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ENHANCED GIS-BASED MULTI-CRITERIA DECISION ANALYSIS FOR OPTIMAL FLOOD SHELTER SITE SELECTION: A CASE STUDY OF KUANTAN, MALAYSIA

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Abstract

Floods significantly impact lives, infrastructure, and economies, especially in disaster-prone regions such as Kuantan, Malaysia. This study aims to develop a suitability map for flood shelters in Kuantan, Pahang, by employing the Analytic Hierarchy Process (AHP) and Weighted Overlay Analysis (WOA) within ArcGIS software. Geospatial criteria such as elevation, slope, proximity to disaster-prone areas, landslides, floods, and land use were used as parameters. The results indicated that 21% of flood shelters were in unsuitable locations, 32% were in moderately suitable areas, 39% were in very suitable areas, and 8% were in extremely suitable sites. This study highlighted the critical role of geospatial criteria in selecting flood shelter sites and advocated for continuous reassessment to optimise their effectiveness and safety. The research provides valuable insights for urban planning and disaster risk reduction, emphasising the necessity for strategic, data-driven decision-making to enhance urban resilience against floods.

Keywords: GIS, flood shelters, AHP, evacuation, WOA, flood

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INTRODUCTION

Climate change and urban development significantly contribute to the increased damage caused by floods (Mustafa et al., 2018; Poelmans et al., 2011). Additionally, population growth, particularly in urban areas, heightens the likelihood of land overuse in flood-prone regions (Larsen, 2009; Ran & Nedovic-Budic, 2016). As a result, floods have caused substantial destruction worldwide; in the 20th century alone, flood disasters resulted in over 100,000 fatalities and impacted more than 1.4 billion individuals (Jonkman, 2005). These effects stem from the increased exposure of people and infrastructure to natural hazards, driven by population growth, limited available space, and climate change (Sutanta et al., 2010). The rising number of vulnerable cities and populations highlights the need for local governments to establish effective disaster management operations to enhance urban resilience (Zhao et al., 2017).

In Malaysia, flooding is the country's most prevalent natural disaster, affecting 4.92 million people and causing damage worth several million Ringgit Malaysia annually (Keicho, 2020; Mohit & Sellu, 2013). Fluvial and coastal flooding usually occurs during the monsoon season due to heavy rainfall, while flash floods happen numerous times throughout the year because of uncontrolled urbanisation, water runoff, and ineffective drainage systems (Saad et al., 2023). Consequently, thousands of Malaysians are required to evacuate their homes and relocate to safe shelters or designated evacuation areas (Mohamad et al., 2021; NADMA, 2018).

As the frequency and severity of floods have increased in Malaysia, effective disaster management strategies have become crucial. A key element of these strategies is the establishment of flood shelters, which provide safe havens for affected populations during flood events. Ensuring the provision of safe evacuation centres or temporary shelters during floods in Malaysia is a priority and a primary concern of the Government (Padlee et al., 2018). Selecting suitable sites for these shelters is vital to ensure the safety and accessibility of evacuees. However, there have been instances in Malaysia where evacuees had to vacate the flood shelters and seek refuge elsewhere due to the shelters being inundated. For example, evacuees had to relocate to another flood shelter in Pahang after the shelter in SK Sungai Ular, Kuantan, was flooded (Mabahwi, 2021; Mabahwi et al., 2021). This underscores the importance of examining the site suitability of existing shelters, yet insufficient attention has been paid to this issue in Malaysia.

The aim of this study is to create a land suitability map for flood shelters in Kuantan using the Analytic Hierarchy Process (AHP) and Weighted Overlay Analysis (WOA) in ArcGIS software. By integrating these techniques, this research seeks to provide a robust and systematic approach to evaluating existing suitable sites for flood shelters, considering multiple geospatial criteria such as proximity to flood-prone areas and secondary disasters, elevation, slope, and land use. The use of geospatial criteria as GIS variables is crucial because these factors directly influence the safety, accessibility, and overall effectiveness of flood shelters in disaster scenarios.

