



GIS ANALYSIS OF FLOOD EVACUATION CENTRE PLACEMENT: IDENTIFYING SPATIAL GAPS IN Kuantan, MALAYSIA

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Abstract

Kuantan, Malaysia, faces recurrent flooding that displaces thousands annually, underscoring the need for strategically located evacuation centres (ECs). This study employs a GIS-based spatial analysis, framed by concepts of spatial equity, resilience planning, and disaster risk governance, to assess the distribution, accessibility, and capacity of ECs relative to flood-prone residential areas and vulnerable populations. Results reveal significant spatial inequities: 41% of flood-prone residential land and 66% of at-risk residents are located beyond the recommended 1-km EC coverage radius. Capacity analysis indicates that existing shelters can accommodate only 25% of the population within the covered zones. A suitability analysis integrating proximity to existing ECs, flood risk, and population density identified 14% of flood-prone residential land as “extremely suitable” and 21% as “very suitable” for new ECs. These priority zones are concentrated in peripheral areas with high flood exposure, high population density, and limited current shelter access. Comparative insights from the Philippines, Indonesia, and Bangladesh highlight that such urban–rural disparities in EC access are common in Southeast Asia, often due to centralised infrastructure planning. The study’s findings and GIS-based suitability mapping provide a replicable approach for planners and policymakers, enabling targeted, equitable, and resilience-focused evacuation infrastructure development in flood-prone regions.

Keywords: GIS, Flood, Evacuation Centre, Spatial, Hazard

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INTRODUCTION

Climate change has intensified the frequency and severity of hydrometeorological disasters worldwide, causing extreme weather events to become increasingly unpredictable. Rising global temperatures have altered precipitation patterns, resulting in prolonged and intense rainfall events, particularly affecting regions such as Southeast Asia (Singh & Qin, 2020). Malaysia, located within the tropical monsoon climate zone, is notably vulnerable to these climate-induced disasters, with flooding being the most recurrent and impactful hazard (Md Saad et al., 2023). Seasonal monsoons frequently lead to severe flooding, causing widespread socio-economic disruption and environmental damage. The East Coast region of Malaysia, particularly states such as Kelantan, Terengganu, and Pahang, consistently experiences substantial flood-related impacts including significant infrastructure damage, disruption to economic activities, increased government expenditure on recovery efforts, and prolonged impacts on local economies.

Kuantan, the capital city of Pahang, stands out as especially vulnerable to recurrent flooding due to its geographical characteristics, monsoonal influence, and insufficient flood management infrastructure (Mabahwi & Nakamura, 2024). The city's proximity to significant river systems, ongoing rapid urbanisation, and changes in land use have intensified flooding impacts, regularly displacing thousands of residents. Factors such as heavy rainfall, river overflow, ineffective drainage systems, and proximity to coastal areas amplify flood severity, necessitating large-scale evacuations (Suzuki et al., 2019). Effective disaster preparedness, therefore, is crucial for protecting lives and mitigating flood impacts, highlighting the importance of strategically placed evacuation centres (ECs) to serve as immediate shelters for affected populations.

The spatial distribution of evacuation centres critically affects their capacity to provide timely and effective shelter during flood emergencies (Alam et al., 2021). Poorly positioned shelters lead to accessibility challenges, overcrowding, and increased vulnerabilities for displaced individuals. Strategic location planning, incorporating population distribution, flood risk zones, and geographic accessibility, is essential to ensure that ECs effectively mitigate the impacts of flooding (Mabahwi & Nakamura, 2024). Geographic Information Systems (GIS) serve as a robust methodological framework for assessing these spatial factors, providing valuable insights into gaps and inadequacies in existing shelter networks (Rahman et al., 2021).

This study employs GIS-based spatial analysis to evaluate the spatial distribution and adequacy of evacuation centres in Kuantan's flood-prone areas. By assessing shelter locations relative to residential zones, flood-risk areas, and population density, the research aims to identify spatial mismatches and deficiencies in the current evacuation infrastructure. The study's outcomes will inform strategic recommendations to optimise shelter placement, enhance

disaster preparedness, and ultimately improve resilience among communities vulnerable to flooding in Kuantan.

