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Integrating Flood Risk Management into Development Projects: A Conceptual Framework for Resilient Urban Planning

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Abstract

Flood risk is an increasingly critical concern in urban development as the frequency and severity of floods escalate due to climate change and intensified economic activities. Despite extensive studies on flood risk management (FRM), a significant gap persists in practical frameworks that systematically integrate FRM principles across the entire lifecycle of development projects. To address this gap, this study conducted a scoping review of 27 peer-reviewed articles published between 2014 and 2024, retrieved from Scopus, ScienceDirect, and Google Scholar databases. Using a thematic analysis approach, four major themes were identified: (1) the risk–hazard model, (2) risk assessment theory, (3) project lifecycle theory, and (4) risk management theory. These themes were synthesized to develop a unified conceptual framework that embeds FRM throughout project planning, design, implementation, and operation. The proposed framework emphasizes early risk identification, continuous stakeholder engagement, adaptive management, and interdisciplinary collaboration, enabling proactive integration of FRM into development processes. This novel approach aligns flood resilience with broader urban sustainability and planning objectives, offering a practical tool for policymakers, project managers, and urban planners. Future research should focus on empirical validation and contextual adaptation of the framework across diverse socio-economic and geographical settings to enhance its global applicability.

Keywords: Flood Risk Management (FRM), Development Projects, Conceptual Framework, Project Lifecycle Theory, Urban Development Resilience

Introduction

Flooding is one of the most devastating natural disasters, posing severe global risks to human life, infrastructure, and economies. In recent decades, the frequency and intensity of floods have escalated, driven by climate change, which exacerbates vulnerabilities in developed and developing regions [1]. According to the World Meteorological Organization (2021), climate-related disasters, particularly floods, have surged 134% since the 1980s, affecting billions worldwide. This alarming trend underscores the urgent need for comprehensive flood risk management (FRM) strategies, particularly in rapidly urbanizing areas, where the convergence of urban expansion and flood risks intensifies the potential for catastrophic losses [2].

Unfortunately, many development projects fail to incorporate flood risk considerations during the planning and execution phases, jeopardizing sustainability and increasing vulnerability [3].

Urbanization, driven by population growth and economic development, often occurs in flood-prone regions, further intensifying flood-related risks. Urban projects often disrupt natural hydrological systems, leading to increased surface runoff and reduced water absorption [4]. Without integrating flood risk management from the outset, development projects become more susceptible to direct and indirect losses from flooding, including infrastructure damage, economic disruptions, and diminished investor confidence [5].

Reactive approaches to flood risk management, often implemented after flood events, are less effective and more costly than proactive measures, which integrate adaptive strategies to account for future climate scenarios [6,7]. Thus, there is a pressing need for a structured flood risk management framework embedded in the entire lifecycle of development projects, ensuring flood risks are mitigated early on. Despite the recognized benefits of embedding flood risk management in development projects, a significant gap exists in the literature regarding practical frameworks that facilitate this integration.

While extensive research addresses flood risk management strategies and urban resilience, few studies offer systematic approaches for incorporating these strategies across all phases of a project's lifecycle, from planning and design to construction and operation [4],[8]. This gap highlights a critical barrier to effective flood risk mitigation, particularly in rapidly urbanizing areas where infrastructure development is vulnerable.

This study aims to fill this gap by proposing a conceptual framework integrating non-structural flood risk management measures into development projects. Embedding FRM across the full project lifecycle will measurably increase urban project resilience by improving early risk identification, adaptive responses, and stakeholder coordination. The framework aims to enhance project resilience and mitigate flood vulnerabilities by promoting adaptive management, stakeholder engagement, and aligning flood risk management with broader project management processes.

Materials and Methods

Formulation Research Questions

The research question guiding this study informed the scoping review: What are the key components of a conceptual framework linking FRM to development projects?

Systematic Searching Strategies

The systematic search strategies involved identification, screening, and eligibility assessment. These phases were conducted to ensure a rigorous investigation.