LITERATURE REVIEW

Site Suitability of Flood Shelters

A vital aspect of the preparedness phase in urban resilience planning involves identifying emergency locations that serve two primary purposes: offering temporary shelter from secondary damage and facilitating efficient rescue operations (Zhao et al., 2017). Ensuring the evacuation of affected populations to safe areas is crucial, necessitating meticulous planning of evacuation shelters.

A primary consideration in planning evacuation sites is evaluating the spatial distribution and demands of potential evacuees. This factor significantly influences the appropriateness of shelter locations and the efficiency of evacuations. Urban shelters need to provide refuge within a reasonable distance and time frame during a disaster (Chen et al., 2018; Yu et al., 2015). Estimating shelter demand requires an analysis of potential disaster-affected areas and population distribution (Chen et al., 2016, 2020). For example, Chen et al. (2018, 2020) utilised census data to predict street-level population density for future urban planning, conducting a risk analysis to identify disaster-prone areas and using GIS to overlay these results to estimate shelter demand.

Additionally, proximity to residential areas is a crucial factor in determining suitable evacuation sites. Building emergency shelters within a 1 km radius of the residential regions ensure accessibility and reduces evacuation time. Studies by Sanyal and Lu (2009), Anhorn and Khazai (2015), and Kusumo (2016) emphasised the importance of this proximity. Kusumo (2016) discovered that most respondents preferred to evacuate within 1 km of their homes, indicating a strong preference for nearby flood shelters. Analysing the radius of shelters from settlements helps determine the coverage and adequacy for affected populations.

Minimising the distance at-risk populations must travel to reach shelters is also vital. Shelter accessibility is a significant concern in evacuation modelling (Chen et al., 2018; Cova & Church, 1997; Kongsomsaksakul et al., 2005). Populations tend to evacuate to shelters with easy access to evacuation routes (FDEM, 2018). Therefore, proximity to highways and evacuation routes is important (Kar & Hodgson, 2008). Ideally, the time required to walk to emergency shelters should be within 5 to 15 minutes (Unal & Uslu, 2016; Wei et al., 2012).

Flood risk is another crucial factor when selecting evacuation sites. It is imperative to ensure that flood shelters are not constructed in high-risk inundation areas and are situated outside flood-prone zones, including those within a 100-year floodplain. Guidelines from international organisations such as the

American Red Cross (2018), FDEM (2018), FEMA (2013, 2015), and Sphere (2011, 2015) support these precautions. Shelters located in flood-prone areas pose additional risks to evacuees (FEMA, 2013, 2015; Kar & Hodgson, 2008). Additionally, shelters should be located within 1 km outside of flood-prone areas to ensure accessibility and safety during flood events (Kongsomsaksakul et al., 2005; Kusumo, 2016).

Topography and elevation are also essential in determining the suitability of shelter sites due to their impact on risk exposure and vulnerability to hazards (Sabri & Yeganeh, 2014). Chen et al. (2018) suggested that flood level, terrain, and elevation should be the primary criteria for determining the suitability of flood shelter sites, as topography affects flood severity, flow size, and direction (Kia et al., 2012; Sabri & Yeganeh, 2014; Saini & Kaushik, 2012). Low-lying areas are particularly susceptible to flooding; therefore, constructing shelters on higher elevations or elevating them through construction is essential (FEMA, 2015; Gol-UNDP, 2006). The International Federation of Red Cross and Red Crescent Societies (2011) sets the standard for flood shelters to be located above the highest estimated flood level.

Furthermore, the slope is another critical factor. Flood shelters should not be built on land with a slope gradient of 30° or higher to avoid the risk of landslides or mudslides (Melgarejo & Lakes, 2014; Sphere, 2011, 2015). Additionally, shelters should not be situated on or near fault lines, with slopes ideally between 2% and 4%, not exceeding 7% (Geng et al., 2020; Kilci et al., 2015). Kusumo (2016) recommended slopes of less than 5%. Ensuring the slope criterion does not exceed 1:15 is important to maintain accessibility for individuals with disabilities (Handicap International-Nepal Programme, 2009).

