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RESEARCH ARTICLE

Strategic Identification of Flash Flood Risks in Malaysian Construction: Integrating Stakeholder Perspectives for Enhanced Resilience in Pre-Construction and Construction Phases

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ABSTRACT - The Malaysian construction industry faces escalating challenges from flash floods, exacerbated by rapid urbanization and climate change. While geographic and infrastructural vulnerabilities are well-researched, a critical gap exists in understanding how construction-phase activities contribute to flood risks. This study addresses this gap by systematically identifying flash flood risks associated with the pre-construction and construction phases, offering industry professionals and policymakers actionable insights. Through semi-structured interviews with 29 key stakeholders, including project managers, engineers, and public authorities, this study applies thematic analysis to uncover three primary risk categories: (1) location risks, including inadequate stormwater management and topographic challenges, (2) pre-construction risks, such as project scale, site location, and offsite impacts, and (3) construction-phase risks, particularly poor scheduling, and failure to implement best management practices. The findings highlight that insufficient planning and mitigation during construction significantly heighten flood vulnerabilities, yet these factors are often overlooked in current practice. To address these challenges, this research proposes a comprehensive framework for integrating flood risk management into construction project planning and execution. Key recommendations include using sustainable construction techniques, such as permeable surfaces, bio-retention ponds, detention ponds, silt fences, and green infrastructure. For policymakers, the study calls for updated regulatory guidelines to enforce stricter flood resilience measures in construction projects. Through targeted solutions for industry experts and policymakers, this research strengthens Malaysia's construction industry, enabling safer, more sustainable growth in flood-prone areas.

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1. INTRODUCTION

Flash floods are a major global hazard characterized by their sudden onset, rapid rise in water levels, and severe consequences for human life, property, and infrastructure. Several factors, including intense convective rainfall, sudden releases from natural blockages, glacial lake outbursts, and structural failures of dams and embankments, can trigger these events [1]. Climate change, urban expansion, and inadequate land management have significantly exacerbated the frequency and severity of flash floods in many regions [2]. For instance, rapid urbanization and industrial expansion into floodplains have heightened Egypt's vulnerability to flash floods, necessitating comprehensive risk management strategies incorporating hydrological models and GIS for mitigation [3]. Similarly, Romania's Valea Rea catchment area, prone to slope flash floods, underscores the need for spatial analysis and risk assessment models to predict and manage these events in built-up areas [4]. Despite advances in hydrology, meteorology, and engineering, real-time flash flood forecasting remains a significant challenge, highlighting the importance of community-based participatory approaches to early warning systems and risk reduction [5]. Addressing the multifaceted challenges of flash floods requires an integrated approach that enhances risk assessment and management practices.

The construction industry is particularly vulnerable to flash floods. Unfinished structures, open excavation sites, and the absence of permanent drainage systems during early construction stages intensify this risk. Flash floods can cause project delays, cost overruns, and safety hazards. For example, waterlogged construction sites may halt work for extended periods, and damaged materials may require replacement, while the structural integrity of partially completed buildings can be compromised. Additionally, construction workers face serious safety risks, including drowning, electrocution, and injuries from debris [6], [7]. The rapid onset of flash floods, driven by factors such as intense rainfall, topography, and land use/land cover (LULC), results in significant financial losses and infrastructure destruction, particularly in urban areas where impermeable surfaces exacerbate runoff [8]. In highly urbanized regions, developing river valleys and constructing embankments may impede natural water flow, leading to elevated flood wave levels and intensifying their destructive impact on buildings and structures [9]. Additionally, flash floods can disrupt sewer systems, undermining transport infrastructure, especially in areas with complex underground water patterns, thereby complicating construction activities and urban sustainability. Therefore, a comprehensive and adaptive approach is essential to ensure the resilience

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and sustainability of infrastructure in flood-prone areas. However, many regions lack such strategies, hindering effective flood risk management in the construction sector.

In Malaysia, current flood risk management strategies face several challenges that limit their effectiveness in mitigating the impacts of flash floods. Although some progress has been made, critical gaps remain. Flash floods, often caused by short-term heavy precipitation worsened by climate change, pose severe threats to densely populated urban areas such as Kuala Lumpur and Kajang, leading to substantial economic losses [10–12]. For example, in Kajang City, the estimated average loss per shop due to flash floods in 2014 was RM4,510.07, emphasizing the financial strain on local businesses [10]. Vulnerable populations, especially the urban poor in flood-prone areas, demonstrate resilience by prioritizing safety, health, and food supply, but they remain highly susceptible to the recurring effects of flash floods [13]. Malaysia lacks a robust legislative framework tailored to flood control, relying instead on general disaster management directives that do not sufficiently engage citizens or address flood-specific needs [14]. However, innovative infrastructure solutions like Kuala Lumpur's SMART tunnel, which serves as both a motorway and floodwater channel, have successfully mitigated flood impacts. Such projects underscore the need for similar solutions to protect urban areas and support sustainable development [12, 15]. Furthermore, advanced predictive modelling techniques, such as the Ensemble FR-AHP method, can help local authorities plan land use and enhance drainage systems, thus reducing flash flood susceptibility [16]. Integrating these strategies into a comprehensive flood risk reduction framework is essential to safeguard economic stability and promote resilient urban development in Malaysia.

The Malaysian construction industry faces several unique challenges in managing flash flood risks, which must be addressed to ensure long-term sustainability. The absence of adequate infrastructure, such as proper drainage systems capable of handling heavy rainfall, contributes to water accumulation and flooding, increasing the vulnerability of construction projects. Moreover, outdated regulations and guidelines often fail to account for current or future flood risks, leaving the industry unprepared for evolving threats. Financial constraints, particularly for small and medium-sized construction firms, further complicate these challenges, as many lack the resources to implement advanced flood mitigation measures. This is compounded by a skills gap among construction professionals, who may lack the technical expertise to apply advanced flood risk management techniques effectively. Overcoming these challenges will require a coordinated effort to update regulatory frameworks, enhance infrastructure, and improve financial and technical capacity to manage flash flood risks better.