Identification

This first phase was conducted to enhance the keywords used in the search process. Using multiple keywords and databases at this stage was essential to avoid retrieval bias [9]. The search relied on the main keywords, "flood risk management", "flood Risk" , "construction project" and "development projects," as well as several related keywords: "conceptual framework," "construction management," "resilience," and "scoping review." The basic functions of the Boolean operator OR or AND and phrasal-level search were deployed whenever possible. The articles were combined based on two main indexing databases, Scopus and Google Scholar, and several other journal databases: Science Direct, Science of the Total Environment, Nature, SSRN Electronic Journal, Best Evidence of Chinese Education, and Science Insight Education Frontier. The search process was conducted between May and August 2024. This effort retrieved 106 potential articles for the scoping review, and no duplicate records were identified.

Screening

Screening was the second step in the systematic search strategy, distinguishing suitable articles from unsuitable ones for the review. [10] accentuated that any criteria can be selected by the authors if the criteria can address the research question. Articles were selected from those published from 2014 to 2024, and only peer-reviewed articles/documents were selected to ensure article quality. As [11] prescribed, only articles published in English were reviewed to avoid confusion, minimize cost, and reduce time consumption. After discarding 66 articles that had failed to meet the criteria, only 40 articles were retained for the next selection stage.

Eligibility

In the eligibility phase, the 40 shortlisted articles were critically examined to verify their compliance with the predefined inclusion criteria. Abstracts were reviewed in detail to assess the relevance of each study to the research question, while full-text screening was conducted for papers whose suitability could not be determined from the title or abstract alone. Thirteen articles were excluded at this stage as they did not directly address flood risk within the context of development projects, were not peer-reviewed, or were published in non-academic formats. Consequently, 27 studies meeting all inclusion criteria were retained for the final scoping review.

The systematic review process adhered to the PRISMA 2020 guidelines, ensuring methodological rigor, transparency, and reproducibility. Figure 1 presents the PRISMA flow diagram summarizing the identification, screening, eligibility, and inclusion phases. In total, 106 records were initially retrieved from major databases, including Scopus, Google Scholar, and ScienceDirect. Following the screening and eligibility assessments, 27 peer-reviewed studies were finalized for inclusion in the qualitative synthesis.

