Malaysian Journal Of Civil Engineering

Full Paper

A CONCEPTUAL FRAMEWORK FOR FLOOD DISASTER PREVENTION ASSESSMENT IN MALAYSIA

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Article history
Received
05 September 2024
Received in revised form
28 October 2025
Accepted
29 October 2025
Published online
01 December 2025

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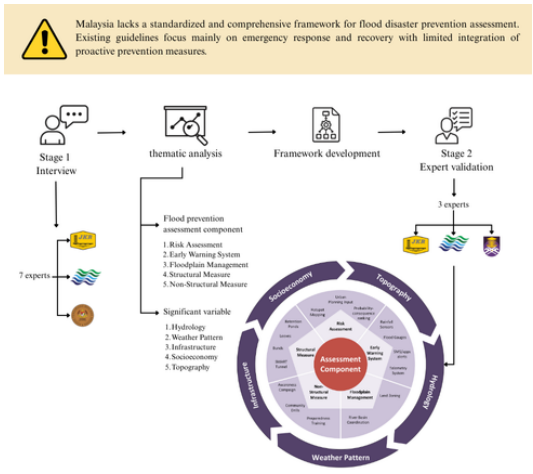
Graphical abstract



Abstract

Floods are among the most destructive natural disasters globally and Malaysia lacks a standardized and comprehensive framework for flood disaster prevention assessment. Existing guidelines focus mainly on emergency response and recovery with limited integration of proactive prevention measures. This study aims to address the gap by developing a conceptual framework for flood disaster prevention assessment tailored to the Malaysian context. A qualitative methodology was adopted involving semi-structured interviews with seven domain informants from the National Disaster Management Agency (NADMA), Department of Irrigation and Drainage (JPS) and the Public Works Department (JKR). Thematic analysis of the interview data identified five core components of flood disaster prevention such as risk assessment, early warning systems, floodplain management, structural and non-structural measures. Furthermore, critical variables influencing assessment effectiveness were identified including topography and hydrology, climate and weather patterns, infrastructure conditions and socioeconomic factors. These elements were systematically integrated into the proposed Flood Disaster Prevention Framework (FDPF), which was then validated through expert review. The framework is intended to enhance inter-agency coordination and strengthen national flood resilience. This research offers a strategic tool to support policy formulation and operational planning in flood disaster risk reduction across Malaysia.

Keywords: Flood Disaster Prevention, Flood Management, NADMA, Risk Management, Thematic Analysis

1.0 INTRODUCTION

Floods are one of the most common and damaging natural disasters around the world. Every year, they cause billions of dollars in economic losses and take thousands of lives. Over the past 30 years, global flood-related damage has reached an estimated US$18 billion annually, with about 6,000 fatalities recorded each year [1]. Malaysia is among the countries at high risk due to its seasonal monsoons and rapid urban development. On average, floods in Malaysia result in RM100 million (around US$33 million) in damages each year [2]. One of the worst floods in modern Malaysian history occurred on December 17, 2014, resulting in the evacuation of 3,390 people from Kelantan and 4,209 from Terengganu [3]. The Malaysian government estimated the total flood damages at RM1 billion (US$284 million), with RM100 million allocated for road repairs in Kelantan and RM132 million in Terengganu [4]. This disaster exposed significant weaknesses in the country's flood prevention and emergency response systems. The challenges mentioned show that there is an urgent need to improve how the country prepares for and prevents upcoming disasters.

While Malaysia applies both structural measures (drainage systems and flood barriers) and non-structural approaches (hazard mapping and public education), there is limited

documentation on how these strategies are assessed and implemented in practice. Although several policies and guidelines exist such as the National Security Council Directive No. 20, they are not specifically focused on flood disaster prevention assessment [5]. Furthermore, existing guidelines tend to focus on emergency response and recovery rather than proactive prevention planning. The absence of a unified national assessment standard has reduced the overall effectiveness of flood mitigation efforts. Hence, a clearer understanding of the current assessment practices, key influencing variables and agency-level perspectives are needed to guide the development of a more structured and practical framework.

In response to these challenges, this study aims to examine existing practices in assessing flood disaster prevention, identify the critical variables that influence assessment effectiveness and propose a conceptual framework that reflects Malaysia's unique geographic and institutional context. Using a qualitative methodology based on semi-structured interviews with informants from the National Disaster Management Agency (NADMA), Department of Irrigation and Drainage (JPS) and the Public Works Department (JKR), this study proposes a Flood Disaster Prevention Framework (FDPF) that aims to support more coordinated policy planning and enhance national resilience to flood risks.