Given flash floods' increasing frequency and severity, Malaysia's construction industry urgently needs a comprehensive risk management approach. Such an approach should incorporate diverse stakeholder perspectives, including government agencies, developers, engineers, contractors, and local communities. Stakeholder engagement is crucial for developing sustainable and effective risk management strategies that address the unique challenges of the construction sector in the context of flash floods. By incorporating these diverse viewpoints, the construction industry can enhance its resilience to flash floods, ensuring project safety, efficiency, and sustainability [17, 18]. Regularly monitoring and maintaining drainage systems and flood-prone areas are also essential for reducing flood risks. Continuous surveillance helps identify emerging vulnerabilities, allowing timely interventions to prevent minor issues from escalating into major flood events. Proactive maintenance ensures that infrastructure remains resilient and functional against flood risks. By integrating comprehensive risk assessments, sustainable practices, and regular maintenance, the Malaysian construction industry can better manage flash flood risks, thereby enhancing the safety and sustainability of infrastructure development.

One of the key challenges facing the Malaysian construction industry is the inadequacy of current flood risk assessment methods. Traditional approaches, which rely heavily on historical data and probabilistic models, often fail to accurately predict flash floods' impact, particularly under changing climatic conditions [90,91]. These methods do not account for the increased variability and intensity of rainfall patterns associated with climate change, leading to under-preparedness and ineffective risk management [19]. Additionally, many construction firms, particularly small and medium-sized enterprises (SMEs), lack the financial and technical resources to implement comprehensive flood mitigation measures. Resource constraints limit their ability to invest in advanced technologies and infrastructure improvements that could reduce flood risks. Moreover, access to specialized knowledge and expertise needed to design and implement effective flood risk management strategies is often lacking [20]. The regulatory framework for flood risk management in Malaysia remains fragmented. Existing regulations do not adequately address the specific needs and challenges posed by flash floods in the construction industry [91, 90]. This highlights the urgent need for updated guidelines that incorporate the latest scientific insights and best practices. Moreover, enforcement of these regulations is inconsistent, leading to gaps in compliance and implementation [21]. Inconsistencies in regulatory enforcement expose the industry to significant risks, underscoring the need for a cohesive and robust regulatory framework that can address evolving flash flood challenges. Coordination among local authorities, urban planners, developers, and construction firms is crucial for effective flood risk management [12, 21, 22]. Strengthening the capacity of these authorities is essential to improve flood preparedness and response [3, 23].

Another pressing issue is the lack of public awareness regarding flood risks and preparedness measures. Educating communities on flood risk reduction can significantly mitigate damage during flood events. Community engagement is a crucial component of effective flood risk management [12]. Additionally, local authorities often lack the power to implement flood management plans fully. Strengthening the role of local authorities and improving enforcement capabilities are critical for effective risk mitigation. Without proper enforcement, compliance with flood management regulations remains weak, exacerbating flood risks [24]. Despite progress in Malaysia's flood management efforts, implementation gaps continue to result in significant losses and damages during flood events. Addressing these gaps is vital to mitigating the impact of flash floods on the construction industry and broader society. Effective flash flood risk management requires coordination among government agencies, construction firms, consultants, and local communities. However, the lack of structured mechanisms for stakeholder engagement often leads to fragmented efforts and missed opportunities for synergistic solutions. Meaningful stakeholder engagement is essential to integrate diverse perspectives into comprehensive risk management strategies [25]. Environmental degradation and poor land-use planning further exacerbate flash flood risks. Rapid urbanization has transformed natural landscapes into built environments, reducing the land's capacity to absorb rainfall and increasing runoff [26]. Insufficient attention to environmental factors during construction planning and design stages can lead to greater vulnerability to flash floods [27]. Sustainable land-use planning and environmental management are therefore critical for mitigating these risks.

The Malaysian construction industry faces several critical challenges in managing flash flood risks, including inadequate risk assessment methods, resource constraints, regulatory gaps, lack of stakeholder coordination, and poor environmental planning. These challenges often lead to project delays, increased costs, and significant safety risks for workers and nearby communities. Additionally, gaps in regulations and enforcement result in non-compliance, exposing the industry to legal and financial risks. To mitigate the impact of flash floods, a comprehensive and integrated approach is necessary one that combines improved risk assessment, adequate resource allocation, stronger regulatory frameworks, and collaborative stakeholder efforts. This study aims to identify key flash flood risks in Malaysian construction projects, analyze stakeholder perspectives, for integrating flood resilience strategies into construction planning and execution. By addressing these issues, the study provides practical recommendations to strengthen policy enforcement and sustainable construction practices, ensuring safer and more resilient development in flood-prone areas.

2. FLASH FLOOD AND RESELIENCE IN CONSTRUCTION

2.1 Flash Flood Risks in Construction

Flash floods, driven by rapid water accumulation following intense rainfall, are among the most destructive natural disasters. Climate change has exacerbated the frequency and intensity of these events, leading to more frequent extreme rainfall. Due to its exposed nature and lack of permanent structures during project phases, the construction industry is particularly vulnerable. As temperatures rise globally, the construction sector faces increasing risks, from halted operations to costly damage to infrastructure and materials [28]. This vulnerability underscores the need for enhanced flood risk management strategies. Key risks include significant delays in project timelines, financial losses, and serious safety concerns for workers. Flash floods can halt operations for weeks, waterlogging sites and damaging equipment, necessitating costly repairs. Safety risks, such as drowning, injuries from debris, and electrical hazards, further complicate recovery efforts [30]. Moreover, partially completed structures are particularly prone to damage, with floodwaters weakening foundations and causing soil erosion, leading to structural instability.

Urbanization trends have worsened flash flood risks, particularly through the conversion of natural landscapes into impervious surfaces like roads and buildings. These surfaces increase surface runoff, heightening flood risks in urban areas already lacking adequate drainage systems [31–33]. The construction sector is particularly impacted in rapidly growing cities, where poor planning and inadequate drainage exacerbate the vulnerability of construction sites to flash floods. Mitigating these risks requires integrating flood risk assessments into project planning. This includes using flood-resistant materials, constructing robust drainage systems, and implementing stormwater management solutions, such as retention basins and permeable surfaces [34, 35]. Real-time monitoring systems, capable of predicting and responding to flash floods, can also enhance preparedness [36]. These proactive measures are essential for protecting construction sites and workers from the destructive impacts of flash floods.

Global case studies, such as Hurricane Harvey's impact on Houston's construction industry and the 2018 Kerala floods, underscore the critical need for resilient construction practices [37]. In both cases, construction sites suffered significant losses due to inadequate flood mitigation measures. These events highlight the importance of incorporating flood-resistant design, better planning, and stronger regulatory frameworks to manage flash flood risks effectively [39]. The construction industry can reduce vulnerabilities and improve long-term resilience by adopting comprehensive flood risk management strategies.