LITERATURE REVIEW

The spatial distribution of evacuation centres (ECs) significantly influences the efficiency and effectiveness of evacuation operations during disasters (Mabahwi et al., 2021). GIS-based spatial analysis provides a systematic approach for assessing EC locations, considering critical factors such as flood risk, population density, and shelter accessibility. Effective evacuation management necessitates precise identification and strategic placement of ECs within optimal distances to at-risk populations. GIS technologies, including buffer analysis and intersect overlays, have become crucial tools for spatial planning in disaster management by highlighting accessibility issues, shelter coverage gaps, and mismatches between EC capacities and population demands (Mabahwi et al., 2021; Sanyal & Lu, 2009).

Buffer analysis is a widely applied GIS technique to evaluate the spatial accessibility of evacuation centres, generally recommending EC placement within a 1-kilometre radius of residential settlements (Lee & Sung, 2013; Mabahwi et al., 2021; Mabahwi & Nakamura, 2024; Sanyal & Lu, 2009; Sritart et al., 2020). Strategic placement within this radius significantly reduces evacuation time and maximises shelter coverage, particularly benefiting populations residing in high-risk zones (Batur et al., 2025; Kusumo, 2016; Sanyal & Lu, 2009). Nevertheless, practical constraints such as uneven spatial distribution and limited infrastructure often challenge effective EC placement. Peripheral and rural communities commonly face insufficient shelter coverage, increasing their vulnerability during flood events (Chen et al., 2020; Mabahwi et al., 2021).

Research in Metro Manila, Philippines, highlighted the challenges resulting from spatial planning inadequacies. GIS-based analysis revealed substantial disparities in ECs coverage, with overcrowding in urban centres and inadequate coverage in peripheral areas. Similarly, studies in Tubay, Agusan del Norte, Philippines, identified significant shelter gaps due to inappropriate or insufficient spatial planning and a lack of comprehensive spatial data (Chen et al., 2020; Muller et al., 2024). Such examples underline the critical importance of incorporating detailed spatial analysis into evacuation planning.

Accurate spatial data is essential for effective EC planning. However, limitations related to data accuracy, reliability, and availability pose substantial challenges in disaster management research. Spatial heterogeneity in population density and variations in infrastructure quality further complicate the planning and effectiveness of evacuation infrastructures. Consequently, advanced spatial analysis, including GIS overlays and buffer techniques, are vital to identify and mitigate these issues (Muller et al., 2024; Sanyal & Lu, 2009).

Additionally, integrating GIS technologies into existing emergency management systems is frequently hampered by resource constraints and technological barriers, especially in developing regions. Addressing these barriers requires concerted efforts, including the development of clear policy frameworks, adequate resource allocation, and capacity building to ensure long-term sustainability and effectiveness of EC planning (Ahmadi et al., 2022; Muller et al., 2024). By addressing these challenges, researchers and policymakers can improve the spatial distribution of evacuation centres, enhancing disaster resilience and reducing risks for affected populations.

Conceptual Framework

This study adopts an integrated framework combining spatial equity, resilience planning theory, and disaster risk governance to guide the spatial analysis of evacuation centres (ECs) in Kuantan.

Spatial equity refers to the fair distribution of public resources, facilities, and opportunities across geographic areas, ensuring that all segments of the population regardless of socio-economic status or location have equitable access to essential services (Soja, 2010). In the context of flood evacuation, spatial equity requires that shelters be located in a manner that minimises travel time, reduces exposure to hazards, and prioritises vulnerable populations.

Resilience planning theory emphasises building the adaptive capacity of communities to absorb, recover, and adapt to shocks such as extreme flooding (Davoudi et al., 2012). Applying resilience principles to evacuation centre planning involves anticipating hazard impacts, safeguarding critical infrastructure, and enhancing redundancy in shelter networks.

