Geohazard Assessment in the Kota Kinabalu area, Sabah, Malaysia

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Abstract. This study focused on the Flood Susceptibility Analysis (FSA) and Landslide Susceptibility Analysis (LSA) of the Kota Kinabalu area, Sabah by using Multi Criteria Evaluation Model (MCE) for FSA and Deterministic Model for LSA. The study area had been affected by flood and landslide throughout the years. The aims of this study are to determine the flood susceptibility level and landslide susceptibility level of the study area and to identify the contributing factors that leads to the geohazards. Thus, a few mitigation measures can be recommended. The contributing factors that leads to the geohazards had been identified through desk studies and fieldwork. The data were obtained and digitized using ArcGIS software and the thematic maps were produced. The factors that contributing to the geohazards such as slope gradient, elevation, topographic curvature, flow accumulation and drainage distance were retrieved from the topographic database, whereas the land use, rainfall, soil types and soil properties were obtained from various agencies. Several areas are considered as susceptible, such as areas of Taman Kingfisher, Kg. Bantayan, Menggatal area, and Kg. Tebobon. To avoid or minimize the flood disasters, the Flood Susceptibility Level Map and the Landslide Susceptibility Map can be used in future development planning and a few structural controls can be implemented such as the land use planning of the area and hazard zoning. This study can be used as a resource for consulting, planning agencies and local governments in managing risk, land-use zoning and remediation efforts to mitigate risks.

1. Introduction
The Kota Kinabalu area are prone to geohazards mainly on flood and landslide. These geohazards are the most too occurred in the study area compared to other geohazard such as earthquake. This is due to the rapid urbanization of the study area which include slope cutting, deforestation and other development activities. Figure 1 shows the past cases of geohazards occurred in the study area.

In August 2017, a series of flood occur in Kota Kinabalu affecting several places such as Menggatal and Kg. Rampayan due to the heavy rainfall. At the same time, the heavy rainfall also triggered a few landslides to occur in the study area at Plaza Karamunsing and City Mall. The main objectives of this study are: a) to identify the main geohazards in the study area; b) to assess the factors affecting the geohazards occurrence in the study area; c) to determine the geohazard potential level of the study area; and d) to suggest the suitable mitigation measures for minimizing the geohazard effect in the study area. It is hoped that the outcome of this study can be a reference to the
local authority and other agencies for urban planning and flood mitigation. Figure 2 shows the base map of the study area.

Determining the flood and landslide susceptible/vulnerable areas is very important to decision makers for planning and management of activities. Decision making is a choice or selection of alternative course of action in many fields, both the social and natural sciences. The inevitable problems in these fields necessitated a detailed analysis considering many different criteria. All these criteria need to be evaluated for decision analysis [1-3]. For instance, Multi Criteria Evaluation (MCE) methods has been applied in several studies since 80% of data used by decision makers are related geographically [4-5]. Geographic Information System (GIS) provides more and better information for decision making situations. It allows the decision makers to identify a list, meeting a predefined set of criteria with the overlay process, and the multi-criteria decision analysis within GIS is used to develop and evaluate alternative plans that may facilitate compromise among interested parties [6-8].

Figure 1. Past cases of landslides and flood geohazard.
Figure 2. Base map of the study area.

2. Materials and Methods

Two models were used to determine the FSL and LSL which are the AHP Model for flood and Deterministic Model for landslide. Figure 3 shows the flowchart of the study.

2.1 Phase 1
Phase 1 involved desk studies and fieldwork to determine the parameters affecting the flood and landslide. After the parameters were determined, its data from various agencies were obtained. The base map of the study area was also prepared in this phase and a few locations was pinpoint for fieldwork.

2.2 Phase 2
Phase 2 were carried out after the data had been obtained. The data obtained was digitized using ArcGIS software. Based on the previous study by [9], the weighted value calculated can be applied in the study area (Table 1). In this study, eight parameters had been identified and used in the equation below. The weighted value for each parameter determines the effects of the parameter to the flood disaster. The higher weighted value is the most affecting factors in the flood disaster.

\[ (32.53 \times \text{Rainfall}) + (22.74 \times \text{Drainage Density}) + (15.84 \times \text{Flow Accumulation}) + (11.08 \times \text{Landuse}) + (7.19 \times \text{Elevation}) + (4.89 \times \text{Slope Gradient}) + (3.35 \times \text{Soil Textures}) + (2.38 \times \text{Slope Curvatures}) \]  

Figure 3. Methodology flowchart.