2.2 Malaysia Context

Malaysia's geographical location and tropical climate make it highly susceptible to flash floods, particularly during the Southwest Monsoon (May- September) and Northeast Monsoon (November-March). These seasonal rainfalls, combined with Malaysia's complex topography of mountainous regions and river networks, frequently result in severe flash floods [40]. The heavy rainfall and storms during monsoon seasons exacerbate the country's vulnerability, posing significant risks to the construction sector, which often lacks protective infrastructure during early project phases. Rapid urbanization has further increased flash flood risks. The transformation of permeable surfaces like forests into impervious areas such as roads and buildings has reduced the land's ability to absorb rainfall, leading to higher runoff levels. Inadequate urban planning and drainage systems in cities like Kuala Lumpur, Penang, and Johor Bahru compound these risks, causing frequent disruptions due to flash floods [41, 42]. While driving urban development, construction activities can disturb natural drainage and increase soil erosion, worsening flood risks. However, the industry can potentially mitigate these risks by incorporating green infrastructure and improving drainage.

Flash floods profoundly impact construction projects, causing extensive delays, escalating costs, and creating hazardous conditions for workers. [43] and [44] reported that several major infrastructure projects in Malaysia were delayed by weeks or months due to flooding, increasing costs through damage to materials and equipment. Moreover, the Malaysian construction sector faces millions of dollars in annual losses as prolonged delays heighten labour and administrative expenses [45]. Safety risks, including electrical hazards, structural failures, and debris-related injuries, necessitate stricter safety protocols and emergency response plans to protect workers [46]. The current regulatory framework for flood risk management in Malaysia is sufficient, but more monitoring is needed to address climate change and urbanization realities. Updated regulations must incorporate modern flood resilience measures in construction standards and building codes [17]. Enforcement remains weak, with inconsistent compliance monitoring posing significant challenges. Strengthening regulatory agencies and ensuring effective enforcement are essential to improving the construction sector’s response to flood risks [47].

A comprehensive, integrated approach to urban planning and flood risk management is essential. This requires coordination across urban planning, environmental management, and construction sectors. Collaborative planning and community engagement can help incorporate flood risk reduction measures into land use strategies, ensuring sustainable solutions. By leveraging technological innovations, updating regulations, and fostering stakeholder collaboration, the Malaysian construction industry can enhance its resilience to flash floods and ensure the safety, sustainability, and efficiency of future projects [13, 48]

2.3 Resilience in Construction Projects

Resilience in construction has become a critical focus due to the increasing frequency of natural disasters, particularly in the context of climate change. Resilience refers to the ability of construction projects to withstand, adapt to, and recover from adverse events such as flash floods. This concept involves not only the physical robustness of infrastructure but also the operational capacity to maintain functionality during disruptions and the preparedness of communities involved in these projects [49, 50]. As natural disasters intensify globally, integrating resilience into construction practices is essential for sustainability and long-term project viability.

In construction, resilience is multi-dimensional: structural resilience refers to the physical strength of buildings to resist natural hazards, operational resilience involves ensuring construction processes can continue despite disruptions, and social resilience emphasizes the readiness of stakeholders and communities to adapt and recover [51–53]. Projects that embody resilience are better equipped to minimize downtime, protect workers, and reduce long-term costs by avoiding extensive repairs and replacements. Additionally, resilient construction contributes to sustainable development by promoting environmental stewardship and reducing vulnerability to climate-related risks [54]. Achieving resilience in construction involves several key strategies. Projects must be designed to withstand environmental challenges using durable materials and advanced engineering techniques [51, 55]. Site selection is crucial in mitigating risks, with planners integrating risk assessments early in the planning phase to avoid hazard-prone areas [56]. Operational continuity plans, emergency protocols, and resilient supply chains are vital to ensure construction progress even during adverse conditions. Collaboration with local communities and stakeholders enhances social resilience and ensures that diverse perspectives are integrated into risk management [57].

Technological advancements further bolster resilience. Geographic Information Systems (GIS) are instrumental in mapping flood-prone areas and informing design decisions. Building Information Modeling (BIM) can enhance stakeholder coordination and improve risk visualization [58, 59]. Green infrastructure, such as permeable pavements and green roofs, reduces runoff and mitigates flash flood impacts while preserving natural barriers like wetlands and mangroves, strengthening ecological defenses [60]. Policy alignment and regulatory reform are essential to fostering resilience in construction. National and local building codes should be updated to reflect the latest disaster risk reduction strategies, and incentive programs can encourage firms to adopt resilient practices [61]. Continuous education and training for professionals, along with public awareness campaigns, are crucial for building a culture of resilience in the construction industry and society at large [51].

3. METHODOLOGY

This study focuses on industrial practitioners in Peninsular Malaysia who have experience managing construction projects, including Project Managers, Site Engineers, Planners, Resident Engineers, Local Authorities, and Directors of Public Work Departments. Data was collected through semi-structured interviews, allowing for in-depth insights into the challenges and strategies related to flash flood risk management during the pre-construction and construction phases. By capturing diverse perspectives from key stakeholders, this study provides a comprehensive understanding of industry practices and policy gaps in mitigating flood-related risks.

The methodology of this study demonstrates significant strengths, particularly through its use of semi-structured interviews, purposeful sampling, and thematic analysis. The semi-structured interviews enable in-depth exploration of participants' experiences, allowing for the collection of rich, nuanced data that is essential in qualitative research [62].

Purposeful sampling ensures that the insights are highly relevant and credible, as they are drawn from experts with direct experience in managing construction projects. The thematic analysis further enhances the study by systematically identifying patterns and themes within the data, providing a comprehensive and well-organized interpretation of the complex issues. These methodological choices collectively contribute to the rigor and impact of the research findings. Figure 1 provides an overview of the methodology employed. The following subsections present the methods employed for collecting and analyzing the identification of flash flood risk in Malaysia and for enhancing construction resilience in the pre-construction and construction phases.