Disaster risk governance, as framed by the United Nations Office for Disaster Risk Reduction (UNDRR, 2019), highlights the importance of coordinated policies, participatory decision-making, and transparent allocation of resources in managing disaster risks. This governance lens underscores that spatial planning for ECs should be embedded within broader institutional frameworks, ensuring accountability and sustainability.

By integrating these three perspectives, the present study not only evaluates the geographic distribution of ECs but also interprets the results through lenses of fairness, adaptability, and institutional effectiveness, enabling recommendations that are both spatially targeted and policy relevant.

MATERIALS & METHOD

Kuantan, the capital of Pahang, has been selected as the study area due to its recurrent flooding. The district is highly susceptible to seasonal floods, which pose significant challenges to residential, commercial, and rural areas alike. Recognising the severity of flood risks, the National Physical Plan 3 has classified Kuantan District as a high-risk flood zone, with the city itself identified as

particularly vulnerable to inundation (PLANMalaysia, 2018). Furthermore, the Kuantan Local Plan 2035 highlights that a substantial portion of the district's residential areas remains at risk of flooding (Majlis Perbandaran Kuantan, 2019).



Figure 1: Location Plan of Kuantan
Source: Majlis Perbandaran Kuantan, 2019

DATA COLLECTION

A site visit to Kuantan, Pahang, was conducted in February 2025 to identify and verify the spatial locations of evacuation centres (ECs). This field survey aimed to complement and validate GIS-based spatial data (land use layer) on ECs provided by PLANMalaysia. Additionally, population data for this study were obtained from an open-source platform (WorldPop), in TIFF format. The integration of field data, official spatial datasets, and population distribution information enhances the reliability and accuracy of the study's geospatial analysis. Data on the capacity of evacuation centres were also obtained from the Civil Defence Department, enhancing the assessment of shelter adequacy in relation to the at-risk population.

GIS-based Analysis

This study utilised ArcGIS to analyse the spatial distribution of evacuation centres relative to residential areas, employing geospatial techniques to assess population demand and evacuation capacity. Key GIS processes included spatial

data integration, overlay analysis, and zonal statistics, buffer analysis and site suitability analysis.

1. **Mapping and Plotting EC Locations:** The study began with geocoding and mapping of EC locations in GIS. Spatial data provided by PLANMalaysia were used to generate a point layer representing ECs in Kuantan. This served as the base map for further spatial analysis.
2. **GIS Buffer Analysis:** A GIS buffer analysis using ArcGIS software was conducted to evaluate the spatial coverage of evacuation centres. A buffer zone of a 1-kilometre radius was generated around each EC to represent the standard acceptable walking distance for residents during emergencies. The buffer tool in ArcGIS was employed for this step, creating circular polygons surrounding EC points to illustrate coverage areas visually. Following buffer generation, an overlay analysis was performed by intersecting the buffer zones with the residential land-use layer. This intersection allowed the researchers to calculate precisely how much residential land falls within and outside these 1-km buffers. Additionally, this buffer overlay was intersected with flood-prone residential areas and the population grid dataset to quantify the total residential land area and population effectively served by existing ECs. This approach clearly highlighted spatial disparities and identified locations lacking adequate shelter coverage.
3. **Population Grid Intersection Analysis:** Population data obtained in raster format from WorldPop (2013) were first georeferenced and clipped to match the Kuantan District boundary. Using ArcGIS, the raster data were converted to vector polygons representing grid cells. The intersect overlay analysis was then conducted by combining the population grid data layer with flood-prone residential zones and EC buffer layers. This intersection provided precise quantification of populations residing within flood-prone zones and within the 1-km buffer radius of ECs. The Zonal Statistics tool in ArcGIS further facilitated summarising and extracting demographic information from these intersections, providing detailed insights into the spatial relationship between the population at risk and shelter locations.
4. **Flood-Prone Zone and Residential Overlay Analysis:** An intersect overlay analysis was performed using ArcGIS by overlaying the flood-prone area layers with residential land-use layer. This overlay analysis involved the following technical GIS steps: (1) flood-prone area layers were prepared and validated for spatial accuracy; (2) residential land-use polygon were spatially referenced within ArcGIS; (3) the Intersect tool in ArcGIS was applied to merge the two layers into a single new layer, thereby enabling the precise

