Assessment of Flood Susceptibility Analysis Using Analytical Hierarchy Process (AHP) in Kota Belud Area, Sabah, Malaysia

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Assessment of Flood Susceptibility Analysis Using Analytical Hierarchy Process (AHP) in Kota Belud Area, Sabah, Malaysia

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Abstract. This study aims to assess the flood susceptibility analysis using a Geographical Information System (GIS) based-heuristic analysis, namely the Analytical Hierarchy Process (AHP) model. Eight relevant physical parameters have been selected, namely, drainage density, drainage proximity, elevation, slope angle, slope curvature, land use, soil type, and topography wetness index. The relative importance of these factors has been compared in the pairwise matrix to gain weight values during the process of the Analytical Hierarchy Process (AHP). The flood susceptibility zones have been mapped according to their weightage value. Finally, the flood susceptibility map was prepared and classified into six classes as very low, low, moderate, high, and very high susceptibility using the natural break classification method. The accuracy of the flood susceptibility model was validated using the Area Under the Curve (AUC) analysis. The AUC for success rate was estimated at 82.13%.

1. Introduction

Floods are the world's most common naturally occurring disasters. The flood susceptibility map is an instrument for assessing flood level [1]. Flood susceptibility maps can be developed using Geographical Information System (GIS) because GIS can manipulate multi-dimensional natural hazard phenomena using a spatial element [2].

Multi-criteria decision analysis is an essential tool for analysing complex decision problems, often involving inadequate data or criteria [3-4]. This method could be used to ensure optimal decision making by integrating technical, environmental, and socio-economic objectives [5]. Analytical Hierarchy Process (AHP) from Saaty [6] is a popular technique in the field of multi-criteria decision-making [7-8]. An Analytical Hierarchy Process (AHP) method that weights the relative importance of the parameters should be correlated with the physical parameters used in this study.

This study presents an integrated approach using GIS and AHP for creating flood susceptibility maps from the available database for the case study of the Kota Belud area, Sabah. The main objective of this

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study is to identify the flood susceptibility level using the spatial AHP to understand the relative importance of the parameters used. The flood susceptibility map produced was then validated through the Area Under Curve (AUC) analysis to verify the precision and accuracy of the model.

2. The Study Area

The study was carried out in Kota Belud, Sabah, Malaysia covering a total area of 124km2. The longitudinal and latitudinal extensions of the study area are 116°28'37.631"E–116°18'47.156"E and 6°18'32.655"N–6°25'49.605"N, respectively. The topographic setting of this area is mainly controlled by its lowland in the north-west part and the hilly region in the southern part. There are five main rivers, namely as Sungai Kadamaian, Sungai Wariu, Sungai, Gurong-Gurong, Sungai Tempasuk, and Sungai Abai, which always involved in a flood event.

This area is known as a flood-prone area and cases of devastating flooding in Kota Belud, Sabah have been growing recently [9-11]. In 2017, around 4,441 peoples affected by this event involving 62 affected villages (Figure 2). These flooded areas have affected individuals and their properties substantially. All the activities such as mapping, observation, and monitoring are more focused on the lowland area, which have high inundation possibilities (Figure 3).