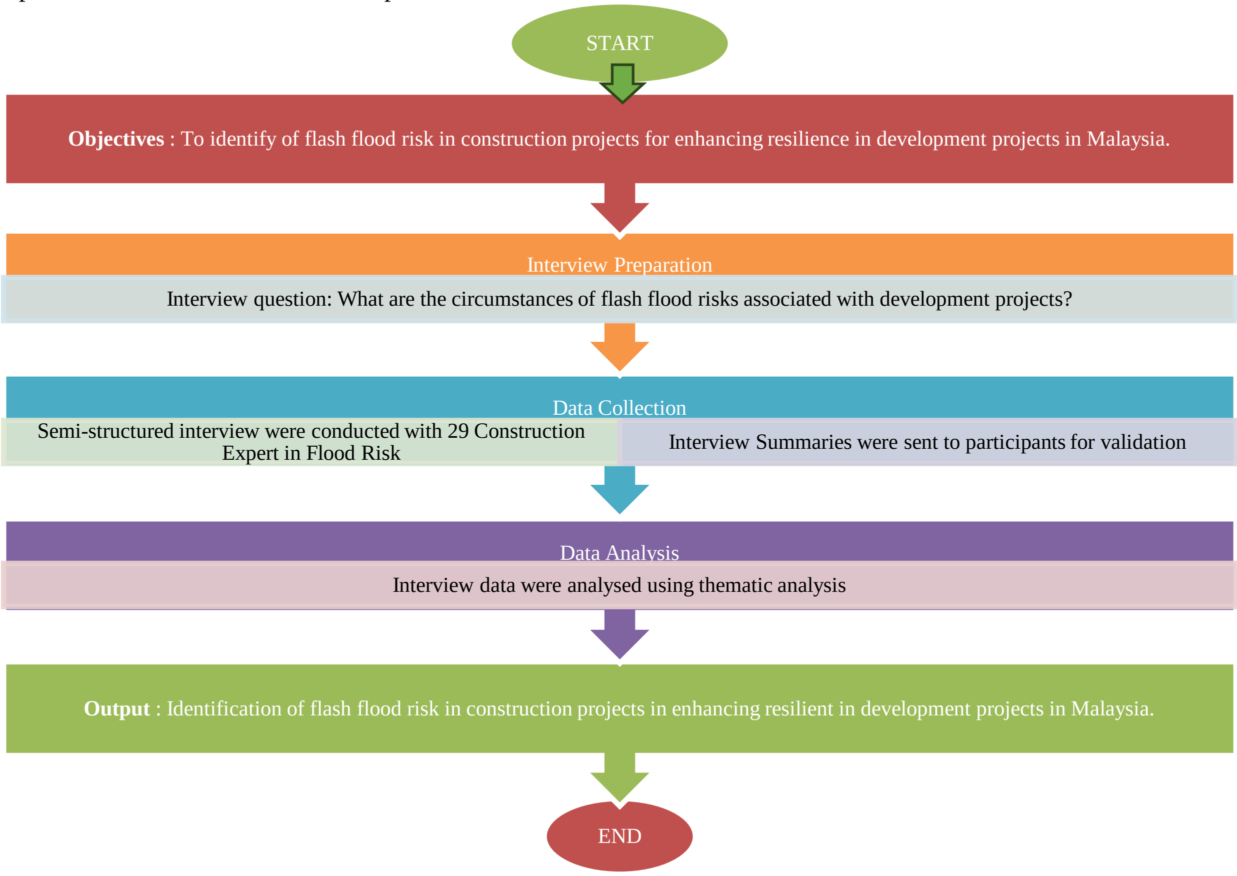

Figure 1. Overview of the research methodology

3.1 Interview Preparation

This study gathers qualitative data through semi-structured interviews with construction professionals. This method has been used to identify dynamics of human behavior in response to flooding, such as changes in risk perception and adaptive behaviors [63] and face barriers in providing flood risk advice due to regulatory issues, lack of formal guidance, and insufficient training [38]. Semi-structured interviews have been chosen as the data collection method due to their effectiveness in enabling the interviewer to clarify, understand, and explore the perspectives and experiences of the participants. Interviews serve as a valuable tool for researchers to use existing theories, facilitate the emergence of granular knowledge, and validate existing knowledge using data from the specific context being studied [64, 65].

Building upon the insights from prior literature, a targeted interview question has been carefully crafted: “What are the circumstances of flash flood risks associated with development projects?” This question acts as the cornerstone of the interview, guiding the conversation towards a comprehensive exploration of the obstacles encountered in enhancing construction resilience. An interview protocol was developed to ensure a structured and productive interview process. This protocol acts as a guiding framework, delineating the structure and objectives of the interview session [29]. The interview protocol underscores the voluntary nature of participation and the interviewees' autonomy. Additionally, it emphasizes the importance of open communication by encouraging interviewees to express any queries or reservations before commencing the interview.

3.2 Data Collection Method

The data collection process involves conducting semi-structured interviews with construction experts. Construction experts are individuals who possess hands-on experience and expertise in managing development projects within the construction industry and must possess knowledge about flood risks in development projects. By selecting construction experts as participants, the research ensures that the insights gathered stem from individuals with direct experience and specialized knowledge in construction projects. Moreover, prior research has selected construction experts as their target population (e.g., [66–68]). Open-ended questions were employed to extract the maximum information from the participants. The sampling method used was purposive, a non-random technique that does not stipulate a specific minimum or maximum number of participants. Instead, it empowers the researcher to gather data by interviewing individuals who can offer insights pertinent to the study [69, 70].

The interview process was initiated with an introduction outlining the motivations behind the interview and the topics to be addressed. Following this, the primary interview question was presented to the participants. Subsequent questions were posed based on the participants' responses. These follow-up questions aimed to confirm the correct understanding of the information provided and to attain a deeper understanding of the statements shared. In cases where a direct response or additional information was not forthcoming, the interviewer endeavored to rephrase the question and allowed the participants ample time to respond. Participants were encouraged to continue if they commenced their responses but did not complete them. Subsequently, a summary of each interview was prepared and shared with the participants for validation.

In this study, data saturation was achieved after interviewing the twenty-nine participants. Data saturation refers to the point in qualitative research where further data collection is unlikely to provide new or additional insights [71], [72]. It is a common method used to assess the sufficiency of data sample sizes when no further data points are needed and the data becomes redundant [73]. Thus, the data collected was considered saturated, indicating that additional interviews would not have contributed substantially to new information or insights. Table 1 shows the list of participants, which includes 29 construction experts.