Each parameter is divided into its sub-parameters and the thematic maps was produced. Using the data in Table 1, thematic maps of the parameters were produced, and each sub parameter were assigned with the corresponding weightage.
Table 1. The weighted value of the parameters and sub parameters.

| Main Parameters | Total Weighted | Sub Parameters | Weighted Values |
|-----------------|----------------|----------------|----------------|
| Rainfall        | 0.3253         | 0 – 40 mm      | 0.0624         |
|                 |                | 41 – 100 mm    | 0.0986         |
|                 |                | 101 – 200 mm   | 0.1610         |
|                 |                | 201 – 300 mm   | 0.2618         |
|                 |                | > 300 mm       | 0.4162         |
| Drainage Density| 0.2274         | 0 – 50 m       | 0.4162         |
|                 |                | 51 – 100 m     | 0.2618         |
|                 |                | 101 – 150 m    | 0.1610         |
|                 |                | 151 – 200 m    | 0.0986         |
|                 |                | > 200 m        | 0.0624         |
| Flow Accumulation| 0.1584         | Very Low       | 0.1238         |
|                 |                | Low            | 0.1470         |
|                 |                | Moderate       | 0.1402         |
|                 |                | High           | 0.2278         |
|                 |                | Very High      | 0.3612         |
| Landuse         | 0.1108         | Residential    | 0.3162         |
|                 |                | Commercial     | 0.2509         |
|                 |                | Institution & School | 0.2193 |
|                 |                | Public         | 0.1380         |
|                 |                | Infrastructures| 0.0756         |
|                 |                | Agricultural & Forestry | 0.0756 |
| Elevation       | 0.0719         | < 5 m          | 0.2940         |
|                 |                | 6 – 10 m       | 0.2681         |
|                 |                | 11 – 20 m      | 0.2113         |
|                 |                | 21 – 30 m      | 0.1507         |
|                 |                | > 30 m         | 0.0759         |
| Slope Gradient  | 0.0490         | 0 – 5 (o)      | 0.0623         |
|                 |                | 6 – 15 (o)     | 0.0986         |
|                 |                | 16 – 30 (o)    | 0.1611         |
|                 |                | 31 – 60 (o)    | 0.2618         |
|                 |                | > 60 (o)       | 0.4162         |
| Soil Textures   | 0.0335         | Lokan          | 0.0199         |
|                 |                | Weston         | 0.0308         |
|                 |                | Tanjung Aru    | 0.0323         |
|                 |                | Kinabatangan   | 0.0433         |
|                 |                | Tuaran         | 0.0595         |
|                 |                | Dalit          | 0.0811         |
|                 |                | Crocker        | 0.1102         |
|                 |                | Sapi           | 0.1495         |
|                 |                | Brantian       | 0.2018         |
|                 |                | Klias          | 0.2716         |
| Slope Curvatures| 0.0238         | Convex         | 0.5389         |
|                 |                | Concave        | 0.2973         |
|                 |                | Straight       | 0.1638         |

For Deterministic Analysis, the thematic maps were produced based on the following equation:
\[ F = c' + (\gamma - m \gamma w) z \cos^2 \beta \tan \phi' / \gamma z \sin \beta \cos \beta \]  

in which:
- \( c' \) = effective cohesion (kPa = kN/m²).
- \( \gamma \) = unit weight of soil (kN/m³).
- \( z \) = depth of failure surface below the surface (m).
- \( zw \) = height of groundwater table above failure surface (m).
- \( m = zw/z \) (dimensionless).
- \( \gamma w \) = unit weight of water (kN/m³).
- \( \beta \) = slope surface inclination (°).
- \( \phi' \) = effective angle of shearing resistance (°).

2.3 Phase 3

In Phase 3, the thematic maps produced were used in the Multi-Criteria Evaluation and Deterministic Model. The data were analyzed using the weightage overlay approach. By using the raster calculator function in ArcGIS software, Equation 1 & 2 was used, and the Flood Susceptibility Map and Landslide Susceptibility Map was produced.

3. Flood Susceptibility Analysis (FSA)

3.1 Rainfall

Flood occurs during rainfall due to the natural watercourses do not have the ability to convey excess water. Flood is often associated with extreme rainfall. When the water cannot seep immediately into the ground, it flows down the slope as runoff. Thus, increasing the amount of runoff to the river and increases the level of water. When the water level rises, it starts to overflow to the adjoining areas of the river area and causes flood.