Land use surrounding potential shelter sites also plays a significant role in determining their suitability (Kusumo, 2016; Sanyal & Lu, 2009; UNHCR, 2007). Locations at risk of secondary disasters, such as rain-induced landslides, should be avoided (Anhorn & Khazai, 2015; Geng et al., 2020; International Federation of Red Cross and Red Crescent Societies, 2011; Sphere, 2015; Wei et al., 2012). A recommended distance of more than 3 km from landslide-prone areas is advisable (Chen et al., 2018; Liu et al., 2011). Additionally, shelters should be situated away from hazardous facilities, such as industrial areas, to minimise the risk of incidents like fires or explosions and avoid secondary hazards caused by dangerous materials (Anhorn & Khazai, 2015; Kusumo, 2016; Tai et al., 2010; Wei et al., 2012).

In conclusion, multiple criteria must be considered when evaluating the suitability of urban shelter sites. Evaluation indicators should integrate domestic and international experience, current research, and the natural geographical features of the area under consideration. As Wang (2019) pointed out, there is no universal model for shelter site suitability evaluation. However, ensuring accessibility, safety from floods and secondary disasters, suitable topography, and proximity to residential areas are critical in planning effective and resilient evacuation shelters.

MATERIALS AND METHODS

The Kuantan District in Pahang was selected as the focus of this study due to its designation as a high-risk flood area under the National Physical Plan 3, with Kuantan City identified as particularly susceptible to flooding (PLANMalaysia, 2018). Furthermore, the Kuantan Local Plan 2035 highlights that a majority of residential zones in Kuantan are vulnerable to flooding (Majlis Perbandaran Kuantan, 2019). These aspects underscore the necessity of evaluating the suitability of existing flood shelters in Kuantan to bolster the region's resilience.

The analysis employed a GIS-based approach combined with the Analytic Hierarchy Process to determine the suitability of flood shelter sites. The GIS-based site suitability assessment was executed using a multi-criteria analysis method, which integrates and transforms both spatial and non-spatial input data into a comprehensive decision-making output. Research by Mendoza (2000) and Mighty (2015) emphasised the critical role of GIS in multi-criteria site suitability analysis, given that such evaluations are intrinsically multi-criteria. Land suitability assessment is a complex decision problem involving multiple factors, necessitating rigorous criteria evaluation like AHP for precise and informed decision-making (Malczewski, 2004; Mighty, 2015). AHP provides a structured decision-making hierarchy using a predefined reference scale, considering the factors influencing decisions and the importance of decision points relative to these factors. The variations in value are thus converted into percentage representations of decision points (Şentürk & Erener, 2017).

Initially, the analysis involved mapping all flood shelters. Topographic mapping of the district was derived from a Digital Elevation Model (DEM) to study elevation changes and slopes. Shuttle Radar Topography Mission (SRTM) elevation data were imported into ArcMap at elevation points. These data were processed using the Raster Interpolation analysis tool and Inverse Distance Weighting (IDW) to generate the DEM, which was subsequently converted into a slope map using the 3D Analyst extension – Raster Surface – Contour. Layers indicating flood-prone and landslide areas were sourced from government data. However, the original shapefile was not in raster format and thus unsuitable for GIS reclassification techniques and Weighted Overlay Analysis. The Spatial Analyst Tools- Distance- Euclidean Distance was utilised to determine whether flood shelters are situated within or outside hazard-prone areas. This approach was optimal in the study for converting the layer into the raster format and identifying the location of flood shelters relative to hazard zones. The Proximity tool was used to ascertain the distance between flood shelters and landslide-prone areas.

