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Flood Susceptibility Analysis using Multi-Criteria Evaluation Model: A Case Study in Kota Kinabalu, Sabah

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This study focused on the Flood Susceptibility Analysis (FSA) of the Kota Kinabalu area, Sabah by using Multi Criteria Evaluation Model (MCE). The study area had been affected by flood throughout the years. The aims of this study are to determine the flood susceptibility level of the study area and to identify the contributing factors that leads to the flood disaster. Thus, a few mitigation measures can be recommended. The contibuting factors that leads to flood disaster 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 flood disaster such as slope gradient, elevation, topographic curvature, flow accumulation and drainage distance were retrieved from the topographic database, whereas the land use, rainfall and soil types 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 can be used in future development planning and a few structural control can be implemented such as the reconstruction of drainage in the study area and a warning system. 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.

Keywords: Flood Susceptibility Analysis (FSA), Multi Criteria Evaluation (MCE), Kota Kinabalu, Sabah.

I. INTRODUCTION

Flood is one of the major geohazards in Malaysia. As with landslide, tsunami, siltation and coastal erosion, these have repeatedly occurred in the region with disastrous effect. In Kota Kinabalu, flood had been a major problem. The subsequent transition of landuse from rural development to intensive urban development presents many social and environment issues.

In 2014 from October 7 to October 10, Kota Kinabalu suffered its worse flood ever (Figure 1). A few of the main road in Kota Kinabalu were flooded such as Sulaman Road, Lok Kawi Road and Kolombong Road. The flood coincided with continuous heavy rainfall due to typhoon Phanfone and typhoon Vongfong. Another recent flood occur in Kota Kinabalu on August 2017 affecting several places. Recently, in August

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2017, a few places in Kota Kinabalu was hit by a flash floods after a heavy rainfall.

The main objectives of this study are: a) to determine the flood susceptibility level of the study area; b) to identify the contributing factors that leads to the flood disaster; and c) to recommend suitable mitigation measures for minimizing the flood vulnerability and risk. 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 1. Location of the study area

II. LITERATURE REVIEW

In the recent years, there have been many studies on flood susceptibility/hazard/risk mapping using GIS tools (Hess *et al.* 1990; Le Toan *et al.* 1997) and many of these studies have applied using probabilistic methods (Landau *et al.* 2000; Farajzadeh, 2001; 2002; Horrit & Bates, 2002; Pradhan & Shafie, 2009). In different ways, hydrological and stochastic rainfall method has also been employed in other areas (Blazkova & Beven, 1997; Cunderlirk & Burn, 2002; Ebisemiju, 1986; Heo *et al.* 2001; Nageshwar & Baghabat, 1997; Yakoo *et al.*, 2001;

Villiers, 1986). Likewise neural network methods have been applied in various case studies (Honda *et al.*, 1997; Islam & Sado, 2002; Sanyal & Lu, 2005).

Determining the flood susceptible/ vulnerable areas is very important to decision makers for planning and management of activities. Decision making is actually 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 a large number of different criteria. All these criteria need to be evaluated for decision analysis (Sinha *et al.*, 2008; Yahaya, 2008, Chen *et al.* 2011). For instance, Multi Criteria Evaluation (MCE) methods has been applied in several studies since 80% of data used by decision makers are related geographically (Istigal, 1997; Siddayao *et al.* 2014). 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 Determining the flood susceptible/ vulnerable areas is very important to decision makers for planning and management of activities. Decision making is actually 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 a large number of different criteria. All these criteria need to be evaluated for decision analysis (Sinha *et al.*, 2008; Yahaya, 2008, Chen *et al.* 2011). For instance, Multi Criteria Evaluation (MCE) methods has been applied in several studies since 80% of data used by decision makers are related geographically (Istigal, 1997; Siddayao *et al.* 2014). 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 (Ho *et al.* 2002; Ouma & Tateishi, 2014; Collins *et al.* 2001).