2.0 METHODOLOGY

2.1 Research Design

This study adopted a qualitative research design using in-depth interviews, guided by a phenomenological approach. This design is appropriate for understanding how participants perceive and make sense of real-world experiences related to disaster management. A semi-structured interview format was selected as it balances a structured set of key questions with the flexibility to ask follow-up prompts. This allowed informants to share their experiences in detail and provided opportunities to explore occurring insights during the interviews [6, 7].

2.2 Sampling Strategy

Informants were selected using purposive sampling, a method that allows researchers to identify individuals with specific knowledge and experience related to flood disaster management [8]. This study implemented a two-stage sampling process with each stage applying different selection criteria. In stage 1, the selection focused on senior and mid-level officers from the National Disaster Management Agency (NADMA), Department of Irrigation and Drainage (JPS) and the Public Works Department (JKR) who were directly involved in policy development and operational planning. To confirm relevant expertise, participants were required to have at least five years of professional experience in disaster management or related fields, direct involvement in flood prevention or response planning along with specific knowledge of institutional procedures, risk assessments or mitigation strategies. Participation was voluntary and informed consent was obtained. According to Muellmann, et al. [9], six interviews are typically sufficient to reach data saturation. Seven informants were engaged and the key insights provided were consistent with the findings from a larger sample size, making this sample size appropriate for capturing relevant data.

A separate group of three experts was selected in stage 2 to confirm an independent review of the framework. This panel included a Senior Engineer from JPS, a director from JKR and a Senior Lecturer in water resources from a local public university. Each expert had more than ten years of professional experience in flood management or related areas. Their role was to evaluate the framework for relevance to the Malaysian context and practicality for implementation. Based on these criteria, all the informants in stage 1 and 2 were selected and outlined in Table 1.

Table 1 List of informants

Stage	Name	Expert designation	Working Experience	Agency
Stage 1	Expert 1	Assistant Director, Planning and Disaster Preparedness Division	10 years	NADMA
	Expert 2	Assistant Director, Mitigation Division	8 years	NADMA
	Expert 3	Assistant Director, Logistic and Support Division	7 years	NADMA
	Expert 4	Chief Assistant Director, Operations Coordination Division	12 years	NADMA
	Expert 5	Assistant Administrative Officer, Infrastructure and Transport	6 years	JKR
	Expert 6	Assistant Administrative Officer, Facility Management Division	9 years	JKR
	Expert 7	Senior Assistant Director, Corporate Division	15 years	JPS
Stage 2	Expert 8	Senior Engineer, Flood Mitigation & River Basin Management	14 years	JPS
	Expert 9	Director, Flood Management	19 years	JKR
	Expert 10	Senior Lecturer, Water Resources & Environmental Systems	16 years	UiTM

2.3 Interview Protocol Development

The interview questions were developed based on a review of relevant literature and were reviewed by two academic informants for clarity and relevance before data collection began. Key questions included:

1. What components of flood disaster prevention assessments are currently implemented by your agency?
2. What methods or practices are used to evaluate and manage flood risk before an event occurs?
3. What are the most important factors or variables considered during flood prevention planning?
4. Can you share examples of flood prevention projects or strategies that have been successfully implemented in your area of responsibility?

To improve the quality of the interview protocol, two academic informants reviewed the draft. Their feedback was used to improve the wording, structure and flow of the questions. The questions were designed to be open-ended so that informants could share their thoughts freely and provide detailed responses based on their experiences.

2.4 Data Collection Procedure

Data was collected through semi-structured interviews conducted via Google Meet. Interviews lasted approximately 50 minutes and were audio recorded with the participants' consent. After each interview, the audio recordings were transcribed verbatim using MAXQDA 2022 to ensure accuracy and to preserve the original meaning of the participants' responses [10]. Transcripts were reviewed and cross-checked by the researcher to ensure consistency before beginning the analysis process. Participants were also given the opportunity to review their transcripts to confirm the accuracy of their responses.

