GIS-based multi-criteria analysis to identify site suitability of flood shelters in Kuantan, Malaysia

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Abstract. The aim of this paper was to identify site suitability of flood shelters in Kuantan by using GIS based multi-criteria analysis integrated with Analytic Hierarchy Process. Based on the developed criteria range, result shows that, 21% of flood shelters in Kuantan are located at unsuitable places; 32% of the shelters are located at moderate to more suitable site; 39% of the flood shelters are located at very suitable site; and 8% of the shelters are located at extremely suitable site.

1. Introduction
The effect of flooding, the number of vulnerable cities, and population continues to grow worldwide. Experts therefore believe that post-event response needs to become more effective and to rely on science and emphasize the need for local councils to set up emergency response management to enhance urban disaster resilience [1–6]. Priorities for local authorities to handle the increased number of climate related disasters should include providing safe shelters for the affected population [7,8] provided that creating flood shelter or evacuation centers within cities is an effective method to increase resilience in the society [1].

In disaster-prone developing countries such as Malaysia, flood shelters should be located effectively, with safety in mind, as floods is one of the most damaging natural disasters affecting 4.9 million people and causing several million Malaysian Ringgit losses every year [9]. Moreover, annually, thousands of people have to evacuate their homes to a shelter or designated evacuation area in Malaysia. For instance, in the years 2016-2017, approximately 95,929 victims had to evacuate due to floods [10]. Since the number of flood victims and evacuees in Malaysia has been significantly high annually, securing flood shelters across the country is among the most important tasks of flood risk management in Malaysia.

However, creating flood shelters alone is not enough, as there are other important factors to consider such as the site suitability of the shelters. Previous studies also demonstrated the value of enhancing disaster preparedness by recognizing and providing adequate areas for emergency shelters prior to disasters [2,11–13]. The selection of a suitable flood shelter site is a crucial point in the planning of shelters, as candidate shelters can be unsafe and therefore more damaging than anticipated. For example, the study of Southern Florida shelters showed that 48% of established shelters and 57% of candidate shelters were located in physically inappropriate locations [14,15].
In Malaysia, there have been several occasions when evacuees have had to vacate the flood shelters to seek shelter at a different place due to flood shelters being inundated [16]. For example, evacuees had to move to another flood shelter in Pahang after the flood shelter in SK Sungai Ular, Kuantan was inundated [17]. This shows why examining the site suitability of existing shelters is important. Yet, far too little attention has been paid to examine the site suitability of existing flood shelters in Malaysia. Therefore, the objective of this study is to identify the site suitability of flood shelters in Kuantan, Malaysia by using multi-criteria GIS-based analysis.

2. Site suitability criteria for flood shelters

The criteria used by decision-makers for suitable site selection are geographical, which means that the site selection process is a spatial decision challenge [18]. Spatial decision-making issues also call for a large number of alternatives to be tested on the basis of several criteria, since spatial decisions are multi-criteria in nature [18].

The realistic approach to reduce flood hazards in densely populated developing countries is to construct flood shelters in highly flood-prone settlement areas in order to provide maximum protection for planning units and minimize the overall risk of vulnerable communities [19]. This indicates that flood shelters should be placed within the current residential area or within 1 km radius of each residential area [2,20,21]. Findings from Kusumo [20] reveal that the majority of people prefer to evacuate within one kilometer of their own residential area and do not prefer flood shelters outside their own residential area. Analyzing the radius of flood shelters in settlement helps in determining the coverage and adequacy of flood shelters for affected populations.

The basic setting of flood shelters is not to be located at any area that is most likely to be inundated. Specifically, various international emergency shelter guidelines state that safe flood shelters should not be located in flood prone area or within the 100-year floodplain [22–30]. This is because shelters in flood-prone areas may be vulnerable to damage from hydrostatic and hydrodynamic forces associated with rising flood waters and can pose an additional risk to occupants [24,25,27]. Moreover, there should be no possibility for river flooding in the region around a shelter that could flood roads and block access to shelters [31]. Study by Kongsomsaksakul, Yang and Chen [32] and Kusumo [20] stated that the ideal distance of shelters should be within one kilometer distance outside of the flood prone area.