Table 1. Participant's profile

Participant	Gender	Highest Academic Qualification	Designation	Experience in Construction (years)
P1	Female	Doctoral (Civil Engineering)	Resident Engineer	15
P2	Male	Doctoral (Civil Engineering) PE	Resident Engineer	18
P3	Female	Bachelor of Civil Engineering	Civil Engineer (DID	14
P4	Male	Bachelor of Civil Engineering	Engineer	12
P5	Female	Bachelor of Civil Engineering	Engineer PWD	9
P6	Female	Doctoral (Civil Engineering) PE	Deputy Director PWD	14
P7	Male	Bachelor of Civil Engineering	Site Engineer	9
P8	Male	Bachelor of Civil Engineering	Project Manager	14
P9	Male	Bachelor of Civil Engineering	Design Engineer	12
P10	Male	Bachelor of Urban Planning and Regional Planning	Senior Planner	20
P11	Male	Bachelor of Civil Engineering	Site Engineer	12
P12	Male	Bachelor of Architecture	Senior Architecture	20
P13	Female	Bachelor of Civil Engineering	Planning Engineer	9
P14	Male	Master of Science (Construction Project Management)	Senior Projects Manager	25
P15	Male	Bachelor of Civil Engineering (PE)	Director PWD	18
P16	Male	Bachelor of Civil Engineering	Design Engineer	8
P17	Male	Bachelor of Civil Engineering (PE)	Senior Civil Engineer	14
P18	Male	Bachelor of Civil Engineering	Project Manager	9
P19	Male	Doctoral (Civil Engineering)	Senior Civil Engineer	15
P20	Male	Bachelor of Civil Engineering (PE)	Resident Engineer	20
P21	Male	Bachelor of Civil Engineering	Resident Engineer	18
P22	Female	Bachelor of Civil Engineering (PE)	Senior Civil Engineer (PWD)	12
P23	Female	Bachelor of Civil Engineering	Planning Engineer	9
P24	Male	Bachelor of Civil Engineering (PE)	Resident Engineer	18
P25	Female	Bachelor of Civil Engineering	Civil Engineer (DID)	11
P26	Male	Bachelor of Civil Engineering	Project Manager	8
P27	Male	Bachelor of Civil Engineering (PE)	Consultant Engineer	20
P28	Female	Bachelor of Urban Planning and Regional Planning	Senior Planner	15
P29	Male	Bachelor of Architecture	Senior Architecture	12

3.3 Data Analysis

The data analysis involved conducting a thematic analysis to identify the risks posed by construction activities at different stages of construction projects. Thematic analysis was chosen as a suitable approach for making sense of qualitative data [74]. Other construction management research has also used this method to analyze qualitative data (e.g.,[75]; [21]; [76]). Thematic analysis is exploratory as it aims to discover and understand the rich complexity of the data without imposing preconceived ideas or frameworks. Theme development in thematic analysis is flexible as it can depend on the experience and expertise of the researcher to unveil underlying meanings [77]. The process of thematic analysis followed the six phases described by [74]. In the initial phase, the authors familiarized themselves with the interview data by reading and taking notes to capture initial ideas and insights. The second phase involved generating initial codes to encompass potential themes and patterns observed in the data. These codes were continuously reviewed, discussed, and modified as necessary. The authors identified themes based on the initial codes during the third phase. The process involved frequently referring to the codes and original data. The themes were thoroughly reviewed in the fourth phase to ensure comprehensive data coverage. The authors refined and defined the themes and cross-referenced them with coded extracts and the entire dataset. Additional themes that emerged were also considered at this stage. The authors described and named the themes in the fifth phase, ensuring alignment with independently coded responses. This process involved constant cross-referencing with codes and interview transcriptions to maintain consistency. Finally, in the sixth and final phase, the analysis findings were reported, presenting the identified themes for the specific risks posed by construction activities at different stages of construction projects.

4. RESULTS

4.1 Identification of Flash Flood Risks in Malaysian Construction

Table 2 and Table 3 summarize the themes and sub-themes of the identified flash flood risk in the construction sector by analyzing the interview data. This study has identified three main themes of flash flood risk in the Malaysian construction sector. The first theme is existing location risk, including geography, topography, infrastructure /existing location storage capacity, stormwater management, and land use land cover. In contrast, the second theme is pre-construction phases, including project size/type, location, development phases, offsite impact, and waterway and floodplain. Meanwhile, the third theme is construction phases, which are concise in scheduling, best management practices, and construction practices.

Table 2. Identification of flash flood risk in Malaysia's construction sector

	Themes	Subtheme
Identification of Flash Flood Risks in Malaysian Construction	Existing Location	Geography
		Topography
		Infrastructure/Existing Storage Capacity
		Stormwater Management
		Land Use Land Cover
	Pre-Construction Phases	Projects Size/Type
		Location
		Development Phases
		Offsite Impact
		Waterway and Floodplain
	Construction Phases	Scheduling
		Best Management Practices
		Construction Practice

Table 3. Interview-derived themes and subthemes

Code	Subthemes	Themes	Participants
FR1	Geography	EL	P1, P6, P11, P15, P24, P27, P28
FR2	Topography	EL	P6, P11, P5, P4, P7, P8
FR3	Infrastructure/Existing Storage Capacity	EL	P1, P3, P7, P6, P17, P18
FR4	Stormwater Management	EL	P4, P12, P14, P23, P21, P17, P29
FR5	Land Use Land Cover	EL	P7, P9, P18, P10, P22, P25
FR6	Project Size/Type	PCP	P2, P1, P4, P7
FR7	Location	PCP	P9, P5, P3, P9, P21
FR8	Development Phases	PCP	P8, P12, P18, P19
FR9	Offsite Impact	PCP	P2, P14, P22, P14
FR10	Waterway and Floodplain	PCP	P13, P23, P10
FR11	Scheduling	CP	P1, P19, P21, P25, P27
FR12	Best Management Practices	CP	P1, P16, P17, P25
FR13	Construction Practice	CP	P20, P26, P29

*Notes: EL=Existing Location; PCP = Pre-Construction Phases; CP = Construction Phases

4.2 Flood Risk Discovery in Pre-Construction and Construction Phases

Table 4 presents a comprehensive overview of the key factors contributing to the eight identified flood risk factors during development projects' pre-construction and construction phases. These factors, which significantly impact the construction project cycle, are classified as follows: in the pre-construction phase, they include project size/type, site location, development stages, offsite impacts, and waterway and floodplain considerations. In the construction phase, the identified factors encompass scheduling, best management practices (BMPs), and construction methodologies. Each of these factors represents distinct challenges to effectively executing construction projects. The subsequent subsections provide an in-depth analysis of these flood risk factors, focusing on their specific impacts on project execution and implementation in the construction industry. This structured analysis highlights the complexities inherent in both pre-construction and construction phases and offers insights into potential strategies for mitigating these risks and enhancing project outcomes.