2.5 Thematic Analysis

The data collected in this study were analysed using thematic analysis which is a method used to identify, organise and interpret patterns or themes found in qualitative data. This approach helps researchers understand important ideas that are directly related to the study's objectives [11]. Thematic analysis is flexible and can be used with different research approaches, making it suitable for the phenomenological design of this study.

An inductive coding approach was used to allow themes to occur from the data without imposing predefined categories. The analysis began with open coding, where the researcher broke down the interview transcripts into smaller segments and assigned codes to meaningful units of information. This approach makes sure that the coding process remains grounded in the data and accurately displays the participants' perspectives on flood disaster prevention. Codes were organized and managed using MAXQDA 2022 which aided systematic categorization and retrieval of data segments [10]. The researcher first read through the interview transcripts to become familiar with the content. Then, specific parts of the data were coded and grouped into categories. These categories were later grouped into main themes that represent key findings in the study. This process ensured the data were analysed in a clear and organised way. To improve accuracy, the interview transcripts were sent back to the informants for review before the final analysis was completed. The visual representation of the thematic analysis steps used in this study was adapted from Naeem, et al. [12] with modifications to reflect the inductive and framework-development focus of the research. The steps used in the thematic analysis are shown in Figure 1.

To ensure the trustworthiness of the findings, strategies such as member checking, peer debriefing and audit trails were applied. Themes were discussed with academic peers to verify interpretation and consistency.

3.0 RESULTS AND DISCUSSION

3.1 Theme 1: Prevention Assessment Components

Informants were asked to provide their perspectives on the various components of flood disaster prevention assessments currently implemented in Malaysia. Representatives from all agencies were interviewed using a common set of semi-structured questions to ensure consistency in data collection. Through thematic analysis of the interview transcripts, five key components of flood disaster prevention assessment were identified: risk assessment, early warning systems, floodplain management, structural measures and non-structural measures. The insights and viewpoints shared by the informants are summarized in Table 2.

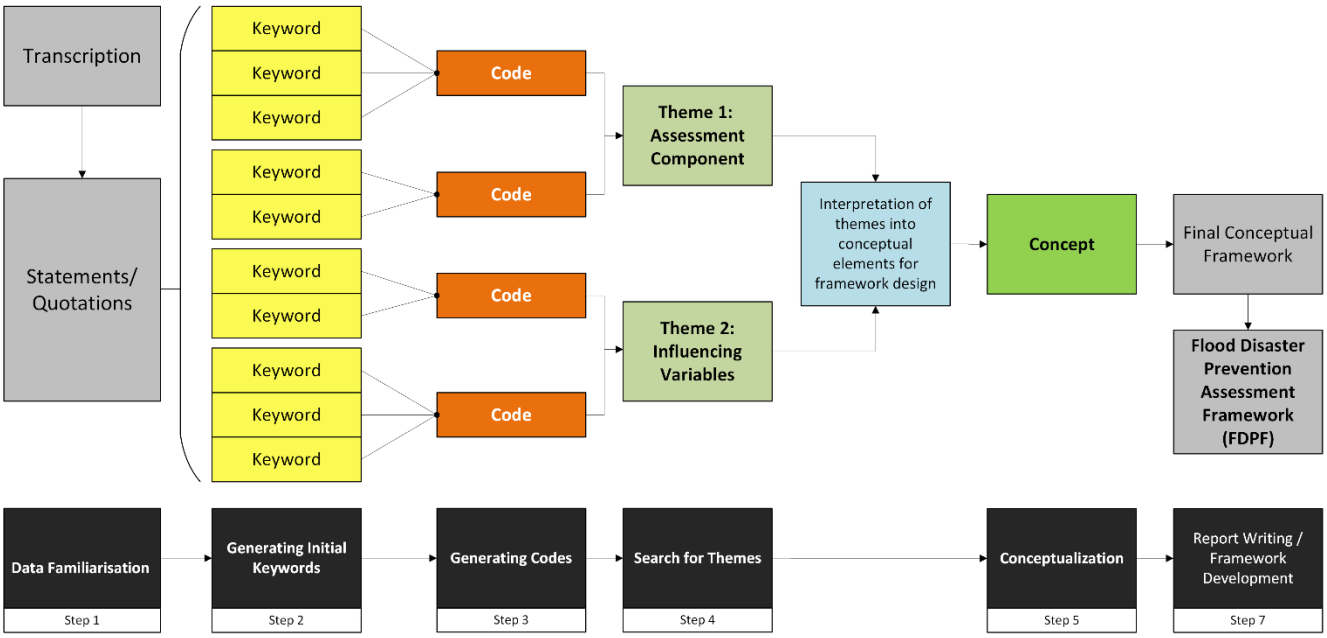


Figure 1 Thematic analysis process for developing the Flood Disaster Prevention Assessment Framework (FDPF)