The suitability maps in GIS were generated based on criteria weighted according to their significance as derived from the AHP. To construct a GIS-based multi-criteria analysis, WOA was integrated with AHP, a method widely used in GIS-based site suitability, selection, and evaluation studies. In this research, weights were assigned based on flood shelter suitability standards. The variables for this analysis included: (1) shelters located outside flood-prone areas, (2) shelters positioned away from secondary disaster sites, such as landslides, by a minimum distance of 3 km, (3) shelters situated on elevated terrain with slopes preferably between 2% and 5%, not exceeding 7%, and (4) shelters distant from industrial zones.

Figure 1: Location plan of Kuantan
Source: Majlis Perbandaran Kuantan (2019)

Weighted Overlay Site Suitability Analysis

To evaluate the final site's suitability, all variables (criteria) identified in the GIS analysis were converted to raster format, reclassified, and then overlaid using the Spatial Analyst - Weighted Overlay tool (refer to Figures 2 to 7). The weights were determined using the AHP scale to produce the final suitability results. In GIS, the Weighted Overlay Analysis facilitates the ranking of areas where a value of 0 indicates 'not suitable' or 'restricted', thereby excluding certain areas from consideration. In this study, regions prone to landslides, forest reserves, and agricultural land, which collectively comprise 91.23% of Kuantan, were categorised as 'restricted' and considered highly unsuitable for the placement of flood shelters. Additionally, industrial zones were also classified as restricted, as shelters should not be situated in proximity to them. The influence of each AHP weight in GIS, expressed as a percentage, is equally set, indicating the equal importance of all criteria in the suitability assessment. Table 1 summarises the criteria used in the WOA, integrated with AHP in GIS.

Table 1: Weighted Overlay

Criteria (raster layer)	Influence (%)	Field	Scale value (AHP)	Description scale
Flood prone area	25%	Flood area	1	Less suitable
Secondary disasters	25%	Landslide	Restricted	Restricted
Elevation	25%	<5 m	1	Less suitable
		5.1 m – 10 m	3	Moderately suitable
		10.1 m – 15m	5	More suitable
		15.1 m – 20 m	7	Very suitable
		>20.1 m	9	Extremely suitable
Slope	25%	1%-1.9%	5	More suitable
		2%-4%	9	Extremely suitable
		4.1%-5%	7	Very suitable
		>5%	1	Less suitable
Land use	25%	Residential	9	Extremely suitable
		Industrial	Restricted	Restricted
		Forest reserve	Restricted	Restricted
		Agriculture	Restricted	Restricted
		Water body	Restricted	Restricted