In addition to the above, topography, elevation, and slope of the flood shelters are also important factors in the placement of flood shelters due to the risk exposure and hazard vulnerability [14,20,33,34]. This is because topography affects the flood severity, flow size and direction [14,33,35,36]. Usually, areas which have a lower elevation are more affected by flood than higher land. Low-lying area is regarded as the most vulnerable area in a flood as a result of rapid inundation due to gravity effect on the water flowing into low-lying area and remaining there for a long time due to elevation [33,35,36].

Therefore, it is imperative that a suitable flood shelter site be located at either an available land on a higher elevation, or have a structure that may be elevated through construction [25,37]. This is also supported by the International Federation of Red Cross and Red Crescent Societies [26] who set the standard of flood shelters to be sited above the highest estimated flood level.

A considerable amount of literature has been written on the role of slope in the design of emergency shelters location [20,38–43]. It is said that location of flood shelters shall avoid slopes gradients of 30 or higher to prevent the risk of landslides/mudslides during heavy rainfall [8,28,29]. Flood shelter sites should not be located at fault lines, and slopes should not exceed 7%, preferably between 2% and 4% [38,40]. On the contrary, Kusumo [20] and The Sphere Project [29] stated that a suitable area of emergency shelter should be on a slope not exceeding 5%, unless extensive drainage and erosion measures are taken to provide adequate drainage to minimize flooding and ponding. Furthermore, in ‘Guidelines for Creating Barrier-free Emergency Shelters for Disaster Preparedness and Disability Nepal’ [44], the slope criteria of shelter were clearly defined to not exceed 1:15 to ensure handicapped person and persons using wheelchair can easily access the shelter.
Land use is another important component in defining suitable spatial locations for flood shelters [20,21,34]. Shelters should be located away from hazardous facilities such as industrial area to avoid any harmful incidents of fire or explosion [2,13,20,45]. Flood shelters must also be sited away from locations at risks of secondary disaster such as landslides during heavy rain [2,26,28,38,45]. Furthermore, when selecting evaluation indicators, the domestic and international experience and the predecessors’ research and the natural geographical features of the study area should be integrated. Therefore, a universal ready-made emergency shelter suitability evaluation model is not applicable in every context [46].

All of the above recommended criteria for suitable flood shelter locations according to literature can be summarized as follows: 1) Flood shelters should be situated in a residential area so that it can provide full protection for planning units and minimize the overall risk to vulnerable communities.; 2) flood shelters should be located outside flood prone areas; 3) flood shelters should be located on a slope not exceeding 7%, preferably between 2% and 5% elevation; 4) flood shelters should be located away from industrial area; 5) flood shelters should be sited away from areas at risk of secondary disasters such as landslides, 6) flood shelters should be located in one kilometer radius of residential area to give maximum protection coverage to affected population.

3. Methodology

3.1. Study area

The selected area of study is Kuantan, Pahang, Malaysia, which is listed as a high risk of flooding district under the National Physical Plan 3 (NPP3), and defined by the Kuantan Local Plan 2035 to have the majority of residential neighborhoods deemed as risk areas for flooding [47]. This indicates the need to examine the suitability of existing flood shelters in Kuantan to increase the area’s resilience.

Kuantan District is 296,042.09 hectares or 8.20% of the total size of the State of Pahang in Malaysia. The capital city and main administration of Pahang are in Kuantan District (Kuantan City). The district has a population of 443,796 [47]. Land use in the study area mainly consists of forest reserves (158,244.82 hectares, 53.45%) followed by agriculture (111,989.15 hectares, 37.83%). The overall built area in Kuantan District is 5.3%, comprising residential (1.94%) and institutional and public facilities (1.32%). Other land uses, such as commercial areas, industry, infrastructures and utilities, are between 0.2% and 1% and are considered minor. Urbanization in the district is centralized at the city center while the west side of the district is dominated by forests and agriculture.