Table 2 Informants' opinion on flood disaster prevention assessments components in Malaysia

Components of Disaster Prevention Assessment	Informants' Opinion
Risk Assessment	• Risk scores rank various locations and infrastructure based on their likelihood of flooding and the potential consequences of flood events • Risk register development to document identified risks, their probabilities and associated impacts • Integrating risk assessment findings into urban planning processes such as adequate drainage systems, retention ponds, and green spaces
Early Warning System	• Integrates data from various sources, including river gauges and rainfall sensors to provide real-time information on water levels and weather conditions • Disaster Operations Control Centres (PKOB) activation at state and district levels. Disaster response efforts can center the coordination to areas at risk of flooding • Development of protocols for spreading flood warnings through multiple channels such as SMS alerts and social media • Telemetry systems for real-time data collection and analysis, as well as mobile applications that provide users with up-to-date information on flood risks and road conditions
Floodplain Management	• Integrated River Basin Management (IRBM) to reduce flood risks by implementing preventive measures. • Involves coordinated management of land, water and related resources across various sectors within a river basin
Structural Measures	• Focuses on desilting, expanding and maintaining drainage infrastructure to ensure efficient stormwater management • Construction of levees and dikes along riverbanks and multipurpose dams and reservoirs to regulate river flows and store excess water during heavy rainfall • Flood bypass channels that divert excess water away from populated areas during heavy rainfall • Retention and detention ponds to temporarily store excess rainwater. Example projects like the Batu/Jinjang Pond Project in Kuala Lumpur • River bunding along riverbanks to prevent overtopping during floods
Non-Structural Measures	• Concentrate on laws, rules and other steps that can assist in lessening the effect of floods • Aid in the evaluation of flood disasters such as emergency preparation planning and emergency response procedures • Outreach and education programs that contribute to spreading knowledge about flood hazards, preparedness and response

Based on Table 3, risk assessment was described by informants as a critical starting stage for prevention planning. Informants stated the use of risk scores and registers to evaluate flood-prone areas and the potential impact of flooding. One expert explained,

"In our flood prevention planning, risk assessment is always done first… it's impossible to effectively prioritize resources or design appropriate mitigation measures without foundational assessment."

These findings supported by Zhu, et al. [13], who discuss the importance of integrating flood risk data into both assessment and management strategies. Their study focuses on the HV-SS model (hazard vulnerability-source-sink model) which demonstrates that the integration leads to a more effective decision making. However, several informants noted challenges in making sure that up-to-date data is used effectively across agencies, displaying concerns raised by both Zhu, et al. [13] and Mukhtar, et al. [14] about data fragmentation between agencies as it significant barrier for an effective decision making. Informants suggested the development of a centralized data platform would consolidate data from various sources such as JPS, MetMalaysia and NADMA. The findings also align with international practices such as in Bangladesh where real-time flood risk data is more efficiently integrated into flood management strategies [15].

In practice, NADMA broadcasts warnings through multiple platforms including SMS, MyCuaca, official websites and social media. Informants emphasized that using various communication channels helps increase reach especially in urban areas, as supported by Kuller, et al. [16]. They assert that the use of multiple platforms is critical to make sure that flood alerts reach various populations, particularly in urban environments where different demographic groups may rely on different communication methods. As emphasized,

"…rural areas often have a limited mobile network coverage."

As noted by Sunkpho and Oottamakorn [17], the challenge lies in ensuring stable wireless connectivity especially in remote areas where network coverage may be inconsistent. Kuller, et al. [16] suggested that sirens can be integrated as an additional audible warning method for rural areas or areas with low technological penetration. Informants also described how telemetry systems, rainfall sensors and river gauges are used to trigger multi-platform alerts. The activation of Disaster Operations Control Centers (PKOB) at both district and state levels allows early warnings to be translated into coordinated response efforts. Informants stated,

"*JPS will monitor river levels and rainfall hourly through their telemetry system. Once thresholds are reached, alerts will be issued to the public through SMS, MyCuaca app and social media."*

"PKOB is activated immediately so that coordination happens before flood rises."