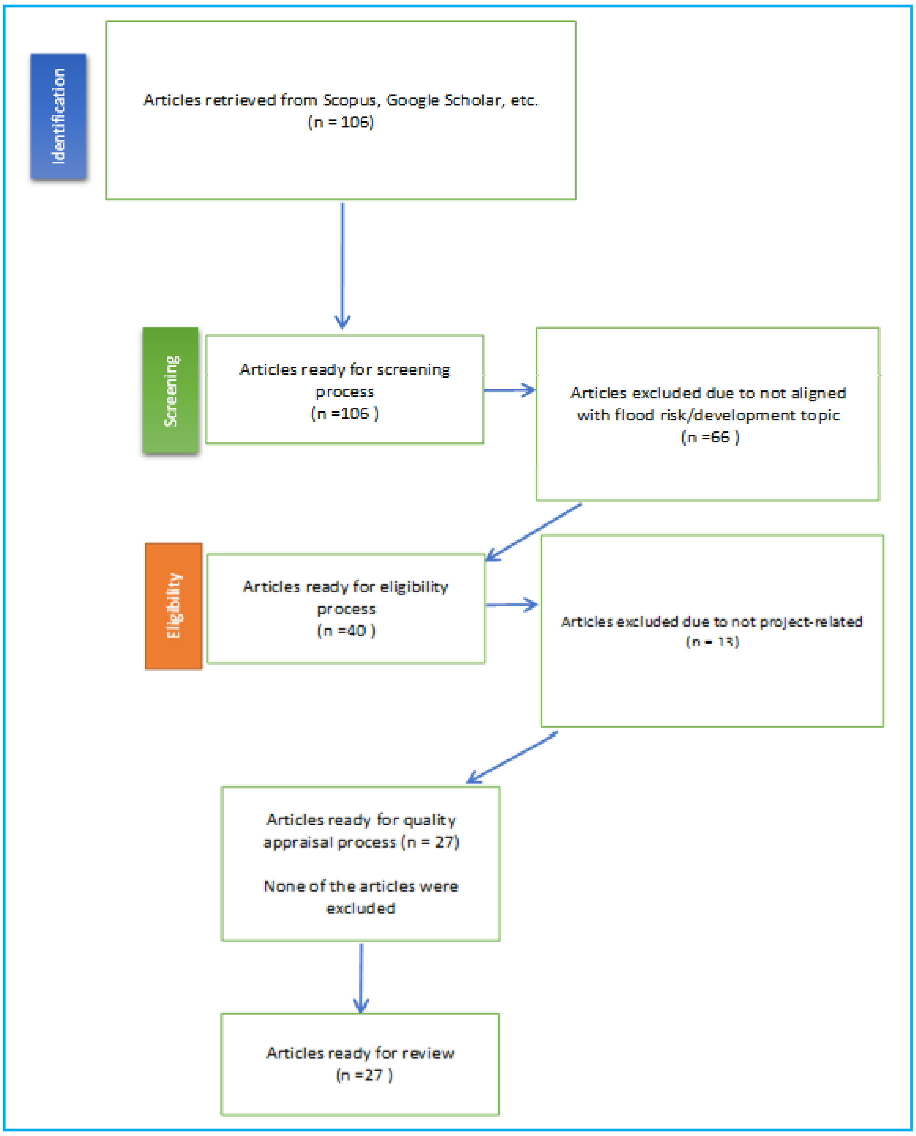

Figure 1. PRISMA flow diagram summarizing the identification, screening, eligibility, and inclusion phases

Data Extraction and Analysis

The research question guided the data extraction process. All data from the selected studies were related to flood risk in development projects or projects related to flood risk management. The conceptual framework is indirectly considered upon determining their ability to address the research question. This qualitative study adopted thematic analysis to assess the captured data. This analysis identified themes based on patterns retrieved from the selected studies, as well as similarities and correlations between the abstracted data [12]. At the first stage of the synthesis, data similar or related to each other were pooled in a specified theme. At this stage, six main themes were identified. In the second stage, the themes were re-examined to ensure their usefulness and accurate representations of the data. During this process, two themes, the theory of change and the systems approach, were excluded due to their limited connection with the main research question. The other four retained themes are the risk-hazard model, risk assessment theory, project lifecycle theory, and risk management theory.

The Emerging Themes

Risk Hazard Model

Floods, as one of the most destructive natural disasters, require effective flood risk management (FRM) strategies, particularly as climate change accelerates their frequency and intensity. The Risk-Hazard Model provides a comprehensive framework for managing flood risk through its three core components: hazard, exposure, and vulnerability. "Hazard" refers to the probability of a flood, influenced by factors such as climate change, topography, rainfall patterns, urbanization, and land use changes [13–15]. Climate change, for instance, has exacerbated extreme weather events like heavy rainfall, increasing the likelihood of flooding. Structural measures such as levees, dams, and enhanced drainage systems are commonly used to manage hazards, but they often face criticism due to high costs, environmental impact, and limited efficacy in extreme flood events [16,17].

The second component, exposure focuses on identifying populations and assets at risk of flooding. Factors like population density, land use, and urbanization are key in determining exposure levels [18,19]. Urbanization has heightened exposure by concentrating people and infrastructure in flood-prone areas. Effective exposure management involves limiting development in high-risk zones and adapting building designs to withstand potential floodwaters. Early warning systems also play a critical role in mitigating flood risk by facilitating timely evacuations [20–22]. However, the effectiveness of such systems relies on accurate forecasting and sufficient community preparedness, which are often lacking in less developed regions.

The final component, vulnerability, refers to a community's capacity to withstand flood impacts, influenced by socioeconomic factors such as poverty, infrastructure quality, and resource availability [8], [23]. Communities with fewer resources typically exhibit higher vulnerability due to limited preparedness and mitigation capabilities. Addressing vulnerability requires a multifaceted approach that includes upgrading infrastructure, enforcing resilient building standards, and implementing flood education programs [24-26]. The risk-hazard model, encapsulated by the equation (1).

$$\text{Risk} = \text{Hazard} \times \text{Vulnerability} \tag{1}$$

Effective flood risk management requires addressing these interconnected factors to reduce flood risk and enhance community resilience. However, successful implementation demands a nuanced understanding of local contexts and the integration of interdisciplinary approaches.