quantification of residential land at risk of flooding; (4) EC buffer zones (1-kilometre radius polygons) were subsequently overlaid onto the intersected layers to further quantify the proportion of flood-prone residential areas effectively covered by existing evacuation shelters. This comprehensive multi-layered overlay analysis enabled the identification and quantification of spatial gaps in shelter distribution relative to areas exposed to flooding, providing detailed insights into the effectiveness of current EC placement strategies.

5. **EC Capacity vs. Population Demand Analysis:** To perform this analysis, a spatial join was conducted in ArcGIS between EC locations (point vector data) and the intersected population grid dataset. This involved combining evacuation centre points with corresponding polygon grid cells representing population data derived from WorldPop. The spatial join operation in ArcGIS linked each evacuation centre to nearby population grid cells within the previously generated 1-km buffer zones. Attribute calculations were then carried out within ArcGIS to sum the population counts from grid cells intersecting each EC buffer, thus quantifying the potential demand for each evacuation centre. Subsequently, this calculated demand was compared to the capacity data collected from field.
6. **Suitability Analysis:** To complement the spatial gap assessment, a GIS-based site suitability analysis was conducted to identify optimal areas for future evacuation centre (EC) development in Kuantan. The analysis integrated three spatial criteria:
 - Proximity to existing ECs – areas beyond the 1-km coverage buffer were prioritised, as they represent underserved zones.
 - Flood-prone residential areas – polygons overlapping high flood-risk zones were assigned higher suitability scores.
 - Population density – areas with higher concentrations of at-risk residents received greater weights.

Each criterion was standardised to a uniform scale and assigned a weight according to its relative importance: distance from existing ECs (40%), flood-prone residential areas (35%), and population density (25%). The Weighted Sum tool in ArcGIS was used to combine these layers, generating a continuous suitability surface. The resulting suitability map (Figure 6) was classified into five categories using natural breaks (Jenks) classification (Less suitable; Moderately suitable; More suitable; Very suitable; Extremely suitable). This classification allows for fine-grained prioritisation, enabling decision makers to focus first on “extremely suitable”

and “very suitable” zones where EC coverage gaps overlap with high flood vulnerability and population density.

Sensitivity Analysis were conducted to assess the robustness of the GIS-based suitability analysis, a weight sensitivity test was conducted within the ArcGIS environment. A one-at-a-time variation of each criterion weight ($\pm 10\%$) was applied while keeping the others constant. The recalculated suitability surfaces were then compared with the baseline using ArcGIS overlay and zonal statistics. Across scenarios, the extent of the top-two suitability classes (“extremely suitable” and “very suitable”) changed by less than 5%, and priority zones exhibited more than 80% spatial overlap with the baseline map. These results confirm that the suitability surface generated through the GIS weighted overlay method is stable under reasonable perturbations of criterion weights, thereby increasing confidence in its reliability for planning decisions.