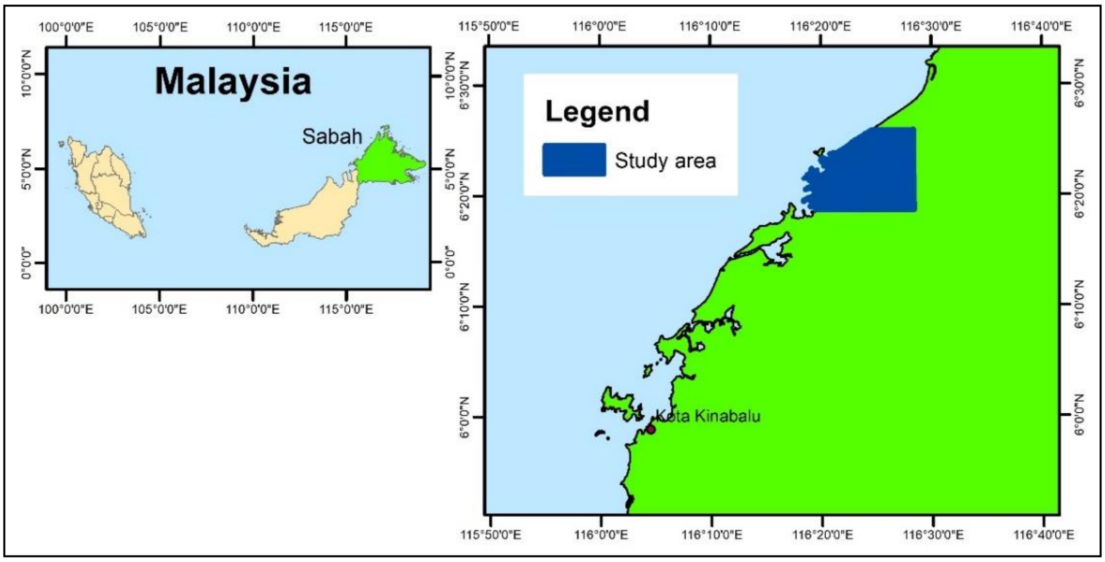

Figure 1. Location of Kota Belud area, Sabah, Malaysia.

Figure 2. Flooding scenarios in lowland area.