Risk Assessment Theory

A comprehensive framework for flood risk assessment must integrate multiple dimensions to address the complexity and multifaceted nature of flood hazards. Effective flood risk management requires considering hydrological, hydraulic, and socio-economic factors, collectively informing the accurate evaluation and mitigation of risks. Large-scale modelling, though valuable for estimating metrics like Expected Annual Damage (EAD) and Expected Annual Population Affected (EAPA), faces inherent challenges due to uncertainties in hydrological and hydraulic processes, as well as the characterization of exposed assets and vulnerabilities [27,28]. These uncertainties underscore the crucial need for reliable data and consistent assumptions, as inconsistencies can result in substantial deviations in risk estimates across regions.

The complexity of flood risks, particularly flash floods, is exacerbated by various factors such as rainfall, soil type, land use, and human activities [29], [30]. Utilizing geographical detectors to quantify the contribution of these factors improves the precision of risk distribution analyses, offering a more nuanced approach to targeting mitigation efforts. However, the dynamic interplay of these factors, particularly under the influence of climate change and urbanization, poses a challenge to accurate risk prediction. Integrating hydrodynamic models with geospatial methodologies has become essential for comprehensive flood risk assessments, enabling detailed analyses of vulnerabilities across different geographical scales and enriching our understanding of how flood risks manifest in diverse contexts [31,32].

Incorporating high-resolution data and advanced tools, such as machine learning, has significantly improved predictive capabilities [33,34]. However, data availability and consistency remain challenges, particularly in resource-limited regions. Adaptive capacity is another critical dimension in flood risk assessment, especially in urban areas. By analyzing economic, social, and geographic indicators, adaptive strategies can generate spatial distribution maps that guide targeted interventions [35]. Empirical studies suggest that adaptive indicators can reduce flood risk by up to 45% [29]. However, the lag between urban planning and policymaking, compounded by rapid urbanization and climate change, limits the implementation of these strategies. This gap highlights the pressing need for forward-looking policy frameworks that incorporate adaptive capacities into urban development.

Projects Lifecycle Theory

Project lifecycle theory, developed by [36–38], offers a comprehensive framework for managing construction projects by outlining key stages critical to project success. [36] Expand the traditional five-stage lifecycle into eight distinct phases, emphasizing the importance of risk management as an ongoing process throughout the project. This extension reflects the complexity and dynamic nature of construction projects, underscoring the need for a proactive and holistic approach to risk mitigation. [37] complements this by providing a prescriptive methodology for navigating the project lifecycle, focusing on meticulous planning and execution. However, while this structured approach offers clarity, it may lack the flexibility to handle unpredictable challenges, particularly in large-scale construction projects. [38] contribute by introducing a lifecycle function model tailored to construction projects, facilitating real-time decision-making through integrated management information systems. Despite its advantages, the practical application of such systems is often hindered by technological and operational barriers, especially in complex environments where user adoption and system integration pose significant challenges.

The strength of project lifecycle theory lies in its structured approach, which systematically addresses the stages of initiation, planning, execution, control, and closure. Each stage requires specific competencies from project managers, such as defining objectives, managing stakeholders, and executing plans precisely. However, the effectiveness of the theory depends on its adaptability to the unique context of each project. Strict adherence to the model without considering project-specific risks, external factors, and evolving challenges can lead to inefficiencies and even project failure. This is especially relevant in flood risk mitigation projects, where delays or oversights can have a severe impact on vulnerable communities [39-41]. Thus, while Project Lifecycle Theory provides a valuable framework, its successful application requires a flexible approach that allows for continuous adjustment and responsive decision-making throughout the project lifecycle.