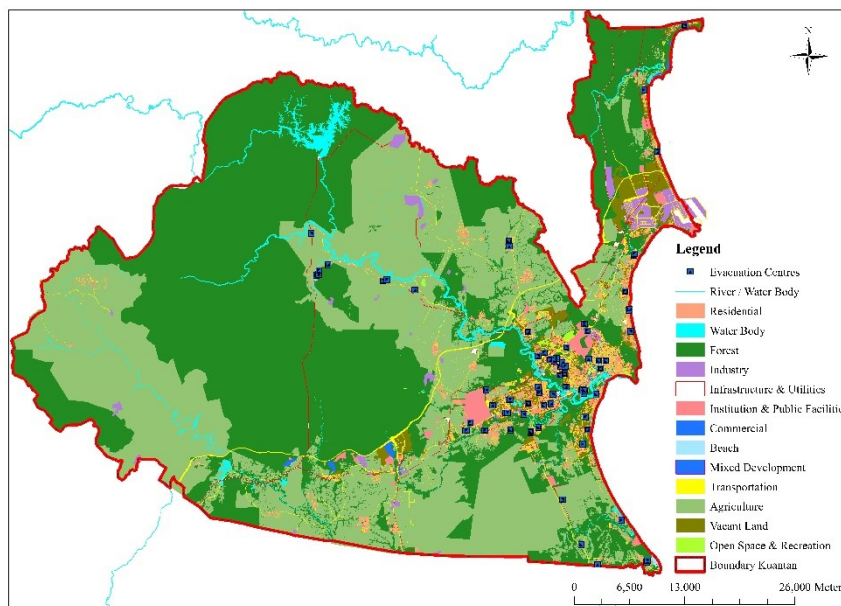


Figure 2: Spatial Distribution of Evacuation Centres

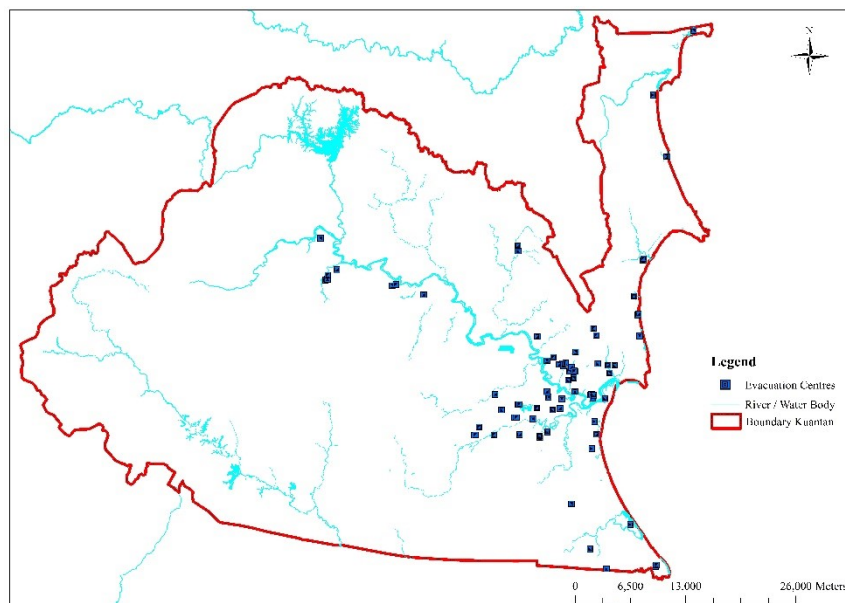


Figure 3: GIS Mapping of Sporadic and Scattered Evacuation Centres

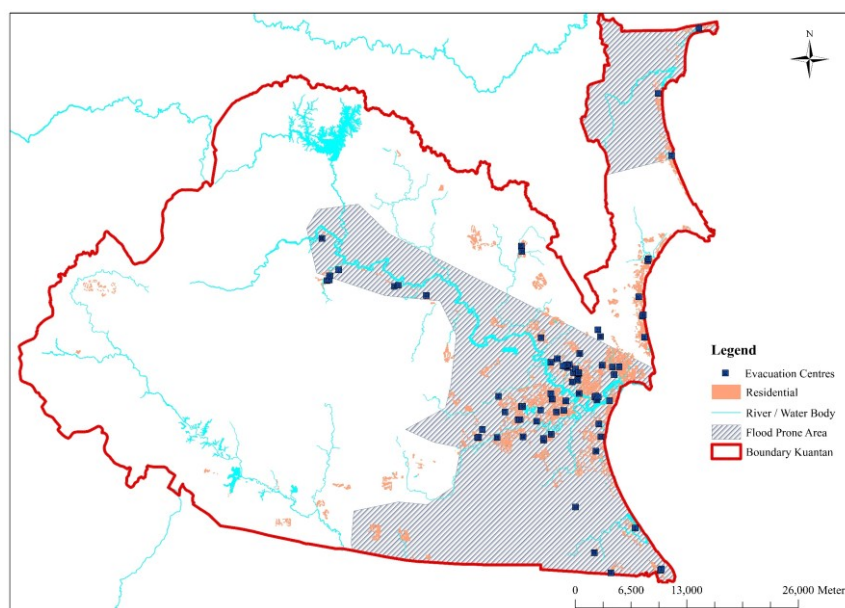


Figure 4: GIS-Based Overlay of Flood-Prone and Residential Area

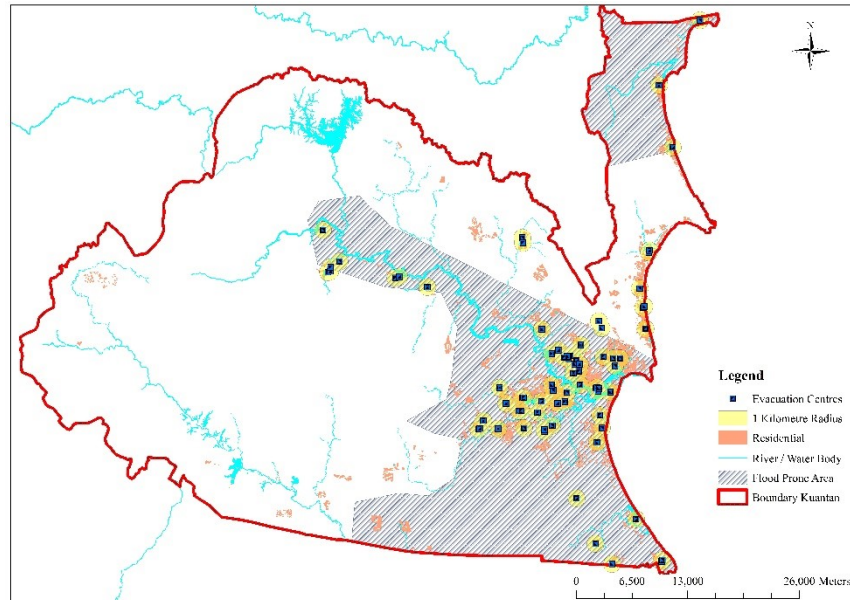


Figure 5: 1-km Evacuation Centre Radius Overlay with Residential and Flood Areas

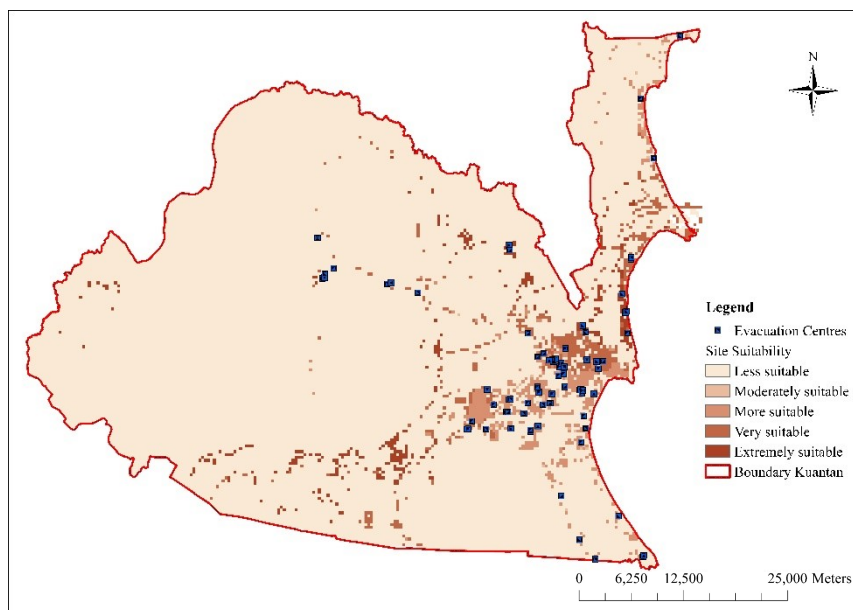


Figure 6: GIS-based Suitability Map

FINDINGS

A total of 85 evacuation centres (ECs) were identified from the collected data. The spatial distribution of ECs was found to be sporadic and scattered, lacking a clearly definable pattern (refer Figure 2 and refer Figure 3). Most ECs were concentrated in Kuantan City, with fewer centres located in peripheral areas, indicating a pattern where the availability of ECs diminishes with increased distance from the city centre. This uneven distribution highlights the challenge in providing equitable shelter access to all residents during flood emergencies.