Mohammed Zain, et al. [18] said that early activation of response centers such as PKOB is crucial in coordinating efforts between local governments and agencies. This approach follows the guidelines set by the Sendai Framework for Disaster Risk Reduction that focuses on the importance of real-time data [19].

Other than early warning, the effectiveness of structural measures depends on the maintenance and conservation of infrastructure, as well as its ability to be adapted to changing flood patterns [20]. JPS is an important role in the component by continuously monitoring river systems to ensure that levees and flood diversion channels are functioning optimally. As an informant from JPS said,

"We monitor river levels and rainfall in real time… levees and flood bypass channels will remain effective"

This real-time monitoring allows JPS to act proactively by adjusting flood management infrastructure as conditions change. It is important as extreme weather can overwhelm existing flood management infrastructure if it is not maintained or monitored regularly. One key point in the study by Moon, et al. [21] is the hybrid strategy approach that combines structural measures with Green Infrastructure (GI) techniques to enhance urban flood resilience. The hybrid strategy combines physical measures such as underground drainage tunnels and stormwater systems with natural systems like rain gardens and green roofs to reduce runoff and enhance flood mitigation measures. The results of their study demonstrated that applying a hybrid strategy could reduce peak flow by up to 37.3%, flood volume by 71.5% and flooded areas by 93.6% in certain cases. Malaysia could take this innovative approach as a model to integrate structural and natural systems for more sustainable and resilient flood management.

Some informants contend that structural measures alone cannot address all flood-related risks since it can lead to a false sense of security and increased vulnerability over time, especially when urban development in flood-prone areas continues unchecked [22]. Therefore, the integration of structural measures with non-structural measures is essential for a more comprehensive flood prevention strategy [23]. Informants highlighted that community-based initiatives and public education are key to improving resilience.

"Sometimes we do flood awareness programs so that communities are prepared and know how to respond when floods occur"

This is consistent with Fekete, et al. [24], who states that participation in flood risk management nurtures a sense of ownership and commitment to preparedness efforts, thus making non-structural measures just as critical as physical interventions. Furthermore, non-structural measures also tend to incline to be more cost-effective than physical infrastructure as they typically require lower capital investment and can be implemented much faster [25].

3.2 Theme 2: Influencing Variables

Following the analysis of the prior interview, the following points were extracted from the transcript such as topography and hydrology, weather patterns, infrastructure and socioeconomics. Table 3 summarizes the experts' opinion on variables that affect flood disaster prevention assessments.

Table 3 Informants' opinion on variables that affect flood disaster prevention assessment in Malaysia

Variables that Affect Flood Disaster Prevention Assessment	Informants' Opinion
Topography	• Topography refers to the physical characteristics of the terrain, such as its height, slope and form • Topography controls how water moves through the landscape while hydrology is essential for preventing floods since it affects how much water is available in the ecosystem
Hydrology	• Hydrology is the study of water in the environment such as rainfall, runoff and groundwater. •
Weather patterns	• Malaysia sees higher-than-average rainfall during La Nina period that can raise flood intensity. • Development of hydrological modeling methods to simulate rainfall-runoff relationships under different climate scenarios
Infrastructure	• Drainage system design and maintenance are crucial to prevent floods in metropolitical areas. • Efficient drainage systems can decrease the risk of flooding • Flooding may have a significant impact on highways, bridges and other infrastructures which can worsen the evacuation plans and emergency response operations
Socioeconomic	• Low-income areas are more susceptible to flooding since they have less access to resources and infrastructures • Income and poverty should be considered as socioeconomic factors in the assessment to guarantee that vulnerable populations are protected and supported

In Table 3, informant agrees that topography and hydrology as among the most significant variables in flood prevention assessment. They noted the importance stating that understanding the natural flow of water is critical to design an effective flood prevention strategy. This is also consistent with Abdelal, et al. [26] who emphasizes that in regions like Petra, Jordan, where flash floods are common, hydrological models are essential for predicting water movement and designing flood management strategies. One informant noted that,

"In my view, land shape and elevation are essential in determining how water behaves."