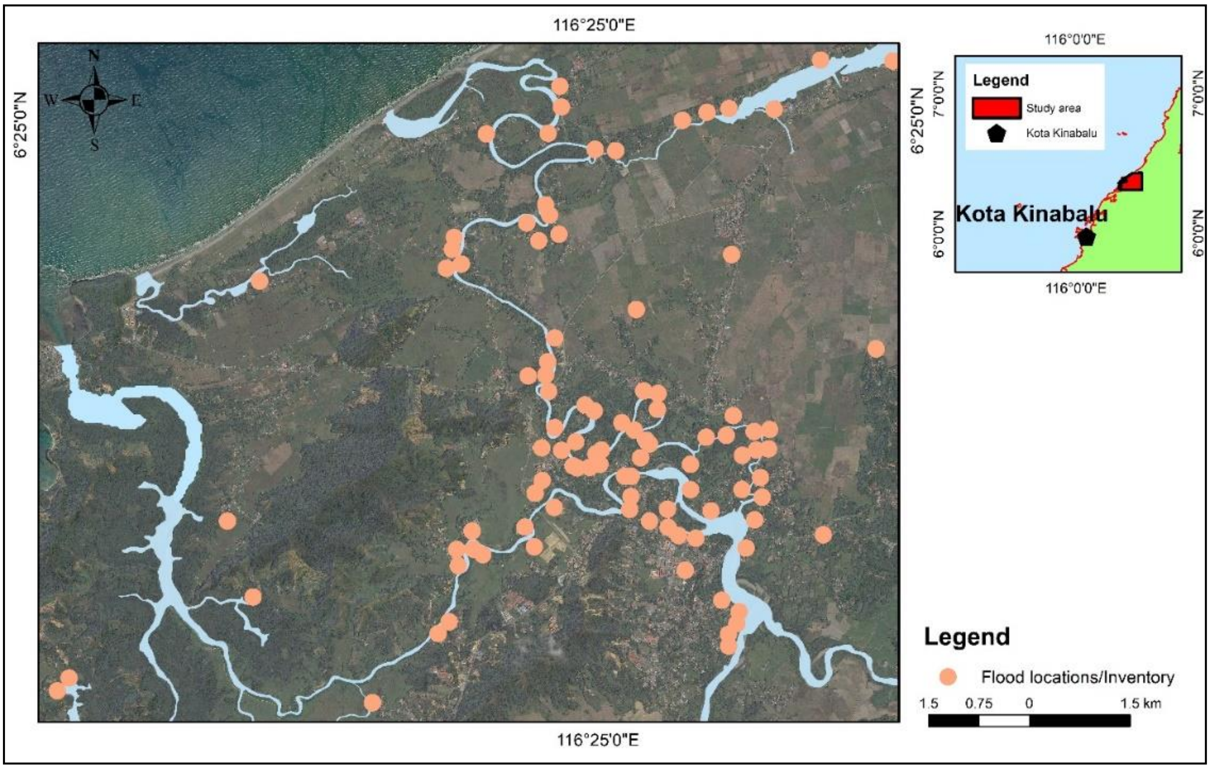

Figure 3. Map of affected villages in Kota Belud area, Sabah, Malaysia

3. Material and Methods

The methodology is summarized in Figure 4. As shown in Figure 3, spatial analysis in GIS has been used to manipulate eight physical parameters in the production of flood susceptibility map. The methods used in this study to produce conduct the flood susceptibility analysis consists of three stages namely; stage 1 – selection of physical parameters influencing flood potential in the study area, stage 2 – Analytical Hierarchy Process (AHP) and assign weight to classified thematic layers and stage 3 – estimation and classification of the flood susceptibility map based on each index (Table 1). Last but not least, validate the model using the Area Under the Curve (AUC) approach.

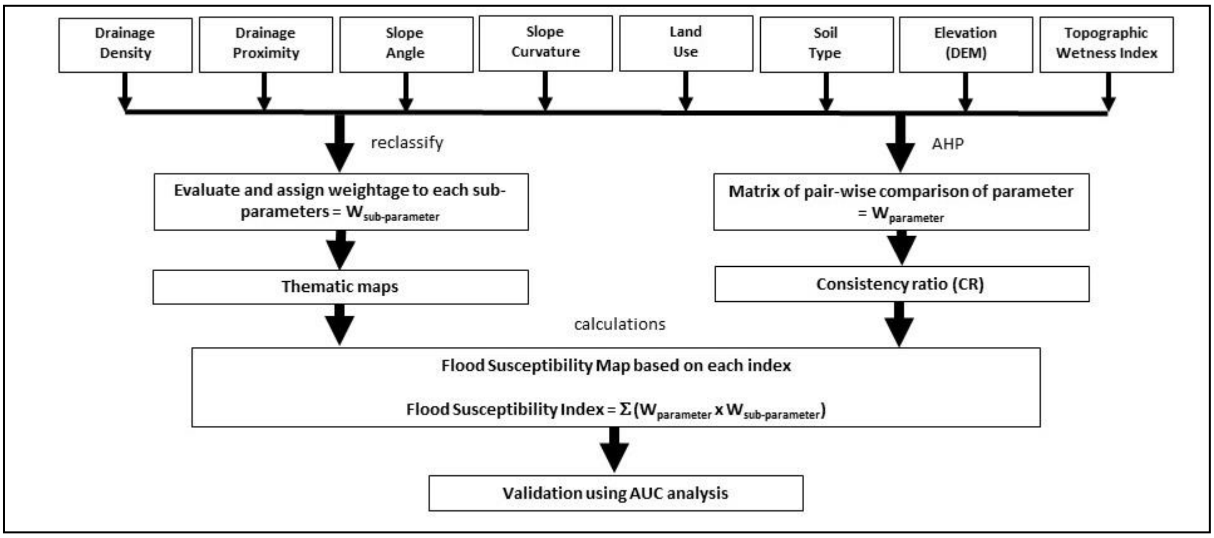

Figure 4. Flowchart showing the methodology used in this study.

3.1 Physical Parameters Influencing Flood Potential

The eight physical factors contributing on flood occurrence such as drainage density, drainage proximity, slope angle, slope curvature, elevation, soil type, land use, and topographic wetness index were prepared using ArcGIS software (Figure 5). To delineate different flood hazard zone in the study area, traditional data sets have been extracted from different government agencies and Interferometric Synthetic-Aperture Radar (IFSAR) data with the 5 m spatial resolution are used and processed for the Digital Elevation Model (DEM).

Timbalai RSO Borneo (meters) was used to rectify the dataset. The DEM was used to extract elevation, slope angle, slope curvature, and topographic wetness index. The drainage system in the study area was extracted from 1:50 000 topographic map and has been processed using hydrology tools in ArcGIS to gain the drainage density and buffer tools to classify the distance from the river (drainage proximity) with 50 m intervals. The soil type map was prepared based on soil data derived from the Agriculture Department of Sabah (JPNS), whereas the land use map was prepared from the topography map available.

After preparation of the thematic layers, all the layers have been converted into raster format with 5 m resolution. After that, the raster files have been reclassified using AHP ranks.