Table 4. Supporting statements

Subthemes	Supporting statements
Project Size/Type	"Large infrastructure projects such as highways significantly impact stormwater runoff, increasing flood risks." (P1)
	"High-rise buildings create impervious surfaces, contributing to urban flooding." (P4)
	"Residential developments lack sufficient stormwater controls in flood-prone areas, worsening flood risks." (P7)
Location	"Construction near rivers worsens flooding by disrupting natural water flow." (P5)
	"In coastal areas like Penang, the combination of construction activities and heavy rainfall worsens flooding." (P3)
	"Urban projects near drainage systems contribute to flash floods due to increased runoff." (P9)
Development Phases	"During the design phase, it's crucial to integrate flood risk assessments early on. Many developers overlook this, which leads to serious problems later" (P8)
	"Feasibility studies should always consider local flood history to avoid future issues with runoff and drainage." (P12)
	"Each construction phase has unique flood risks that need careful management." (P18)
Offsite Impact	"Construction projects significantly impact neighbouring communities, especially when proper drainage systems aren't considered. We've seen flash floods even in areas that were historically flood-free." (P2)
	"Projects near urban centres overload the local drainage systems, impacting surrounding areas." (P14)
	"Flash floods from large construction projects often impact neighbouring communities." (P22)
Waterway and Floodplain	"Construction near floodplains disrupts natural water absorption, causing severe floods." (P13)
	"Encroaching on floodplains heightens flood risks for the surrounding area." (P23)
	"Large projects near rivers reduce the floodplain's ability to manage heavy rainfall." (P10)
Scheduling	"Timing construction activities during dry seasons can mitigate flood risks." (P19)
	"Scheduling construction during the monsoon season was a mistake. We had severe runoff and soil erosion issues that could have been avoided." (P21)
	"Proper scheduling can mitigate flood risks, but most developers don't consider the local rainy seasons." (P25)
Best Management Practices	"Silt fences and temporary drainage systems have been useful in minimizing runoff, but they are not always used." (P16)
	"Implementing BMPs like detention ponds and permeable pavements during the planning phase could have prevented a lot of the flooding issues we faced." (P17)
	"Retention ponds help manage stormwater and reduce flash flood risks on site." (P25)
Construction Practices	"Preserving natural vegetation during construction has proven effective in reducing runoff and preventing flash floods." (P20)
	"Integrating permeable surfaces into the construction design helps mitigate flash floods." (P29)
	"Low-impact development techniques reduce the impact of construction on flood risks." (P26)

4.2.1 Projects size/type

Large-scale construction projects, such as high-rise buildings or infrastructure developments (e.g., highways, railways), significantly impact stormwater runoff. These projects often involve extensive land clearing, alterations to topography, and the creation of vast impervious surfaces, all of which exacerbate the risk of flash flooding. Impervious surfaces hinder water infiltration into the soil, increasing runoff volumes that can overwhelm local drainage systems. For instance, the construction of highways in Malaysia has been shown to exacerbate downstream flooding by altering natural water flows and increasing runoff velocity. This highlights the critical need to integrate advanced stormwater management systems, such as retention ponds and permeable pavements, into the planning stages of such projects to mitigate flood risks.

Residential developments and industrial parks similarly pose substantial flood risks, particularly in flood-prone areas or lacking adequate stormwater controls. The development of residential complexes often entails significant alterations to the natural landscape, including vegetation removal, which would otherwise serve to absorb rainfall. Inadequate green spaces or stormwater infrastructure provision in such projects can intensify urban flooding, as observed in many rapidly urbanizing Southeast Asian cities [78]. Likewise, industrial parks characterized by large warehouses and expansive parking lots substantially increase the impervious surface area, contributing to on-site and off-site flood risks.

The cumulative impact of these developments on regional hydrology is profound. Large-scale projects can disrupt watershed dynamics, increasing the risk of flash floods in upstream and downstream areas. To mitigate these adverse effects, developers must comply with local environmental regulations and integrate sustainable practices into their designs. The long-term flood risks associated with large construction projects can be significantly reduced by incorporating strategies such as rainwater harvesting systems, green roofs, and bio-retention swales. While large-scale construction is often a vital driver of economic growth, balancing development with responsible water management practices is crucial to avoid exacerbating flood risks in surrounding communities.

4.2.2 Location

Construction activities in or near natural floodplains, rivers, or coastal areas significantly increase the risk of flash floods. These areas are inherently prone to flooding during heavy rainfall events, and construction can exacerbate these risks by altering the natural water flow. For instance, floodplain developments often reduce the region’s capacity to absorb excess rainwater, displacing floodwaters and increasing flood depths and velocities in nearby areas. In Malaysia, where tropical storms and monsoons are frequent, the problem is especially acute. Coastal areas, such as Johor and Penang, are particularly vulnerable due to their low elevation and proximity to the sea. In these regions, tidal influences combined with heavy rainfall can overwhelm drainage systems, especially when construction activities reduce the landscape’s natural permeability, contributing to flash floods, coastal erosion, and sedimentation issues [79].

Riverside construction also poses substantial flood risks. By altering floodplains and reducing rivers’ ability to naturally accommodate and disperse floodwaters, construction projects near rivers often intensify flooding during peak storm events. Flash floods in these areas are sudden and highly intense, threatening construction projects and surrounding communities. Effective planning must consider the river’s flood history, local water table levels, and the capacity of nearby drainage systems to handle sudden increases in water flow [80]. Similarly, the proximity of construction sites to major urban drainage systems must be carefully evaluated. Urban drainage networks are often overburdened in cities like Kuala Lumpur due to rapid urbanization and aging infrastructure. Runoff from construction sites can exacerbate flooding, especially in older cities where drainage systems were not designed to handle large-scale urban development. Poorly planned developments in areas like the Klang Valley have frequently led to localized flash floods, disrupting construction activities and urban infrastructure [81].

Beyond the immediate risks, construction in flood-prone areas has long-term implications for the built environment and local ecosystems. Disrupting wetlands or mangrove ecosystems, for example, reduces natural flood barriers, leaving coastal regions more vulnerable to storm surges and rising sea levels. Therefore, construction in sensitive locations requires comprehensive flood mitigation strategies, such as implementing flood detention basins, green infrastructure, and elevated construction designs that minimize disruption to natural hydrological cycles. Balancing development needs with responsible water management is crucial to reduce long-term flood risks and protect surrounding communities

4.2.3 Development phases

The risk of flash floods varies significantly across the different phases of development, requiring the integration of strategic planning, engineering, and environmental considerations. From the initial feasibility study to the design and documentation phases, flood risk mitigation plays a critical role in ensuring the resilience of development projects, particularly in flood-prone regions like Malaysia. Comprehensive flood risk assessments are essential during the feasibility study, including analyzing historical flood data and climate change projections. Environmental Impact Assessments (EIA), mandated by regulations such as Malaysia’s Environmental Quality Act 1974, further evaluate how a proposed development might disrupt hydrological systems. These early assessments are especially vital in regions prone to monsoonal rains and rapid urbanization, where poorly planned projects can exacerbate flash flood risks.