Source: Authors, 2024

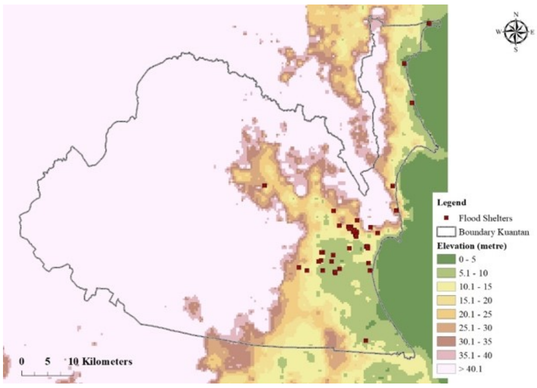

Figure 2: Elevation
Source: Authors, 2024

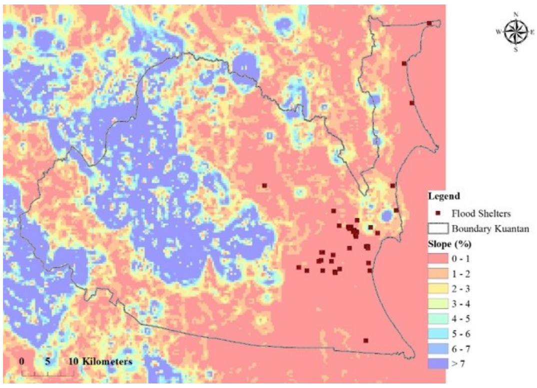

Figure 3: Slope
Source: Authors, 2024

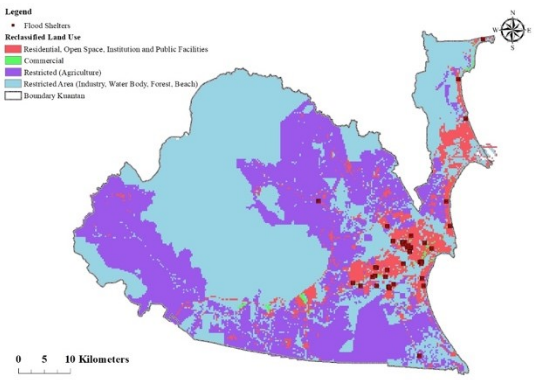

Figure 4: Reclassified Land Use Suitability
Source: Authors, 2024

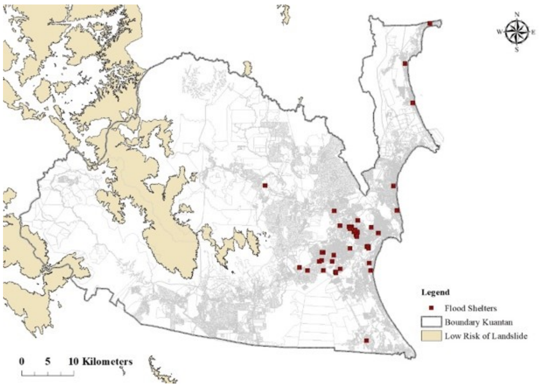

Figure 5: Low Risk of Landslides
Source: Authors, 2024

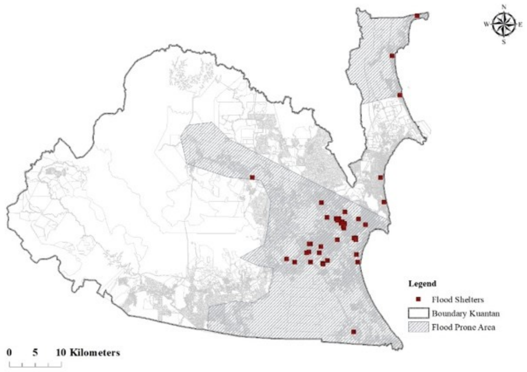

Figure 6: Flood Prone Area
Source: Authors, 2024

RESULTS AND DISCUSSION

The GIS-based multi-criteria Weighted Overlay Analysis forms the foundation of this study. It integrates a land use map with other relevant criteria to evaluate the suitability of flood shelters in Kuantan. This overlay method is crucial for demonstrating the interrelationships between various criteria.

Secondary disasters in Malaysia, most notably landslides, typically occur after heavy rainfall (Chan, 2015a, 2015b). By analysing the landslide risk layer, it was found that some shelters are in proximity to areas with a low risk of landslides. The proximity tool in GIS indicated that 4% of the shelters are situated between 1.4 km and 1.9 km from potential landslide areas, while the remaining 96% are over 9.4 km away. However, since this layer represents a low landslide risk, the impact on shelters is expected to be minimal. Additionally, elevation and land structure influence the distance travelled by landslide debris.

An analysis of flood-prone areas indicates that 56.8% of Kuantan's total area, amounting to 168,292.9 hectares out of 296,042 hectares, is susceptible to flooding. Notably, 82% of shelters are located in these flood-prone zones, which, according to the initial criteria, would be deemed unacceptable. However, an alternative perspective suggests that placing flood shelters within highly flood-prone residential areas may effectively mitigate flood hazards in developing countries by providing maximum protection and reducing the overall risk for vulnerable communities (Chowdhury et al., 1998; Sanyal & Lu, 2009). This view is corroborated by Kusumo (2016), who found that many residents prefer evacuation centres to be located within their residential areas, even if these areas are prone to flooding. Given that 73.51% of residential settlements in Kuantan are in flood-vulnerable zones, situating flood shelters within these areas could be considered practical and responsive to community preferences.