![Figure 1. Study area](image-url)
3.2. Data collection
The suitability analysis data were gathered from four different sources. Location of flood shelters were collected by reviewing past flood reports, and site visit to Kuantan in January 2020.

The number of flood evacuees for flood shelters in Kuantan were collected by phone interviews with Civil Defense Kuantan in August 2020. Spatial data to be processed in GIS such as land use, flood prone area, and location of landslides were collected during interviews with flood-related agencies in Malaysia in February 2019 and January 2020. Data received were already in GIS ‘shapefile’ by PLANMalaysia (formerly known as Town and Country Planning Department, Malaysia) and Department of Irrigation and Drainage, Malaysia.

The highest recorded level of flood data was obtained through reviewing flood reports by Department of Irrigation and Drainage Malaysia. However, during data collection, elevation and slope data were not available. Therefore, elevation and slope data were extracted from NASA’s Shuttle Radar Topography Mission (SRTM) in GPX format, converted to feature in ArcGIS in order to create the Digital Elevation Model and slope map.

The population data for this study was collected from the Department of Statistics Malaysia and through open source of ‘WorldPop’ [48] in TIFF format. Moreover, this study used Open Street Map as the road network dataset (in QGIS). Overall, software used for this research were ArcGIS and QGIS.

3.3. Analysis techniques
The greatest benefit of an integrated multi-criteria analysis in GIS is the ability to simultaneously evaluate both quantitative and qualitative criteria [49]. In order to construct GIS based multi-criteria analysis, this study integrates the weighted overlay analysis with Analytic Hierarchy Process (AHP) (refer to sub-topic 3.3.1).

ArcMap was used to create the map and boundary for the study area. The topographic mapping of Kuantan District was derived from a digital elevation model (DEM) to investigate the elevation variations and the slope of the land surface. By using the Conversion Tool GPX to Feature, this study managed to extract SRTM elevation data to ArcMap in terms of elevation points. The data was then processed by using Analysis Tools-Raster Interpolation and IDW to create the DEM. From the DEM, a slope map was produced by using 3D Analyst-Raster Surface-Contour.

In order to identify whether the flood shelters were located in the hazard prone area or outside the risky area, Euclidean Distance Tools was used. By creating a raster layer, it was possible to identify the location of flood shelters in relation to the hazard area. The ‘Proximity’ tool was used to identify the distance of flood shelters from landslides area. In analyzing the proximity and radius of flood shelters, this study used the buffer analysis and Overlay-Intersect tool. To determine the vulnerable population (those living in the flood-prone areas), this study extracted population data from the ‘TIFF’ format of the World Population [48] and used the Zonal Statistic and Clip tool to extract population data for each grid cell of the base map.

3.3.1. Determining criteria weights using AHP
In weighted overlay analysis, determination of weight is very important, and therefore, the decisions made need to be confirmed by multiple decision-making analyses which is the AHP [50]. Analytical Hierarchy Process (AHP) is an efficient multi-criterion decision-making approach that allows the decision-maker to tackle a complex problem with multiple competing and subjective criteria [51]. The AHP approach incorporates mathematics and psychology in dealing with complex decisions and turns them into a simplified form of hierarchy. The decision on the dominance of one criterion over another is based on the authors' experience and the literature review [52].

AHP can be used for ranking alternatives and measurement of criteria weights by pairwise comparison matrix, where each criterion is evaluated by arranging all possible pairings on a ratio scale to express comparative significance with numerical values [52,53]. Numerical expressions of AHP are defined from range 1-9. The weight criterion is 9 (Extremely suitable); 7 (Very suitable); 5 (More
suitable); 3 (Moderately suitable) and 1 (Not suitable) [52–54]. In GIS the scale can be further reclassified as 0 or No Data or Restricted if certain criteria need to be excluded.