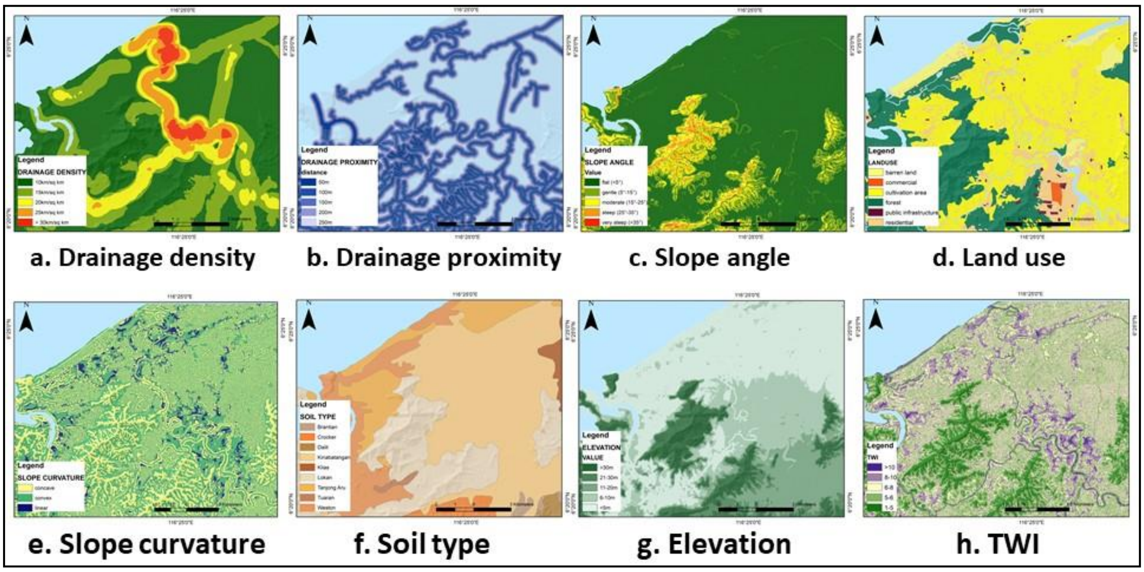

Figure 5. Flood conditioning factor used in frequency ratio model.

3.2 Analytical Hierarchy Process (AHP) model

After preparation of all the thematic layers, the AHP model has been applied to give different weightage value to the parameters were considered in this study. The factors controlling the flood potential of an area are drainage density (DD), drainage proximity (DP), slope curvature (SC), land use (LU), elevation (EL), slope angle (SA), soil type (ST) and topographic wetness index (TWI).

The AHP is a very detailed, well-structured way of interpreting complicated decision-making issues with multiple factors [6,12]. The AHP method was used to determine the weightage value of the flood susceptibility index model and the ranks of various parameters in this study. The flood susceptibility index (FSI) model was calculated based on the following formula (1).

$$FSI = (\sum Wparameter\ X\ Wsubparameter) \tag{1}$$

The AHP in this study consists of two major parts. The first part is to evaluate and assign weightage to each sub-parameter = Wsub-parameter. The second part is composed of matrix of pair-wise comparison of parameter = Wparameter.

The pair-wise comparison is more acceptable if accuracy and theory are the main concern [13]. The process consists of contrasting the criteria and evaluating the relevance of two parameters at a time [14-17]. The criterion pair-wise comparison matrix takes the pair-wise comparisons as an input and produces the relative weights as output.

Further the AHP provides a mathematical method of translating this matrix into a vector of relative weights for the criteria. Moreover, because of the reason that individual judgments will never be agreed perfectly, the degree of consistency achieved in the ratings is measured by a Consistency Ratio (CR) indicating the probability that the matrix ratings were randomly generated. The consistency ratio is done by the following equation [6] Eq. (2).

$$CR = \frac{CI}{RI} \tag{2}$$

Where CI stands for the consistency index, RI indicates the random index. For this study, the consistency ratio (CR) is accepted if the value is < 0.10, and it indicates a reasonable level for the pair-wise comparison matrix. In this study, all parameters considered are evaluated individually and divided into different sub-parameters. A relative scoring using AHP method was used to give different rankings for each sub-parameter and parameter where shown in Table 1.

Table 1. The weighted value of the physical parameters and sub-parameters.

