influence likelihood of flood disaster	Adaptive Capacity to cope with flood impacts
Characteristics	Flood attributes (Pattern, causes and impact)	Interaction of hazard, demographic and socio-economic characteristics	Neighborhood characteristics and architectural features	Pre-disaster preparedness, coping capacity and post disaster recovery

3.3 Conceptual Framework

A conceptual framework presents an integrated way of looking at a research problem. It is a visual representation or narrative of the key variables or constructs of a research and the supposed relationships between them (Adom & Hussein, 2018). It is argued that the entire methodology must agree with the variables, as well as their relationships and context. Thus, a conceptual framework offers a rational framework for carrying out a study as well as the factors that would clarify the fundamental research approach. The proposed framework places physical vulnerability as a function of exposure, susceptibility and resilience (see Figure 2). This approach would leverage on vulnerability dimensions of exposure (*users at risk and flood attributes*); susceptibility (*likelihood of flood disaster based on neighborhood characteristics and architectural features of buildings*); and resilience (*pre-disaster preparedness, household coping capacity, and interventions in post disaster*) to develop a systemic analysis of the most critical indicators influencing physical vulnerability to flood risk in a flood-prone area.

The key assumption in the conceptual framework is that the identification of physical vulnerability indicators is a function of several factors such as the socio-demographic and economic characteristics of the residents; the attributes of the flooding experienced; neighborhood characteristics and architectural features of buildings; and the adaptive capacity of the households (all of which will determine the extent of exposure, susceptibility and resilience of houses and their occupants to flood risk). These assumptions are underpinned by the socio-ecological system theory as previously explained. In real life scenarios, this information can guide the general selection of a range of potential vulnerability variables from which critical contextual indictors can be subsequently derived through empirical surveys. The framework further believes that the most critical physical vulnerability indicators can inform the identification of the most appropriate adaptive architectural design options for building resilience in vulnerable communities. Hence, integrating physical vulnerability indicators with adaptive architectural design enhances the overall disaster preparedness and response capabilities of vulnerable communities.

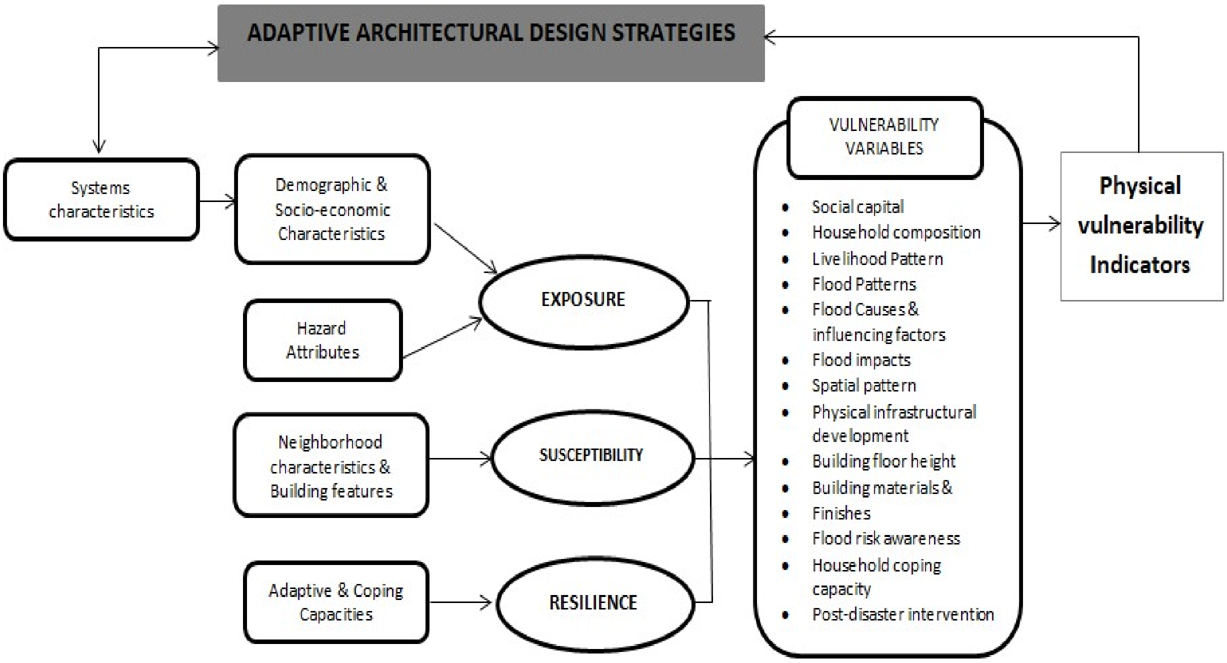

Figure 2: Conceptual Framework **Source:** Researcher, 2024

Beyond disaster risk reduction, the conceptual framework has far-reaching implications. For example, vulnerable communities are often disproportionately affected by natural disasters due to socioeconomic disparities and limited adaptive capacities. Therefore, designing resilient buildings and neighborhoods in underserved areas can help bridge the gap in access to safe and sustainable housing, thereby promoting social inclusion and reducing vulnerability. In addition, the framework, being a participatory-led approach can guide effective and culturally appropriate design solutions, and can also provide the opportunity for communities to take ownership of their resilience-building efforts, thereby fostering a sense of collective responsibility. This implies that through the integration of physical vulnerability indicators with adaptive architectural design, a more resilient, inclusive, and sustainable future can be attained. Drawing insights from this paper has the potential to make valuable contributions to interdisciplinary research, innovative design solutions, evidence-based practice, policy development, community engagement, knowledge sharing, capacity building, and sustainable development efforts. The paper could serve as a catalyst for advancing knowledge and practices aimed at enhancing resilience and reducing vulnerability in communities facing the increasing threat of flooding.

4. Conclusion

This review was conducted to develop a robust framework for evaluating indicators of physical vulnerability in flood-prone residential neighborhoods for developing effective architectural solutions. Central to the conceptual framework is the recognition that adaptive architectural design strategies must be tailored to the unique characteristics and needs of each community. This necessitates a participatory approach: socio-ecological systems theory, which offers a comprehensive and multidimensional understanding of physical vulnerability, taking into account the complex and dynamic nature of flood risk. By considering systems' characteristics that are capable of providing information regarding exposure, susceptibility and adaptive capacity, the framework allows for a comprehensive assessment of context-specific indicators influencing physical flood vulnerability in flood-prone areas, and thus offers a solid basis for designing interventions that are more likely to be culturally sensitive, socially inclusive, and environmentally sustainable.

The application of this conceptual framework allows for a systematic assessment of physical vulnerability indicators in flood-prone areas. This research contributes to the broader discourse on climate change adaptation and provides valuable insights for architects, urban planners, policymakers, and researchers working to address the challenges posed by flood events in vulnerable areas.

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