3.3.2. Weighted overlay analysis

Multi-criteria assessment is an operational method for resolving decision-making problems using multiple criteria [51,55–57]. GIS could assist in categorizing, evaluating and properly arranging usable data on choices (multi-criteria) for spatial planning [51,58].

Weighted Overlay Analysis (WOA) was implemented after calculating weights for each criterion to estimate site suitability of flood shelters. WOA is the approach most widely used in GIS-based site suitability, site selection or assessment studies, and both a quantitative and a qualitative approach can be applied to this method [27,59,60]. In this study the weight was calculated based on flood shelter suitability criteria. In the qualitative process, a subjective opinion-based methodology can be used to establish weights for each variable [27].

From the overlay analysis, values in the raster were reclassified to a common 1 (least suitable) to 9 (highly suitable) suitability scale. The final suitability maps are further classified into (1) not suitable site, (2) moderate to more suitable, (3) very suitable site and (4) extremely suitable site.

4. Results

4.1. Settlement and population at risks of flooding (social suitability)

The study identified 85 existing flood shelters in Kuantan. The shelter’s distribution was sporadic and scattered, and most of the shelters were located in the city area of Kuantan. The number of flood shelters showed a distance-decay nature; decreasing as distance from the city center increased (residential area are centralized in the city center, refer to Figure 2).

An emergency shelter must be located at a place where it can serve the maximum number of its vulnerable neighbors which is in one kilometer radius of settlement area [21]. Kar and Hodgson [27] in their study stated that emergency shelter site suitability criteria must consider the total population in its neighborhood, which means that higher populations are more desirable. Adopting the same technique as Kar and Hodgson [27], the population in the study area was spatially distributed using a standard disaggregation method, assuming equal densities within census units. In terms of social variables of the flood shelters, the study found that flood shelters of Kuantan are located in areas with high concentrations of total population (refer to Figure 2 and Figure 7).

This study used intersection of population grid cells in GIS and identified that 119,548 people out of 355,140 people in the flood prone area were in one kilometer radius from the flood shelters (refer to Figure 2). However, collectively the capacity of the flood shelter was only for 29,700 people (8% from the population in flood prone areas) at any one time. This study did not calculate the capacity of the flood shelters as the capacity had been decided by the government and included in the data collected during site visit.

By intersecting the overlaid layers in ArcGIS, the study found that 4226 (73.51%) hectares out of 5748 hectare of residential area of Kuantan was located in flood prone area (refer Figure 2). The existing flood shelters were centralized at densely populated residential areas. The buffer analysis was used to identify whether the flood shelters are within one kilometer radius from residential area. 2,476 hectares (59%) of residential area in flood prone area are in within one kilometre radius from flood shelters (refer Figure 2). The remaining 41% of residential area in flood prone area unfortunately did not have access to flood shelters within one kilometer.

Assuming there is a large-scale flood, the existing flood shelters would only be able to accommodate 25% of the affected population in 1 km radius. The imbalance between shelter distribution, capacity, and vulnerable population was due to improper shelter allocation in emergency planning. Another point of consideration is that in Malaysia, or Kuantan specifically, the concept of Collective Shelters which promotes the use of existing buildings in the area as flood shelters (e.g. schools and public halls) was being implemented. As such, since the focus was on existing buildings,
there was no proper spatial planning related to risk reduction or disaster management in placing the buildings. Local Authority of Kuantan also allowed their residents to renovate houses in order to add extra storey(s) to the house structure to avoid flood and to make use the concept of ‘shelter in place’ (based on interview with Local Authority of Kuantan).