Parameter	**Class**	$W_{sub-parameters}$	$W_{parameter}$
	10km/ sq km	0.0624	
	15km/ sq km	0.0986	
1.Drainage Density	20km/ sq km	0.1610	11.08
	25km/ sq km	0.2618	
	> 30km/ sq km	0.4162	
	50m	0.4162	
	100m	0.2618	
2.Drainage Proximity	150m	0.1610	3.35
	200m	0.0986	
	250m	0.0624	
	Convex	0.5389	
3.Slope Curvature	Linear	0.1638	2.38
	Concave	0.2973	
	Cultivation area	0.1364	
	Commercial	0.1818	
4.Land Use	Barren land	0.0909	7.19
	Forest	0.0455	
	Government sector	0.2273	
	Residential	0.3182	
	<5m	0.4162	
	6 - 10m	0.2618	
5.Elevation	11 - 20m	0.1610	32.53
	20 - 30m	0.0986	
	>30m	0.0624	
	<5°	0.4162	
	5° - 15°	0.2618	
6.Slope angle	15° - 25°	0.1610	
	25° - 35°	0.0986	15.84
	>35°	0.0624	
	Weston	0.1522	
	Brantian	0.1739	
	Tanjong Aru	0.1739	
	Dalit	0.0435	
7.Soil type	Lokan	0.0435	22.74
	Tuaran	0.1087	
	Crocker	0.0435	
	Kinabatangan	0.1957	

	Klias	0.0652	
	TWI 1-5	0.0624	
	TWI 5-6	0.0986	
8.Topograhic Wetness Index	TWI 6-8	0.1610	4.89
	TWI 8-10	0.2618	
	TWI >10	0.4162	

3.3 Flood Susceptibility Analysis

The initial step in stage 3 is the delineation and calculation processes of data between the parameter's weight to produce a flood susceptibility map using spatial analyst. All the thematic maps produced were analysed through the spatial analyst technique (raster calculator) based on Eq. (3) for flood susceptibility level (FSL) classification are shown in Table 1. The FSL calculation was carried out through a combination of input parametric maps in Eq. (3) with the GIS operations using a grid base.

$$FSI = (\sum(32.53 * EL) + (22.74 * ST) + 15.84 * SA) + (11.08 * DD) + (7.19 * LU) + (4.89 * TWI) + (3.35 * DP) + (2.38 * SC)) \quad (3)$$

4. Results and Discussion

Flood occurrence depends on the topographical conditions of an area [18]. Combining the assessment of these factors using modern techniques can provide an overview of flood susceptibility at different levels. In this study, a total of eight parameters are considered for mapping the flood susceptibility map of the Kota Belud area with the help of the Analytical Hierarchy Process (AHP) model. All these parameters and the result are discussed below.

4.1 Drainage Density

High drainage density area is probably more prone to flooding compared to lower drainage density area. The higher the drainage density, the higher the catchment area that prone to erosion, resulting in sedimentation at the lower ground [19]. Besides, drainage densities are one of the critical keys that control the hazards by indicating the nature of soils and its properties.

The drainage density layer was reclassified using natural break method. Areas with very low density are <10km/km^2 whereas those with very high drainage density are >30km/km^2. For the study area, higher weighted value (0.4162) was assigned to >30km/km^2 density area and lower weighted value were assigned to 10km/km^2 drainage area.

4.2 Drainage Proximity

The occurrence of the flood generally concentrates alongside of the drainage system. Hence, the drainage proximity is an important factor should be considered for accurate flood mapping [18]. Furthermore, the lowest point in the area is generally a stream. As a result of this, the area that is far from the drainage system has a lower susceptibility to flooding occurrence.

The drainage proximity layer was reclassified into five classes according to 50m, 100m, 150m, 200m and 250 m buffer zone. For the study area, higher weighted value (0.4162) was assigned to distance closer to river (50m), whereas lower weighted value (0.1238) was assigned to distance further to river (250m).

4.3 Slope Curvature

In this study, the slope curvature was classified into three classes; concave, linear, and convex. The slope curvature, which cannot be ignored, has an impact on the occurrence of the flood. Negative values of the slope curvature represent concave shape of topography, values near to zero indicate no curvature, and positive values postulate convex character of the landscape [18].