III. MATERIALS AND METHODS

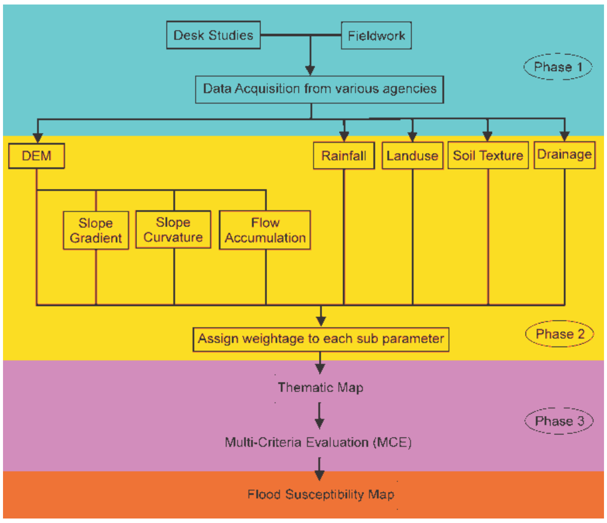

Figure 2. Methodology flowchart

A. Phase 1

Phase 1 involved desk studies and fieldwork to determine the parameters affecting the flood disaster (Figure 2). After the parameters were determined, its data from various agencies were obtained.

B. Phase 2

Phase 2 were carried out after the data had been obtained (Figure 2). The data obtained was digitized using ArcGIS software. Based on the previous study by Rodeano *et al.* (2016), the weighted value calculated can be applied in the study area.

Table 1. The weighted value of the parameters and sub parameters (Rodeano *et al.* (2016)

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 Infrastructures	0.1380
		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

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 food disaster. The higher weighted value is the most affecting factors in the flood disaster.

(32.53*Rainfall) + (22.74*Drainage Density) + (15.84*Flow Accumulation) + (11.08*Landuse) + (7.19*Elevation) + (4.89*Slope Gradient) + (3.35*Soil Textures) + (2.38*Slope Curvatures) (1)

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.

C. Phase 3

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

IV. FLOOD SUSCEPTIBILITY ANALYSIS (FSA)

A. Rainfall

Flood occurs during rainfall due to the natural watercourses do not have the ability to convey excess water. Flood 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 Metrology Department of Malaysia (MetMalaysia) and the Sabah Department of Irrigation and Drainage (DID), the rainfall data were obtained for each stations 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 and Figure 3.

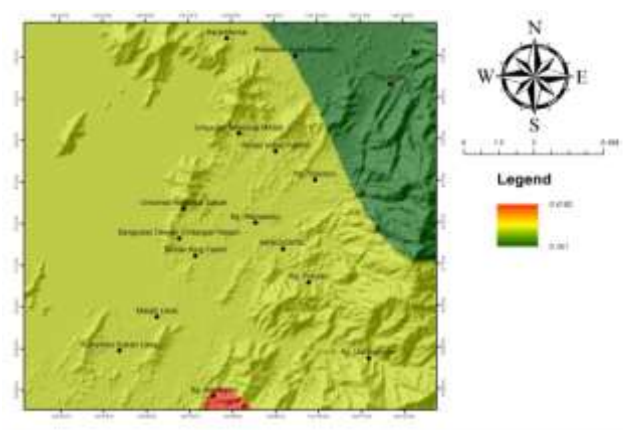

Figure 3. Rainfall Map

B. Drainage Density

Drainage plays an important part in flood occuring 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.

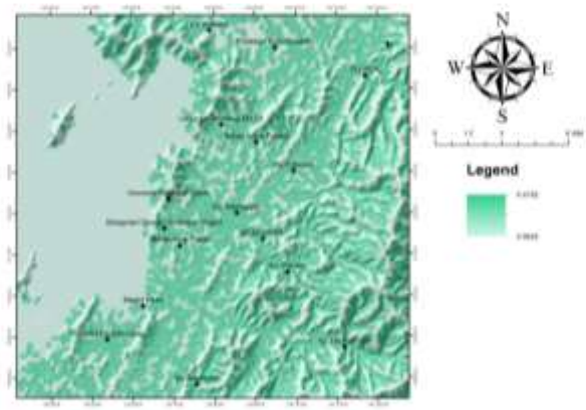

Figure 4. Drainage Density Map

C. Flow Accumulation

Flow accumulation shows the accumulation of water from precipitations with sinks being filled. It was generated from the Digitral 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-groups. The highest flow accumulation area has higher weighted value and vice versa as shown in Figure 5