Sanyal and Lu (2009) emphasise that emergency shelters should be strategically located to serve the maximum number of vulnerable residents, ideally within a 1 km radius of affected settlement areas. Using GIS-based intersect overlay analysis, this study quantified flood vulnerability by identifying that 4,226 hectares (73.51%) of Kuantan's 5,748 hectares of residential land are flood-prone (refer to Figure). The intersect overlay in ArcGIS combined the residential land-use layer with the flood-prone layer to precisely delineate residential areas exposed to flooding.

Buffer analysis further refined this assessment by creating a 1-km radius around each EC to evaluate direct shelter coverage. Results revealed that only 2,476 hectares (59%) of flood-prone residential land falls within this ideal accessibility range (refer to Figure), while the remaining 41% is outside, indicating significant shelter coverage gaps. This detailed GIS analysis indicated that a significant portion of the vulnerable population lacks adequate spatial coverage by existing ECs, highlighting a notable gap in shelter accessibility during flooding events and underscoring the need for strategic shelter placement improvement.

To assess shelter demand, the GIS intersect overlay technique was employed to combine residential areas, population grid cells, flood-prone zones, and buffer areas around ECs. This intersection facilitated precise quantification of residents residing within flood-prone areas that also fall within the 1-km radius of an EC. GIS intersection analysis demonstrated that 119,548 out of 355,140 residents in flood-prone areas live within accessible distances to shelters.

However, the total shelter capacity data from the Civil Defence Agency Kuantan indicated that all 85 ECs combined could accommodate only 29,700 people at one time. Consequently, current evacuation infrastructure is sufficient for approximately 25% of residents within the ideal 1-km buffer zone during large-scale flood events. This finding points to a substantial gap in evacuation centre provision compared to potential evacuation demand, highlighting critical deficiencies in the current emergency planning and management framework.

The suitability analysis (Figure 6) reveals a clear spatial pattern in potential sites for new EC development. Approximately 14% of Kuantan's flood-prone residential areas fall within the "extremely suitable" category. These zones are predominantly located in the northern and eastern peripheries, where current

EC coverage is sparse and travel distances exceed the recommended 1 km evacuation radius.

The “very suitable” category accounts for an additional 21% of the flood-prone residential land. These areas often exhibit moderate-to-high population densities combined with insufficient proximity to existing shelters. Together, the “extremely” and “very suitable” zones comprise 35% of at-risk residential land, representing the highest priority for infrastructure investment.

The “more suitable” category covers 26% of flood-prone residential areas, generally located in semi-urban zones where shelter capacity may still be inadequate during large-scale events. The “moderately suitable” and “less suitable” categories account for 39% combined, largely overlapping with zones already served by ECs within walking distance.

Sensitivity results confirmed robustness: the combined ‘extremely’ + ‘very suitable’ area varied within $\pm 5\%$ across weight scenarios, and the priority polygons exhibited $>80\%$ overlap with the baseline, supporting their reliability for planning. This classification provides a nuanced spatial prioritisation, allowing local authorities to sequence EC development in phases beginning with “extremely suitable” and “very suitable” areas to maximise coverage for underserved populations most vulnerable to flooding.

DISCUSSION

The findings of this study highlight critical spatial and capacity-related challenges in Kuantan’s evacuation centre (EC) network. The GIS-based spatial analysis confirmed that ECs are unevenly distributed, with a high concentration in Kuantan City and a notable scarcity in peripheral and rural areas. This pattern directly raises concerns of spatial inequity, as a significant proportion of flood-prone residents in outlying zones remain beyond the recommended 1-km evacuation radius.