In the study, a rainfall map was developed based on the daily rainfall values (short-term intensity rainfall) for the study area. Based on the information obtained from the Meteorology Department of Malaysia (MetMalaysia) and the Sabah Department of Irrigation and Drainage (DID), the rainfall data were obtained for each station in the study area. The data then extrapolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within the study area. Finally, the resulting raster layer was reclassified into the sub parameters based on Table 1 (Figure 3).

![Rainfall Map](image)

Figure 3. Rainfall Map.

3.2 Drainage Density

Drainage plays an important part in flood occurring as its densities could affect the nature of the soil and its geotechnical properties. The higher the drainage density, the higher the susceptibility of the soil to erosion resulting in sedimentation at the lower grounds. For the study area, drainage density map is produced by generating the buffer zones around the drainage system. Then, it was reclassified into 5 sub-group and the weightage was assigned to each sub-groups, whereas, the area with the lowest weightage was the sub-group >200mm (0.0642) and the highest weighted value was assigned to the sub-group <50m (0.4162) as depicted in the Table 1 and Figure 4.
3.3 Flow Accumulation
Flow accumulation shows the accumulation of water from precipitations with sinks being filled. It was generated from the Digital Elevation Model (DEM) obtained from the USGS. From the generated result, it was then reclassified into 5 sub-groups and the weighted value then assigned to each sub-group. The highest flow accumulation area has higher weighted value and vice versa as shown in Figure 5.

3.4 Land Use
Land use is also one of the factors that contributes to flood disaster. It reflects the current use of the land, its type and its relations to infiltration. Land-cover like vegetation covers by agriculture and forestry sectors gives impact to the soil to act as a water storage, whereas, land use like industrial, and residential sectors covers the soil with impermeable surface such as concrete and tar that absorbs almost no water at all, thus, increasing water runoff.
The study area is a rapid development area with almost 60% of its area had been developed into residential and commercial area. Based on the land use in the study area, the weighted value was assigned to each land use. The highest weighted value was assigned to the residential and industrial area (0.3162) and the lowest weighted value was assigned to the agriculture and forestry area (0.0756). After assigning the weighted value, the land use map was produced (Figure 6).

3.5 Elevation
A Digital Elevation Model (DEM) was obtained from USGS using Shuttle Radar Topography Mission (SRTM) Satellite. It indicates the current elevation of the study area from the sea level. Using the DEM data obtained, the slope gradient, flow accumulation, and curvature data can be obtained. Based on the DEM, the study area can be classified into lowland areas (<10m), moderately highland areas (11m-30m), and hilly areas (>30m). Theoretically, water runoff flows from higher to lower grounds and lastly ends up in the sea. It indicates that the lowland areas have higher tendency to experience floods. Based on Table 1, the lowland areas have higher weighted values than the highland areas as shown in Figure 7.

![Figure 7. Elevation Map.](image)

3.6 Slope Gradient
Slope gradient map shows the steepness of slopes in the study area. Slope gradient controls the duration of overland flow, infiltration and subsurface flow. Areas with high slope gradient does not allow the water to accumulate and results into runoff that leads to flooding. Using the DEM data obtained, the slope gradient map was produced and reclassified into 5 sub-groups. The weighted value from Tab. 1 was assigned to each sub-group (Figure 8).

3.7 Soil Textures
Soil texture indicates the type of soil based on its physical characteristics for unconsolidated deposition and weathering production. It is important to flooding because different textures of soil have different value of permeability that allows the absorption of water and prevents runoff. Soil textures like sandy soil has high porosity and absorbs water faster than clayey soil that has low porosity value.
Based on the soil type map derived from the Agriculture Department of Sabah (JPNS), the soil association in the study area can be grouped into ten (10) groups and the weighted value had been assigned as shown in Table 1 and Figure 9.