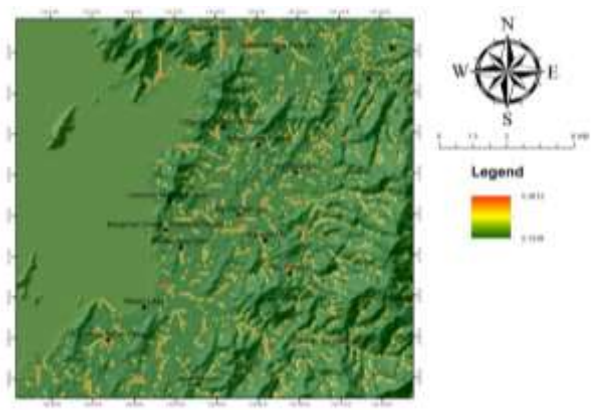

Figure 5. Flow Accumulation Map

D. Landuse

Landuse is also one of the factors that contributes to flood disaster. It reflects the current use of the land, its type and also it relations to infiltration. Land-cover like vegetation covers by agriculture and forestry sectors gives impact to the soil to act as a water storage, where as, landuse 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 commecial area. Based on the landuse in the study area, the weighted value was assigned to each landuse. 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 landuse map was produced (Figure 6).

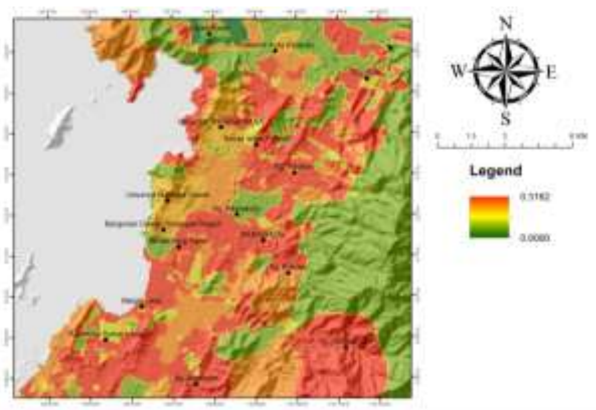

Figure 6. Landuse Map

E. Elevation

A Digital Elevation Model (DEM) was obtained from USGS using Shuttle Radar Topography Mission (SRTM) Sattelite. 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). Theoritically, 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 experiences floods. Based on Table 1, the lowland areas has higher weighted values than the highland areas as shown in Figure 7.

F. 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

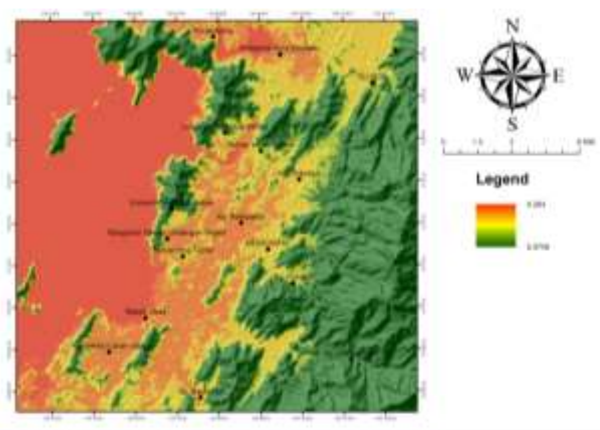

Figure 7. Elevation Map

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 Table 1 was assigned to each sub-groups (Figure 8).