By looking at the capacity and population alone it might seem that the capacity of flood shelters were inadequate. However, an interview with Civil Defense Force of Kuantan revealed that in 2017 only 842 victims needed to evacuate; in 2018 only 8,388 evacuees; while in 2019 there were no flood disaster in Kuantan. The limitation in evacuee data being limited to only years 2017 to 2019, is because prior to 2016, the Civil Defense Force Kuantan did not have any system to record the number of evacuees.

Thus, although by considering the number of population living in flood plain area, the capacity of flood shelters was not adequate, looking at the past number of evacuees shows that the flood shelters were actually enough to accommodate the evacuees. However, in light of climate change and possibility of inundation beyond reasonable forecast, it is highly recommended to increase the capacity and number of flood shelters for an impending large scale catastrophe.

![Figure 2. One kilometre radius of flood shelters](image)

4.2. Flood prone area

An analysis to determine location of flood prone area of Kuantan was conducted by using flood prone layer. By using Intersect Overlay in ArcGIS to determine size and population of flood prone area, the study found that 168,292.9 hectares out of 296,042 hectare of Kuantan District was at risk of flooding, which is 56.8% off the total area of Kuantan. By using intersection analysis, study found that 355,140 people were living in flood prone area, implying that 80% of Kuantan’s population was at risk of exposure to flooding. If flood prone area is considered as the only suitability variable without considering the other suitability indicators, only 18% of existing shelters were spatially located at suitable sites while the rest of the shelters (82%) were spatially located in flood prone area (refer to Figure 3).
4.3. Secondary disaster (landslide)
Secondary disasters that usually occur after heavy rainfall in Malaysia are landslides [61]. By using the disaster GIS layer provided from PLANMalaysia, this study managed to identify that not all flood shelters were located away from the low risk of landslides (refer to Figure 4). By using proximity tool, the study found that 4% of the flood shelters are located at 1.4 km to 1.9 km distance to possible landslides area, while the rest 96% of the shelters were located more than 9.4 km away from landslide prone areas. A distance of more than 3 km from landslide prone area is more suitable for emergency shelter [14,62]. This reflects a 'relatively low chance of landslides and thus suggests that the shelters would most likely not be hit by landslides.
4.4. Elevation
By producing Digital Elevation Model (DEM) in ArcGIS, this study managed to determine elevation of each flood shelter (refer to Figure 5). Based on DEM, 2% of the flood shelters were located at elevation of 5 meters and below; 45% of shelters were located at elevation 5.1 to 10 meters; 12% of shelters were located at 10.1 to 15 meters of elevation; and the remaining 41% of the shelters were located at above 15 meters’ elevation. The highest elevation at flood prone area was 41 meters. The western part of Kuantan is at high elevation and are not affected by flood, however the land use of this area is forest reserve and development is restricted by law [47].

4.5. Slope
Flood shelters should be located on a slope not exceeding 7%, preferably between 2% and 5%. Slope gradient is important to ensure easy access for victims with wheelchair and for transporting goods. The value of slope in constructing secure emergency shelters has also been stressed by the International Federation of Red Cross and Red Crescent Societies [26]. By producing the slope map, this study identified 1% of the flood shelters located at slope exceeding 7% and considered as not suitable for flood shelters. 86% of the flood shelters were located on <1.5% slope; 9% of the shelters located on up to 4% of slope and 4% of the shelters were located on a slope between 4% to 7%. By referring to the slope criteria, 99% of the flood shelters were located on acceptable slope range.

Figure 5. Elevation of Kuantan
4.6. Weighted overlay site suitability analysis

In order to analyze the final site suitability, all of the variables (criteria) in GIS findings mentioned above were converted to raster, reclassified and overlaid by using Weighted Overlay function of the Spatial Analyst toolbox. The weight was processed by using AHP scale in order to get the final suitability results.

In this study, restricted values were used to exclude certain areas from the analysis due to their unsuitability for being a potential site owning to other secondary risks, such as landslide, or being unusable on account for their land-use. As 91.23% of Kuantan land-use is designated as forest reserve and agriculture area, these areas were classified as restricted. Industries were classified as restricted as well as flood shelters should not be built near industrial area.