The buffer analysis showed that only 59% of flood-prone residential land falls within optimal accessibility to ECs, leaving 41% underserved. Population-overlay analysis further revealed that just 34% of the vulnerable population resides within the recommended walking distance, and existing shelters collectively meet only 25% of the capacity needs for those in the covered zone. From a resilience planning perspective, these figures indicate a limited ability to absorb and respond effectively to large-scale flooding events.

The suitability analysis offers a more nuanced view of future planning priorities. Approximately 14% of flood-prone residential land is classified as “extremely suitable” for new EC placement, concentrated in the northern and eastern peripheries of Kuantan. These areas combine high flood risk, high population density, and lack of current EC coverage representing the most urgent locations for intervention. An additional 21% falls under the “very suitable” category, also underserved but with slightly lower flood exposure or population

concentration. In total, 35% of at-risk residential land ranks in the top two suitability classes, providing a clear, evidence-based foundation for phased infrastructure expansion. The weight-sensitivity check indicates the priority zones are stable to reasonable changes in criteria weighting, strengthening confidence in using the map for staged investments.

Comparable challenges have been reported in other flood-prone contexts. In Metro Manila, Philippines, Chen et al. (2020) found severe overcrowding in centrally located shelters and lack of access in peripheral barangays, echoing Kuantan's urban-rural disparity. In Jakarta, Indonesia, (Kusumo, 2016) documented a similar concentration of shelters in urban cores, forcing residents in suburban communities to travel beyond recommended evacuation distances. In Bangladesh, Alam et al. (2021) reported that over half of rural households in flood-prone regions were located more than 1.5 km from designated shelters, significantly increasing evacuation delays. These international parallels suggest that the concentration of ECs in urban cores is a recurring issue in many Southeast Asian flood contexts, often linked to centralised infrastructure planning and inadequate integration of hazard exposure data into site selection.

From a disaster risk governance perspective, the results underscore the need for coordinated, multi-level planning involving local government, community stakeholders, and technical experts. Integrating the suitability map into municipal development plans could ensure that resource allocation is both data-driven and socially equitable. Such integration would also support Malaysia's commitments under the Sendai Framework for Disaster Risk Reduction, which calls for strengthening disaster preparedness and building resilience at all levels.

In sum, applying the combined lenses of spatial equity, resilience planning, and risk governance reveals that Kuantan's current EC network not only lacks spatial balance but also risks leaving its most vulnerable populations underserved during future flood events. Targeted expansion into "extremely suitable" and "very suitable" zones offers the most effective pathway to improving equitable access, reducing evacuation times, and strengthening the district's overall flood resilience.

CONCLUSION

Using GIS-based spatial analysis within the frameworks of spatial equity, resilience planning, and disaster risk governance, this study identified major gaps in Kuantan's evacuation centre network. Forty-one per cent of flood-prone residential land and 66% of vulnerable residents lie beyond the recommended 1-km coverage, while existing shelters can serve only 25% of those within reach. The suitability analysis highlights 14% of land as "extremely suitable" and 21% as "very suitable" for new ECs, concentrated in underserved, flood-prone

peripheral areas. Addressing these priority zones through targeted expansion and capacity upgrades can significantly improve equitable access and reduce evacuation times. The findings and approach are applicable to other flood-prone cities, offering a replicable, data-driven method to guide fairer and more resilient disaster preparedness planning.

The research contributes by providing a detailed, spatially explicit analysis that identifies specific areas needing improved evacuation infrastructure, thus guiding strategic planning decisions. Future studies should integrate real-time population dynamics and detailed accessibility analyses to further enhance flood preparedness and community resilience.

ACKNOWLEDGEMENT

This work was supported by a Universiti Sains Malaysia, Short-Term Grant with Project No: R501-LR-RND002-0000000729-0000.

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Received: 2nd May 2025. Accepted: 10th September 2025