The zoning and land-use regulation phase is equally important in aligning development projects with flood management strategies. In Malaysia, zoning laws influenced by the National Physical Plan and State Structure Plans guide the sustainable use of land, especially in floodplains or areas with inadequate drainage infrastructure. Zoning approvals often come with conditions requiring the implementation of stormwater management systems and other flood mitigation measures. These decisions are not merely technical; they involve political and community considerations, ensuring that changes to land use, such as converting natural floodplains into industrial areas, do not increase flood risks. Poor zoning decisions that result in increased impervious surfaces can disrupt natural water flows and contribute to more frequent and severe flooding downstream [82].

After zoning approvals, the design stage is where flood resilience strategies are integrated into the project's blueprint. Adhering to standards like Malaysia's Urban Stormwater Management Manual (MASMA), developers must ensure that their designs incorporate flood control measures, including permeable surfaces, bio-retention systems, and detention ponds, which help manage surface runoff and preserve natural water flows. Design proposals submitted to regulatory bodies such as the Department of Drainage and Irrigation are reviewed to ensure that flood mitigation strategies are robust and in line with local guidelines. At this stage, collaboration between architects, hydrologists, and engineers is essential to optimize flood-resilient designs, protect natural water systems, and reduce the long-term risk of flash floods.

4.2.4 Offsite impact

Flash floods from construction activities often extend beyond the site, impacting surrounding communities and ecosystems. Projects that alter natural drainage patterns or increase runoff volumes, particularly those with impervious surfaces like roads and parking lots, can overwhelm local watercourses and drainage systems [83]. This offsite impact is especially problematic in urbanized areas with strained stormwater infrastructure. For example, rapid urban development in Kuala Lumpur without adequate stormwater management has contributed to recurrent flash floods, damaging local infrastructure and affecting nearby communities. Similarly, upstream construction activities that involve land clearing or earthworks can lead to significant downstream flooding, as disturbed landscapes lose their ability to absorb water, resulting in rapid runoff and sudden flash floods [84].

In coastal areas, the offsite impact of construction can be even more severe. Natural flood buffers such as wetlands and mangroves are crucial for absorbing floodwaters and mitigating the effects of storm surges. However, when these ecosystems are degraded or removed for development, coastal communities become more vulnerable to both inland and coastal flooding during extreme weather events. In Penang, for example, large-scale coastal developments have been linked to increased flood risks due to the destruction of natural floodplains and insufficient stormwater management systems. Developers must account for the broader hydrological context and use tools such as hydrological modelling and geospatial analysis to predict the potential offsite impact of construction activities [8, 85].

Community involvement is also key in addressing the offsite flood risks associated with construction. Residents, especially in downstream or vulnerable areas, should be engaged early in planning to provide insights into historical flood patterns and ensure adequate mitigation measures. In Kelantan, Malaysia, for instance, communities have worked with local authorities and developers to improve flood defense systems and integrate them with regional stormwater management plans. By incorporating technical assessments and community input, developers can minimize offsite impacts, protect surrounding ecosystems, and ensure the long-term resilience of construction projects and nearby areas.

4.2.5 Waterway and floodplain

Construction near waterways and floodplains is inherently risky due to the potential for sudden water level rises and flash floods. These natural systems act as buffers during heavy rainfall, dispersing excess water and reducing flood intensity downstream. However, development disrupts this function, increasing the likelihood of flooding at the site and in surrounding areas. In Malaysia, where rapid urban expansion frequently encroaches on floodplains, this disruption has exacerbated flood risks in regions like the Klang Valley, resulting in more frequent and severe flood events [86, 87]. When construction compromises these natural flood control systems, local communities and ecosystems bear the brunt of these heightened flood risks.

Adherence to the principles outlined in the Malaysian Urban Stormwater Management Manual (MASMA) is critical to mitigate such risks. MASMA promotes sustainable stormwater management practices, particularly in sensitive areas like floodplains. One of its core guidelines is ensuring that developments do not obstruct the natural flow of water, which is crucial for preventing downstream flooding. Techniques such as detention ponds, bio-retention systems, and constructed wetlands help manage runoff by gradually allowing water to infiltrate the ground rather than overwhelming rivers and streams [88]. MASMA also emphasizes preserving natural waterways and discourages using artificial channels, which can accelerate water flow and lead to flash floods downstream.

Moreover, the cumulative impact of multiple developments near floodplains poses a significant challenge. While individual projects may seem manageable, their collective effect can severely compromise the floodplain's capacity to manage water. This issue is particularly pronounced in rapidly urbanizing areas of Malaysia, were construction along rivers and floodplains compounds flood risks for downstream communities. Therefore, responsible planning and adopting MASMA are essential to ensure that development in flood-prone areas balances economic growth with effective flood risk management.

4.2.6 Scheduling

Proper scheduling is critical to flood risk mitigation in construction projects, particularly in regions with distinct rainy seasons, such as Malaysia. Timing construction activities, especially land clearing, and earthworks, during dry seasons, can significantly reduce the likelihood of flash floods. In Malaysia, where monsoonal rains occur from November to March and May to September, strategically avoiding these periods can minimize the risk of surface runoff and erosion. Land clearing, which exposes soil and removes vegetation, presents a heightened risk, as it can lead to increased surface water accumulation even with moderate rainfall. By scheduling such activities during drier months, developers can mitigate the potential for flash floods and sediment-laden runoff overwhelming local stormwater systems.

Coordination with local weather forecasting services and using historical rainfall data are key to effective scheduling. Advances in meteorological technologies allow construction managers to make informed decisions by anticipating periods of heavy rainfall. Short-term weather forecasts can guide day-to-day project adjustments, reducing the risk of weather-related delays and protecting construction sites from water damage. For projects in flood-prone areas, historical rainfall patterns should inform long-term scheduling decisions to ensure that high-risk construction phases do not coincide with periods of heavy rainfall. This proactive approach helps avoid potential flood risks and safeguards the project and nearby ecosystems.

However, climate change has made weather patterns increasingly unpredictable, requiring more adaptive scheduling strategies. Developers can no longer rely solely on traditional seasonal patterns but must remain flexible, incorporating adaptive project management techniques. Temporary drainage systems, protective coverings, and rapid scheduling adjustments can help mitigate the impact of unforeseen weather events. As extreme weather events become more frequent due to climate change, these adaptive strategies are crucial for minimizing flood risks and ensuring construction project resilience.