The influence (%) AHP in GIS of every weight was set as equal, as all criteria are important in suitability analysis. Strong concentrations of people (Figure 7) and residential areas in need of flood shelters were present in the center of Kuantan. From the final site suitability map (combining social suitability and physical suitability), the study was able to identify that 21% of flood shelters in Kuantan were located at in unsuitable places; 32% of the shelters were located at moderate to more suitable sites, 39% of the flood shelters were located at very suitable sites; and 8% of the shelters were located at extremely suitable sites (refer to Figure 8). The less suitable sites were located near industrial area, river, beach and landslides area.
5. Discussion
The goal of this study is to determine the site suitability of flood shelters in Kuantan, Malaysia, by using GIS-based multi-criteria analysis. The flood prone area map (Figure 3) shows the areas previously affected by floods in Kuantan. This shows that 56.8% of the area are categorized as flood prone area, which is 168,292.9 hectares out of 296,042 hectares (the total area of Kuantan). Based on the analysis, 82% of the flood shelters were located in flood prone areas which are initially unacceptable in our defined criteria.

However, through another point of view, a study by Chowdhury et al [19] in Sanyal and Lu [21] stated that, the effective approach to reduce flood hazards in densely populated developing countries is to construct flood shelters in highly flood-prone settlement areas in order to provide maximum protection for planning units and minimize the overall risk of vulnerable communities. This was also
evidenced in the study of Kusumo [20] who stated that the majority of the people surveyed preferred to evacuate in the flood prone area if it was located in their residential area.

In this case, it is acceptable that most of the flood shelters were located in flood prone area because 73.51% of residential area were located in flood prone zone. In addition, 95% of the flood shelters were located in or near residential area. Buffer analysis and intersect overlay managed to identify that 93.42% of residential area in flood prone area were within one kilometer radius from flood shelters.

The capacity of the existing flood shelters in Kuantan could only collectively accommodate 29,700 people. However, the population at risk of flooding was estimated to be 355,140 people. In addition, considering 6.57% of affected residential area were out of one kilometer radius from flood shelters, it shows that the proportion of flood shelters versus the affected residential area and population was not adequate. On the other hand, it is clear that the decision of flood shelters sitting had not been scientifically done. It also shows the need of more flood shelters to support the disaster-affected residential area. 86% of the flood shelters were located on slopes with less than 1.5% gradient. The remaining flood shelters were located at slope below 7% gradient and were suitable in terms of topography characteristics of locations. Only 1% of the flood shelters were located in locations with a steep slope.

The analysis of all flood shelters was done collectively as it provided the opportunity to examine the overall coverage of existing flood shelters in Kuantan with the potential to identify where new or additional flood shelters might be needed. Based on the site suitability, 21% of flood shelters in Kuantan were located at unsuitable places. 32% of the shelters were located at moderate to more suitable sites; 39% of the flood shelters were located at very suitable sites; and 8% of the shelters were located at extremely suitable sites. The sites of flood shelters that were categorized as unsuitable were located near industrial area, near low places of low risk of landslides, or on steep slopes, or on low elevation near streams and the beach with high possibility of inundation and secondary disaster. These findings are consistent with Kar and Hodgson [27] and Kusumo [20] mentioned that emergency shelters located near industrial area, stream and beach must be considered as physically unsuitable.

6. Conclusion and recommendation

Overall, only 47% of flood shelters in Kuantan were located at spatially suitable sites. The exogenous factors affecting the suitability level of existing flood shelters lies within the top-down approach of flood risk management Malaysia (phase of flood preparedness and flood response). Regulations and guidelines of suitability site for flood shelters need to be formulated in Malaysia in order to increase the society’s resiliency. Governments need to take actions to increase the number of flood shelters in order to protect vulnerable residential areas. This study is an effort to improve the flood preparedness and climate change mitigation in order to increase the resiliency of the country.

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