The informant statement reflects the idea that topography such as land elevation and slope directly influence the accumulation of water. However, Abdelal, et al. [26] also point out that data gaps in rainfall intensity often limit the accuracy of flood prediction. In Malaysia for example, a study conducted by Iqbal, et al. [27] prove that the existing rainfall data is inaccurate without a bias correction. They showed a mean bias of 158% was reduced to -13.3% after applying their two-stage bias correction method. Furthermore, their study also revealed that IMERG, a satellite-based rainfall estimation product, significantly underestimated extreme rainfall events, such as the Malaysia December 18, 2014 flood, where the observed rainfall at some stations reached 354.5 mm but IMERG failed to replicate accurately. Informant supports the statement,

"River gauge systems and rainfall sensors may not capture the extreme variations in water levels that occur during extreme events."

In response, Fung, et al. [28] recommend the use of advanced interpolation techniques to better predict rainfall patterns, particularly in remote regions where data gaps exists. While improving the accuracy of rainfall data is crucial, it must be complemented by adequate infrastructure to handle extreme weather events. Inadequate flood management infrastructure capacity is one of the primary contributors to flood risks it is not designed to manage higher water volumes resulting from climate change and urban development [16]. Informants said,

"Poorly maintained drainage systems, in particular are a major cause of localized flooding...."

"Usually drainage systems aren't cleaned regularly, the trash builds up and blocks the flow of water."

As Rosmadi, et al. [20] emphasize, design and maintenance of drainage systems, levees and flood barriers are essential to make sure that flood management infrastructure can effectively cope with unpredictable and intense rainfall. Moon, et al. [21] found that green roofs and rainwater harvesting systems in urban areas reduced peak flow rates by up to 37.3%. This measure would offer a complementary approach other than the one the informant said.

Informant also states that socioeconomic factor as critical variables in flood disaster prevention assessment. Informants highlighted the big difference between high-income and low-income areas where the latter are more likely to experience more damage due to insufficient infrastructure and limited flood protection.

"Low-income areas are often more vulnerable because they lack a proper drainage system"

According to the informants, low-income communities often heavily rely on external aid during or after disaster. They also have fewer resources to invest such as insurance or even preparedness items [13, 29]. Flood prevention strategies should specifically address the inequities by making sure that the most vulnerable populations are adequately protected and provided with the resources needed. Klijn, et al. [29] also examines how cultural factors influence flood risk management. For example, in some cultures, flooding is seen as a normal part of life, thus less urgency is implemented. On the other hand, in more individualistic or controlist societies, there is a greater emphasis on preventing or mitigating risks through technological solutions and flood defenses. This aligns with Rosmadi, et al. [20], who suggest that cultural values and public perception of flood risks

should be integrated into flood management strategies for long-term effectiveness.

3.3 Framework Validation Process

Validation process was carried out through a two-stage process to make sure its theoretical consistency and practical applicability. In the first stage, semi-structured interviews were conducted with seven experts from NADMA, JPS and JKR to evaluate the practicality, relevance and comprehensiveness of the proposed variables and components. In the second stage, A separate experts were invited to review the finalized framework to confirm that it reflected their professional experiences and the operational realities of disaster management.

The study then employed triangulation method to cross-reference expert opinions with findings from literature review [30]. This process supported the inclusion of key variables such as weather patterns, infrastructure resilience and community preparedness. The draft framework was then sent back the stage 2 informants. Informants confirmed the relevance and practicality of the framework's components and their feedback was instrumental in finalizing the model.

3.4 Development of Flood Disaster Prevention Assessment (FDPF)

The framework was developed through an initial review of the literature that provided foundational concepts, followed by validation through expert interviews. Insights from the interviews, particularly regarding local flood management practices were integrated with factors identified in the literature to create the conceptual framework. Flood prevention issues were carefully analysed to identify and evaluate the variables that influence effective flood disaster prevention. Based on the comprehensive data analysis, the final conceptual framework for flood disaster prevention (FDPF) in Malaysia was established. The proposed framework design reflects the key variables identified through this research. Figure 2 illustrates the development of the FDPF for flood disaster prevention in Malaysia.