4.2.7 Best Management practices

Adopting Best Management Practices (BMPs) during the pre-construction phase is essential for mitigating flood risks and minimizing the environmental impact of construction. BMPs manage stormwater runoff, prevent sedimentation, and control erosion, reducing the risk of flash floods. Silt fences, a commonly used BMP, act as temporary barriers to capture sediment and slow surface water flow, preventing sediment-laden runoff from entering storm drains or waterways. These fences, placed strategically around construction sites, protect downstream ecosystems by preventing sediment from clogging drainage systems and exacerbating flood risks [34].

Other critical BMPs include storm drain inlet protection and erosion control measures. Filters, sediment bags, and gravel barriers around storm drain inlets prevent debris and sediment from clogging municipal stormwater systems, particularly in urban areas with limited drainage capacity. Erosion control methods, such as mulch, geotextiles, and hydroseeding, stabilize exposed soil, reducing the likelihood of erosion and subsequent sediment runoff. Geotextiles protect bare soil, while hydroseeding encourages vegetation growth, further stabilizing the site. These BMPs minimize downstream flood risks by preventing soil erosion and ensuring water channels can handle runoff.

Temporary drainage systems, detention basins, and green infrastructure BMPs are equally important in regions prone to heavy rainfall, such as Malaysia. Temporary drainage systems direct stormwater away from active construction zones, reducing onsite flooding and controlling runoff. Detention basins and retention ponds store stormwater temporarily, releasing it slowly to avoid overwhelming drainage systems. At the same time, green infrastructure such as bio-retention areas and rain gardens allow water to infiltrate the ground, enhancing flood resilience. Implementing these BMPs mitigates the immediate risk of flash floods and contributes to long-term sustainable stormwater management.

4.2.8 Construction practices

Construction practices that prioritize minimizing land disturbance and maintaining natural water flow are critical for reducing flood risks and enhancing long-term resilience. Preserving vegetation is particularly important, as it acts as a natural buffer, absorbing water and slowing runoff, thus preventing flash floods. In regions prone to heavy rainfall, such as Malaysia, maintaining tree cover and plant life during construction helps stabilize soil, intercept rainfall, and reduce erosion. Vegetation enhances water infiltration into the ground, reducing the amount of surface runoff that could overwhelm drainage systems and exacerbate flooding [89].

In cases where land disturbance is unavoidable, integrating green infrastructure solutions, such as permeable surfaces and rainwater harvesting systems, is essential. Permeable surfaces like porous pavements and grass pavers allow water to infiltrate the ground rather than run into storm drains, reducing the volume and speed of stormwater. Rainwater harvesting systems further alleviate runoff by capturing rainwater for reuse, which is particularly useful during monsoon seasons. These systems reduce the risk of flash floods and support sustainable water use by providing an alternative source for irrigation or other non-potable purposes.

Additionally, bioswales and bio-retention systems are valuable green infrastructure solutions that help manage stormwater by mimicking natural drainage processes. These vegetated areas slow down, capture, and filter runoff, improving water quality while reducing flood risks. Low-impact development (LID) techniques should also be employed, emphasizing the preservation of natural landscapes and hydrological systems. By maintaining the natural flow of water and incorporating features like wetlands and forested areas, LID practices reduce land disturbance and promote sustainable stormwater management, mitigating flood risks for both construction sites and downstream communities.

5. CONCLUSION

This study has systematically identified and assessed the flash flood risks associated with construction activities in Malaysia, with a particular focus on the pre-construction and construction phases. Through semi-structured interviews with 29 industry experts and a thematic analysis, three primary categories of flood risks were identified: location risks, including topographical challenges and inadequate stormwater management; pre-construction risks, such as project scale, site selection, and offsite impacts; and construction-phase risks, particularly poor scheduling and the failure to implement best management practices (BMPs). While previous studies have extensively examined geographic and infrastructural vulnerabilities, this research uniquely highlights underexplored risks in project planning and execution, particularly interactions with floodplains, urban drainage systems, and regulatory enforcement gaps. The findings emphasize that insufficient planning and inadequate mitigation strategies during the construction process significantly heighten flood vulnerabilities, yet these factors are frequently overlooked in current industry practices.

To address these challenges, the study underscores the need for a comprehensive, integrated flood risk management framework that aligns industry practices with regulatory guidelines to enhance resilience against flash floods. From an industry perspective, adopting sustainable construction techniques is imperative. The implementation of permeable surfaces, bio-retention ponds, detention ponds, and silt fences can effectively reduce surface runoff and enhance flood resilience. Furthermore, improved construction scheduling and sequencing is essential to minimize land disturbances during high-risk monsoon periods, while enhanced flood risk assessment protocols should be integrated into feasibility studies and site selection processes. Additionally, the incorporation of on-site erosion and sediment control measures is crucial to prevent siltation and blockages in nearby waterways, which are common contributors to urban flash floods.

From a policy standpoint, strengthening regulatory enforcement is essential to ensuring compliance with flood resilience measures in construction projects. Policymakers should prioritize the revision and enforcement of flood mitigation guidelines by mandating stormwater retention systems, flood-adaptive building designs, and buffer zones in high-risk areas. The integration of flood risk assessments into mandatory Environmental Impact Assessments (EIAs) would further enhance regulatory oversight. Additionally, fostering inter-agency collaboration among construction regulators, environmental agencies, and local authorities would improve monitoring and compliance with sustainable flood mitigation practices. Providing financial incentives and subsidies for developers adopting green infrastructure solutions would further promote climate-resilient urban development.

This study contributes to the broader field of construction risk management by addressing a significant gap in flood risk mitigation during pre-construction and construction phases. The insights generated can inform both policy development and practical industry applications, particularly in flood-prone regions where urban expansion and climate variability intensify flood risks. Future research should explore the long-term effectiveness of sustainable flood mitigation techniques, particularly their adaptability to changing climate conditions. Additionally, the development of predictive flood risk models that integrate hydrological data, climate change projections, and urban planning strategies would enable more effective risk assessment and mitigation planning. Assessing the economic and social trade-offs of flood adaptation measures is also critical in ensuring cost-effective and scalable solutions for widespread industry adoption. By integrating proactive flood resilience measures into construction planning and execution, the construction industry, policymakers, and urban planners can significantly reduce infrastructure vulnerabilities, minimize economic losses, and enhance community safety. A strategic, multi-stakeholder approach to flood risk management will be essential in ensuring the sustainability and resilience of Malaysia’s construction industry in the face of evolving environmental challenges.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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