Risk Management Theory

Risk management theory provides a critical framework for systematically identifying, analyzing, and addressing risks throughout a project's lifecycle. This framework is essential in various industries, including software development, construction, and international research collaborations, as it helps mitigate potential risks that could adversely affect project outcomes. As outlined by [36], [42,43], the theory rests on six key principles: risk identification, assessment, prioritization, mitigation, monitoring, and communication. These principles form a structured approach that allows project managers to anticipate and manage risks, thereby increasing the likelihood of project success. However, the practical application often faces challenges. Risk identification is essential but complicated by the unpredictable emergence of new risks, particularly in complex and dynamic environments [44]. Assessing and prioritizing risks requires both qualitative and quantitative methods, yet these processes are frequently hindered by inconsistent data quality and availability. The mitigation phase, central to the theory, demands strategies that are feasible and adaptable to changing conditions a requirement that is often difficult to meet in practice [45]. Continuous monitoring ensures the effectiveness of mitigation strategies, but it requires sustained resources, which can be a limiting factor in resource-constrained projects [46]. Communication, crucial for aligning stakeholders and coordinating actions, is another area where the practical application of the theory can falter, potentially leading to mismanagement and miscommunication.

In Malaysia's flood risk management context, risk management theory offers a comprehensive framework for incorporating proactive risk identification and mitigation into development projects. This approach is especially important

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in flood-prone regions, where infrastructure resilience is critical. Applying these principles can significantly reduce the risks associated with flooding, protecting vulnerable communities and enhancing project sustainability [45,46]. However, successful implementation requires careful adaptation to the region's specific geographical and socio-cultural contexts, as well as strong leadership to navigate unforeseen challenges. Integrating risk management theory with project lifecycle theory could provide a more holistic approach, ensuring that development projects are structurally sound and resilient against evolving risks.

Synthesis of Themes

The four emergent themes - Risk-Hazard Model, Risk Assessment Theory, Project Lifecycle Theory, and Risk Management Theory - collectively form the foundation of the proposed conceptual framework for integrating Flood Risk Management (FRM) into development projects. Each theme contributes a distinct but complementary perspective to understanding and mitigating flood risk throughout the project lifecycle.

The Risk-Hazard Model establishes the starting point by identifying the core components- risk, hazard, exposure, and vulnerability- that define the context for subsequent assessment. Building on this, Risk Assessment Theory provides the analytical tools and quantitative methods to evaluate the likelihood and potential consequences of flooding. Together, these two themes define the problem space of FRM within development settings.

Project Lifecycle Theory introduces the process dimension, ensuring that FRM is embedded across all project phases from initiation and design to construction, operation, and maintenance rather than being confined to the early planning stage. Finally, Risk Management Theory operationalizes the integration by translating assessment outcomes into concrete decision-making steps, including risk prioritization, mitigation, communication, and continuous monitoring.

When combined, these four themes create a cyclical and adaptive framework that links scientific risk understanding with project management practice. The framework emphasizes feedback loops between assessment and action, enabling decision-makers to update risk strategies as project conditions evolve. This synthesis not only bridges theoretical constructs from multiple disciplines but also provides a practical, process-oriented foundation for embedding flood resilience into urban development projects.

Discussion

Integrating the risk-hazard model, risk assessment theory, project lifecycle theory, and risk management theory into a single framework provides a comprehensive basis for embedding flood risk management (FRM) into development projects. The proposed framework moves beyond descriptive models by linking risk identification, assessment, mitigation, and monitoring to distinct phases of project lifecycles. This synthesis ensures that risk management becomes an ongoing process rather than an isolated pre-construction activity, aligning with calls in the literature for adaptive, lifecycle-oriented approaches [2,4,41].

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Compared with previous models such as ISO 31000, the Sendai Framework for Disaster Risk Reduction, and adaptive pathways planning, the present framework offers clearer operational guidance at the project level. ISO 31000 emphasizes risk governance but provides limited direction on applying these principles within specific development stages. The Sendai Framework, while comprehensive in scope, focuses primarily on national policy instruments rather than project-level integration. Adaptive pathway models [6] highlight flexibility and long-term adjustment but often lack the procedural structure required for construction and development management. The proposed framework complements these approaches by embedding adaptive decision-making within project lifecycles, thereby bridging policy intentions and on-site implementation.