Topographic characteristics further influence the suitability of flood shelter locations. The analysis shows that 86% of shelters are located on slopes of less than 1.5%, 13% on slopes under 7%, and only 1% on steep slopes. This indicates that most current flood shelter sites are suitable based on elevation and slope criteria. Additionally, proximity to industrial areas poses significant risks, and these locations are deemed unsuitable for shelters due to potential secondary hazards.

The final site suitability map (refer to Figure 7), obtained by analysing the variables collectively in GIS using a Weighted Overlay Analysis, reveals that 21% of flood shelters in Kuantan are situated in unsuitable locations. Meanwhile, 32% are in moderately suitable sites, 39% in highly suitable sites, and 8% in extremely suitable sites. The least suitable sites were identified near industrial areas, regions with a low risk of landslides, or close to rivers or beaches. These findings align with previous research by Kar and Hodgson (2008) and Kusumo (2016), which emphasised the physical unsuitability of emergency shelters near industrial areas, streams, and beaches. Consequently, these unsuitable sites highlight the need for a more strategic approach to flood shelter placement that prioritizes safety, accessibility, and community preferences.

In conclusion, the GIS-based multi-criteria analysis, combined with AHP, provides a robust framework for evaluating the suitability of flood shelter sites in Kuantan. While a significant proportion of current shelters are located in flood-prone areas, considering community preferences and practical constraints can justify their placement. The critical analysis underscores the necessity for a balanced approach that incorporates both risk mitigation and resident preferences to enhance urban resilience effectively.

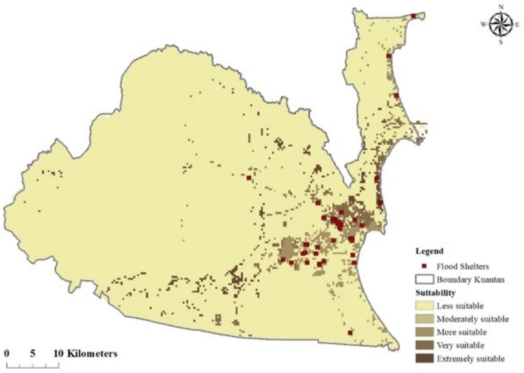

Figure 7: Overall Suitability Map
Source: Authors, 2024

CONCLUSION

This study emphasises the importance of assessing the suitability of flood shelters in flood-prone areas such as Kuantan, Malaysia, through a GIS-based multi-criteria analysis combined with the Weighted Overlay Analysis and the Analytic Hierarchy Process. The results highlight considerable variations: 21% of flood shelters are in unsuitable locations, 32% are in moderately suitable areas, 39% are in very suitable locations, and only 8% are in extremely suitable sites. Unsuitable sites are predominantly located near industrial zones, areas with low landslide risk, steep slopes, and low-lying streams and beaches susceptible to flooding and secondary disasters.

This research underscores the critical role of geospatial criteria, including land use, hazard proximity, and topography, in determining appropriate sites for flood shelters. These factors directly impact the safety, accessibility, and overall effectiveness of evacuation centres during emergencies. The integration of GIS-based WOA and AHP offers a comprehensive framework for site suitability analysis, providing valuable insights for urban planning and disaster risk reduction.

In conclusion, although many current flood shelter locations are unsuitable, there is a practical need to balance accessibility and risk. Future initiatives should focus on the ongoing reassessment of shelter locations, taking into account changing environmental and urban conditions to enhance their effectiveness and safety. This research contributes to the broader discussion on disaster management, highlighting the importance of strategic, data-driven decision-making to strengthen urban resilience against floods.

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