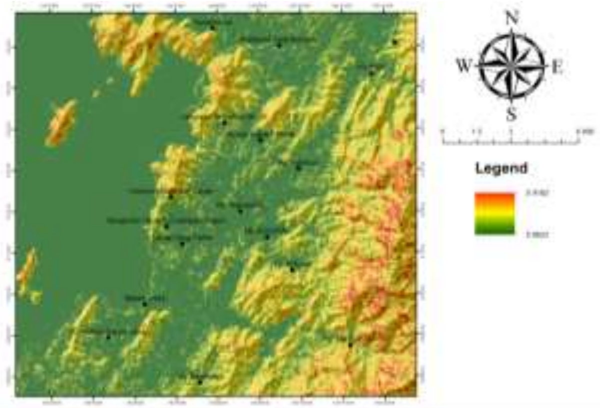

Figure 8. Slope Gradient Map

G. 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.

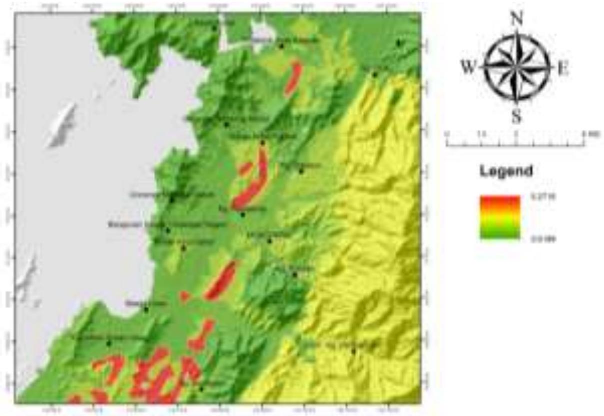

Figure 9. Soil Texture Map

H. 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 flows 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).

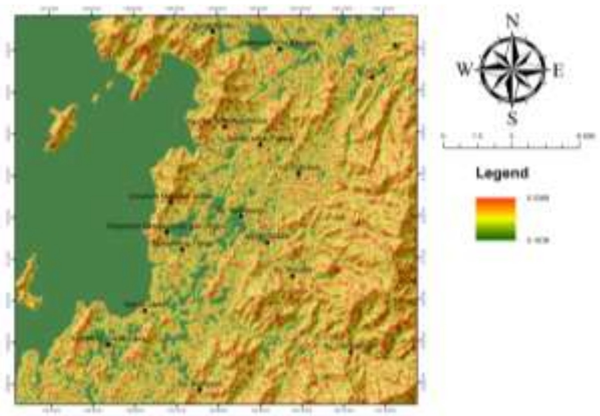

Figure 10. Slope Curvature Map

V. FLOOD SUSCEPTIBILITY LEVEL (FSL)

The maps produced in FSA was used in Eq. 1 and the Flood Susceptibility Level (FSL) map of the study area was produced (Fig. 11). The FSL map suggest that 5.83% of the study area has Very Low Susceptibilty, 40.08% Low Susceptibility, 43.64% Moderate Susceptibility, 10.32% High Suceptibility, and 0.13% has Very High Susceptibility.

Based on Figure 11, Kg. Bantayan have a Very High Susceptibility and areas like Menggatal and Kg. Rampayan have High Susceptibility Level. These area is prone to the flood disaster.

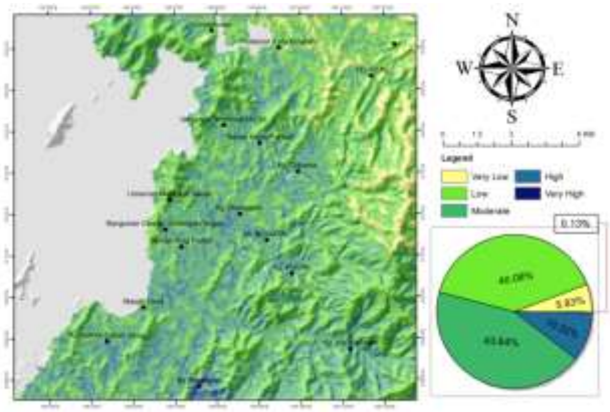

Figure 11. Flood Susceptibility Level Map

Generally, the Very Low to Low Susceptibility Level area refers to a stable conditions 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 reduced 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.

VI. CONCLUSIONS

Based on the results obtained, MCE model allows the determination of Flood Susceptibility Level of Kota Kinabalu area by using GIS techniques, as it allows an efficient uses of spatial data. MCE model also provided an acceptable results as it take 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.

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.

The contributing factors that leads to the flood disaster in the study area are: a) Rainfall, b) Drainage Density, c) Flow Accumulation, d) Landuse, e) Elevation, f) Slope Gradient, g) Soil Textures, and h) Slope Curvature.

Based on the results, a few mitigaton measures can be suggested to reduce the impact of the flood disaster. The awareness of the flood issue is 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 flood compatible development, other agencies shares the responsibility through effective floodplain management and drainage maintainance.

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