3.8 **Slope Curvature**

Slope curvatures influences the dispersion of surface water in the study area. There are 3 types of slope curvature: convex, flat, and concave. Convex type was the most stable type in steep terrain, followed by concave type and the least stable was the flat type. Both concave and convex type tends to concentrate the dispersion of the surface water into small areas of the slopes, whereas, the flat curvature allows the water to flow quickly down the slopes, thereby increasing the chances of flood down the slope. Using the DEM data, the slope curvature map was produced, and the weighted value was assigned based on its type (Figure 10).
4. Landslide Susceptibility Analysis (LSA)

4.1 Digital elevation model (DEM)

A digital elevation model (DEM) was obtained from the USGS open source data. Using the DEM data, the slope gradient ($\beta$) can be generated. The results suggest that 49% of the area can be categorized as “0o – 20o”, 5% as “21o – 40o”, 33% as “41o – 60o”, 12% as “61o – 80o” and 1% as “more than 80o”. More than 40o of slope gradient categories represent the very steep slope segments in the study area.

4.2 Geotechnical Engineering Properties

Geotechnical engineering properties of seventy two (72) soil samples indicated that the soil materials mainly consist of poorly graded to well graded materials of clayey, silty to sandy soils, which are characterized by low to high plasticity, effective cohesion ($c'$) ranges 9.20 kPa to 28.89 kPa (Figure 11), unit weight of soil ($\gamma$) ranges from 14.97 kN/m$^3$ to 22.98 kN/m$^3$ (Figure 12), depth of failure surface ($Z$) ranges from 6.72 m to 21.61 m (Figure 13), effective angle of shearing resistance ($\phi'$) ranges from 3.17o to 20.60o (Figure 14), and height of groundwater table above failure surface ($ZW$) ranges from 1.29 m to 8.62 m.
Figure 12. Unit Weight of Soil ($\gamma$) Map.

Figure 13. Depth of Failure Surface (Z) Map

Figure 14. Shearing Resistance ($\phi$) Map
5. Geohazard Analysis (GA)

The maps produced in FSA and LSA were used in Eq. 1 and Eq. 2 to produce the Flood Susceptibility Level (FSL) map and the Landslide Susceptibility Level (LSL) Map of the study area (Fig. 16). The FSL map suggest that 5.83% of the study area has Very Low Susceptibility, 40.08% Low Susceptibility, 43.64% Moderate Susceptibility, 10.32% High Susceptibility, and 0.13% has Very High Susceptibility and the LSL map (Figure 17) suggests that 44.77% has Very Low Susceptibility, 13.27% has Low Susceptibility, 13.80% Moderate Susceptibility, 18.62% of High Susceptibility, 9.46% of Very High Susceptibility and 0.10% of Severe Susceptibility.

Based on Fig. 16, Kg. Bantayan have a Very High Susceptibility and areas like Menggatal and Kg. Rampayan have High Susceptibility Level. This area is prone to the flood disaster. Generally, the Very Low to Low Susceptibility Level area refers to a stable condition to flood susceptibility. Meanwhile, Moderate to High Susceptibility areas are not recommended to be developed due to high susceptibility/risk. However, these areas can be developed by introducing a few mitigations procedures to reduce the impact of flood disaster. The Very High Susceptibility areas are strictly not recommended for any development and provisions for structural and non-structural works planning control are highly recommended. Based on Fig. 17, the level indicates the stability of the slopes in the study area. Most of the Moderate to Severe Susceptibility areas are located at the hillside are which had a steep slope. Kg. Ulu Kionsom was one of the areas that have high susceptibility level, while other places like Menggatal and Tebobon was situated in the low and flat area have very low susceptibility.
6. Conclusion
Based on the results obtained, AHP Model and Deterministic Model allows the determination of Flood Susceptibility Level and Landslide Susceptibility Level of Kota Kinabalu area by using GIS techniques, as it allows an efficient use of spatial data. MCE model also provided an acceptable result as it takes different contributing factors and its significance into flood mapping and prediction. Overall, the case study shows that MCE model with integration of GIS technique is effective in flood hazard/risk zonation and management, while Deterministic model also provide a good result as it was considering the geotechnical properties of soil to aid in the calculation of landslide hazard.

The study will be a useful resources and guidance to the planning agencies and local authorities for land-use planning and managing hazard/risk. Moreover, the model in the study can be extended to other areas, where other factors can be considered, depending on the availability of data. Based on the results, a few mitigation measures can be suggested to reduce the impact of the flood disaster. The awareness of the flood and landslide issues are not only the responsibilities for local authorities, but all of the stakeholder, both public and private sectors. While the land developer has social responsibility for geohazard compatible development, other agencies shares the responsibility through effective risk management and facilities maintenance.

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