The design of the framework uses a circular model to visually represent the connection of flood prevention components as well as the significant variables. These elements are not linear or hierarchical but emphasize reciprocal influence where each element informs and shaped by others. The assessment component in the center of the circle forms the core of the entire framework. This component represents the foundation of the prevention process such as risk assessment, early warning system, floodplain management, structural as well as non-structural measures. The next layer is the operational cases which provides examples of how each assessment domain is implemented. For example, risk assessment is operationalized through tools such as hotspot mapping, urban planning integration and flood probability ranking. The outer elements represent the variables that influence the component of the assessment and intervention strategies in the inner layers. Each arrow points to the next variable in the chain creating a loop to indicate continuous feedback to the next variable and mutual reinforcement among them.

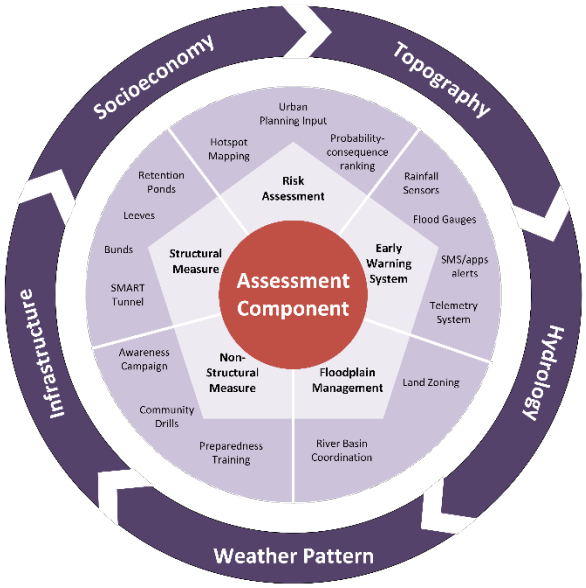


Figure 2 Establishment of Flood Disaster Prevention Framework (FDPF)

4.0 CONCLUSIONS

This study aims to explore and assess the various components of flood disaster prevention strategies and the critical variables that influence these assessments in Malaysia. By exploring various components of flood disaster prevention assessments and identifying the key variables influencing these assessments, this research has developed a conceptual framework tailored to the Malaysian context. Utilizing a qualitative research methodology involving semi-structured interviews with experts from NADMA, JPS and JKR, key insights were gathered and analyzed through thematic analysis. The findings revealed that assessments play a crucial role in flood disaster prevention.

Prevention assessments help evaluate the vulnerability of the population, infrastructure and environment to flood hazards, providing essential insights for effective mitigation strategies. Moreover, these assessments are crucial for informing the planning and allocation of resources, ensuring personnel, equipment and supplies are organized efficiently to meet the needs of affected populations. According to experts, flood disaster prevention assessments also establish a baseline for monitoring and evaluating disaster response, including the effectiveness of interventions and the progress of recovery and reconstruction efforts.

Despite its contributions, sample size of seven informants may not fully capture the diversity of perspectives across all relevant stakeholders in Malaysia's flood disaster management landscape. This scope does not capture the viewpoints of other critical stakeholders such as local governments or non-governmental organizations (NGOs) who are also integral to flood disaster management. The study relies on qualitative data from interviews, which may be subjected to personal biases and interpretations. The interviews also are limited to 60 minutes which may not have allowed sufficient time to explore complex topics in depth. Although the semi-structured format gave a detailed response, follow-up discussions or longer sessions might have provided richer data and deeper insights into critical issues.

To address these limitations, future studies may need to include a larger and more diverse sample of informants, with various levels of government, non-governmental organizations, community leaders, and other stakeholders involved in flood disaster management. Surveys and statistical analyses can also provide a broader understanding of the effectiveness of different flood prevention measures and the perceptions of a wider population. By addressing these suggestions, future research can provide a more comprehensive understanding of flood disaster prevention and contribute to the development of more effective strategies for managing flood risks in Malaysia.

Acknowledgements

The authors would like to acknowledge the Ministry of Higher Education (MOHE) for funding this research under the Fundamental Research Grant Scheme (FRGS) (FRGS/1/2023/TK06/UITM/02/12). The authors also express their sincere gratitude to Universiti Teknologi MARA (UiTM) for its invaluable support in carrying out this study. The resources, guidance and encouragement provided by the Faculty of Civil Engineering were instrumental in the successful completion of this research. The authors also appreciate the contributions of NADMA, JPS and JKR staff who participated in this survey.

Conflicts of Interest

The author(s) declare(s) that there is no conflict of interest regarding the publication of this paper

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