For policymakers, the framework supports the design of regulatory mechanisms that institutionalize FRM across all project phases. By integrating risk identification, assessment, and mitigation into approval processes, authorities can reduce vulnerability to climate-related hazards. Governments can also enhance compliance through financial incentives such as tax relief or resilience-linked grants. For urban planners, the framework offers practical tools for incorporating flood risk considerations into spatial and zoning plans, enabling the identification of high-risk zones and the adoption of adaptive land-use regulations. This aligns with findings by Sayers et al. [4] and Mustafa et al. [27], who emphasize spatial integration as a foundation for flood-resilient urban development. For developers, the framework provides a structured process for risk-informed project planning, minimizing cost overruns, construction delays, and exposure to environmental hazards.

Figure 2 illustrates this process-oriented framework, which begins with the evaluation of exposure and vulnerability and extends through risk assessment, mitigation, and monitoring. Unlike static Environmental Impact Assessment (EIA) models, which often treat risk management as a precondition for project approval, the proposed framework embeds risk assessment and mitigation as cyclical, adaptive components of project execution and maintenance. The iterative feedback loops encourage continuous learning and adjustment, consistent with the adaptive management principles proposed by Rehman et al. [2] and Shah et al. [40].

Despite these advantages, implementing the framework presents several challenges. Regulatory barriers remain substantial, as most planning laws are not designed to mandate dynamic or lifecycle-based FRM. Financial constraints also limit the adoption of advanced assessment tools, especially in developing economies. These observations are consistent with those of Nasiri et al. [25] and Rosmadi et al. [18], who note that institutional inertia and cost constraints are persistent obstacles to mainstreaming resilience into development. Furthermore, stakeholder resistance may occur because the framework demands a shift from traditional, compartmentalized management toward collaborative governance. Overcoming such challenges will require institutional reforms, interdisciplinary coordination, and capacity-building initiatives.

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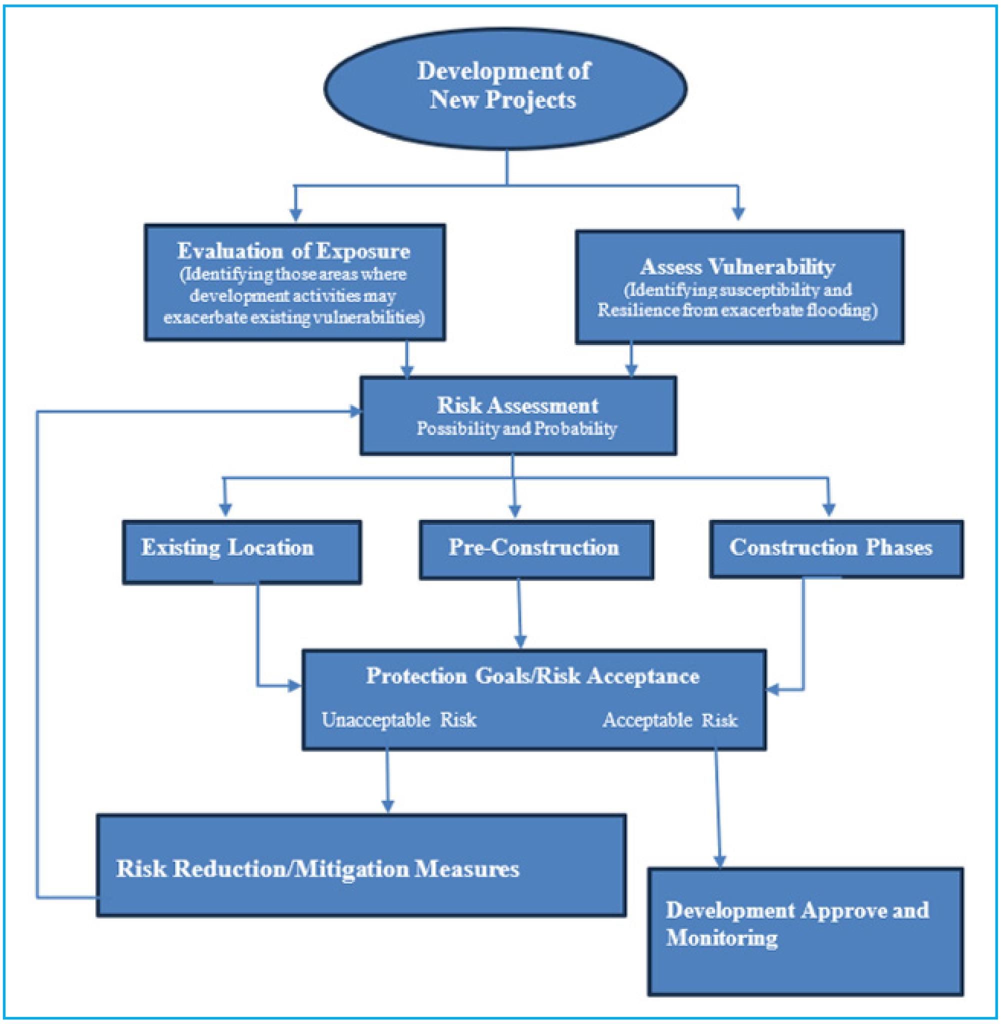

Figure 2. Proposed conceptual framework for operational flood risk assessment and risk management for development projects

The discussion also acknowledges key limitations of this study. The framework was primarily conceptualized and validated using literature focused on flood-prone regions, which may constrain its applicability to other hazard contexts such as droughts or heat risks. The framework also assumes the availability of reliable spatial and hydrological data, which may not exist in all regions. Future research should therefore include empirical validation through case studies and pilot testing in diverse geographical settings to assess adaptability, data needs, and cost-effectiveness. Comparative evaluations across different environmental hazards would further refine its versatility.

In summary, the proposed framework contributes to the evolving discourse on resilient urban development by offering an integrative, operational model that connects theory and practice. By uniting the risk-hazard, assessment, lifecycle, and management dimensions, it provides a structured pathway for implementing FRM throughout project lifecycles. While challenges remain particularly in regulation, finance, and institutional coordination, the framework advances beyond traditional models by promoting adaptive, continuous, and stakeholder-centered risk management as a core principle of sustainable development.

CONCLUSIONS

The proposed conceptual framework integrates the risk-hazard model, risk assessment theory, project lifecycle theory, and risk management theory, offering a comprehensive approach to embedding flood risk management (FRM) into development projects. Each component plays a crucial role: the risk-hazard model enables the precise identification and analysis of hazards, exposure, and vulnerability; risk assessment theory provides a structured methodology for evaluating and prioritizing risks; project lifecycle theory ensures that risk management is sustained throughout the entire project lifecycle; and risk management theory facilitates ongoing monitoring, mitigation, and communication of risks. Together, these elements significantly enhance the integration of FRM into development planning, contributing to more sustainable and resilient urban growth.

Future research should explore the application of this framework across various geographic regions to assess its adaptability and effectiveness in diverse environmental and socio-economic contexts. Developing practical tools such as decision-support systems and software platforms will be essential to simplify and scale the framework's implementation, especially in regions with limited technical capacity. Additionally, innovative financing mechanisms such as public-private partnerships and new insurance models could help overcome the financial barriers to comprehensive FRM in development projects.

Integrating FRM into development planning is critical to ensuring that urban growth is sustainable and resilient to environmental challenges. The proposed framework provides a structured, lifecycle-oriented approach to managing flood risks and safeguarding communities, infrastructure, and investments. As urbanization accelerates, particularly in flood-prone areas, this framework becomes essential for promoting economically viable, environmentally sustainable, and socially equitable urban development. Further refinement and widespread implementation of this framework will be key to advancing global efforts toward resilient urban growth.

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Conflicts of Interest

The authors declare no conflicts of interest, whether financial or non-financial, that could have influenced the work reported in this paper.

Author Contributions

Mohammad Syamsyul Hairi Saad: conceptualization, methodology, formal analysis, writing – original draft preparation. **Mohd Idris Ali:** supervision, validation, writing – reviewing and editing. **Putri Zulaiha Razi:** data curation, investigation, visualization. **Noram Irwan Ramli:** resources, project administration, writing – reviewing and editing. **Ramadhansyah Putra Jaya:** conceptualization, methodology.

Data Availability Statement

The data used to support the findings of this study are included within the article.

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