4.4 Land Use

Land use directly or indirectly influences the infiltration rate, evapotranspiration, and surface runoff generation [20]. The pattern of land use of an area shows the type and natural processes of land utilization by living populations [21]. The changes in the land over time and the impact of natural forces and anthropological activities are essential to consider [18]. These practices are considered as triggering factors for catastrophic natural hazards.

Classification of satellite data was done considering six (6) land use categories, namely cultivation area, commercial area, barren land, forest, public infrastructure and residential. The main land cover in the study area is cultivation area which covers 44% of the study area followed by forest (38%), residential (12%), barren land (4%), public infrastructure (1%) and commercial area (1%).

4.5 Elevation

In the field of flood mapping, the experts believe that the elevation of an area is the primary factor that controls the flood hazard [22-24]. Generally, the area located in lower elevation is more prone to flooding compared to the area located in higher altitudes. Water tends to flow from a higher point to the lower area and, consequently, lower areas with a flat surface are more likely to flood [25].

The spatial distribution of the elevation layer into five (5) classes <5m, 5-10m, 10-20m, 20-30m and >30m. Majority of this study area situated in lowland or floodplain. For this study, higher weighted value was assigned to lower elevation compared to higher elevation as stated in the Table 1.

4.6 Slope Angle

Slope plays a crucial role in regulating the flow of surface water, a significant topographical factor in the hydrological study [26-27]. The slope of a channel in a region is having a direct association with the flow speed [26]. As the slope angle becomes higher, the flow speed also becomes higher [18]. The infiltration process is also partially controlled by the slope angle. The increased slope angle reduces the infiltration process but increases surface runoff, which causes a massive volume of water to stagnate and a flooding situation in the regions where the gradient suddenly decreases [18].

The slope angle was classified into 5 classes based on the slope classification published by the Department of Mineral and Geoscience Malaysia (JMG); flat (<5°), gentle (5°-15°), moderate (15°-25°), steep (25°-35°) and very steep (>35°). For the study area, slope with lower degree angle was assigned with higher weighted value (0.4162) whereas lower weighted value (0.1238) was assigned to steeper slope degree]

4.7 Soil Type

Infiltration varies based on the spatial distribution of soil type, and it controls overland flows and inundation [26]. Porosity and permeability depend on the soil type of an area. Flood intensity can be influenced by such properties of soil type.

4.8 Topographic Wetness Index (TWI)

Topographic Wetness Index (TWI) indicates the topography effect on runoff and the amount of flow accumulation at any river catchment location [28]. The area with higher TWI value is more prone toward flooding compared to lower TWI value [18]. The TWI has no unit and was classified into five classes; <5, 5-6, 6-8, 8-10, >10 using natural break jenk method.

4.9 Assessment of Flood Susceptibility Level (FSL)

The result for the flood susceptibility analysis in Kota Belud area suggest that 15% (19km^2) of the area can be categorized as having very low susceptibility, 11% (14km^2) as low susceptibility, 9% (11km^2) as moderate susceptibility, 34% (42km^2) as high susceptibility and 31% (38km^2) as very high susceptibility (Figure 6). The map was divided into five susceptibility classes: very low, low, moderate, high, and very high using the natural breaks method [29].

The high flood potential locations are situated on the center to the north of study area. The flood susceptibility map shows a pattern of flood directly influenced by elevation parameter due to the high weightage value assigned during the AHP procedure. In this study area, the very high susceptibility areas are located at the north, northwest and northeast, considerably flat in slope and low elevation as considered from DEM. By contrast, areas having a higher degree of slope angle are prone to flooding. Also, two main rivers (Sungai Wariu and Sungai Kadamaian) contribute water to the Sungai Gurung-Gurung and Sungai Tempasuk over these very high susceptibility zones [30-31]. Hence, the elevation and slope angle play a crucial role to control the flood potential of an area [18]. Besides, the land use of the very high susceptibility area is mainly residential, public infrastructure, and cultivation area.

The validation of the model should be examined to demonstrate how well the model has been conducted [32]. The map was validated by comparing the flood susceptibility map with the flood inventory data from the past record through the Area Under the Curve (AUC). The cumulative percentage of flood occurrence was calculated, as a result of the calculation and interpretation, the average ratio of the areas under the curve was 82.13% (Figure 7). This means that the flood susceptibility analysis result that were carried out in this study have a good reliability ($0.8 < AUC < 0.9$) [33].

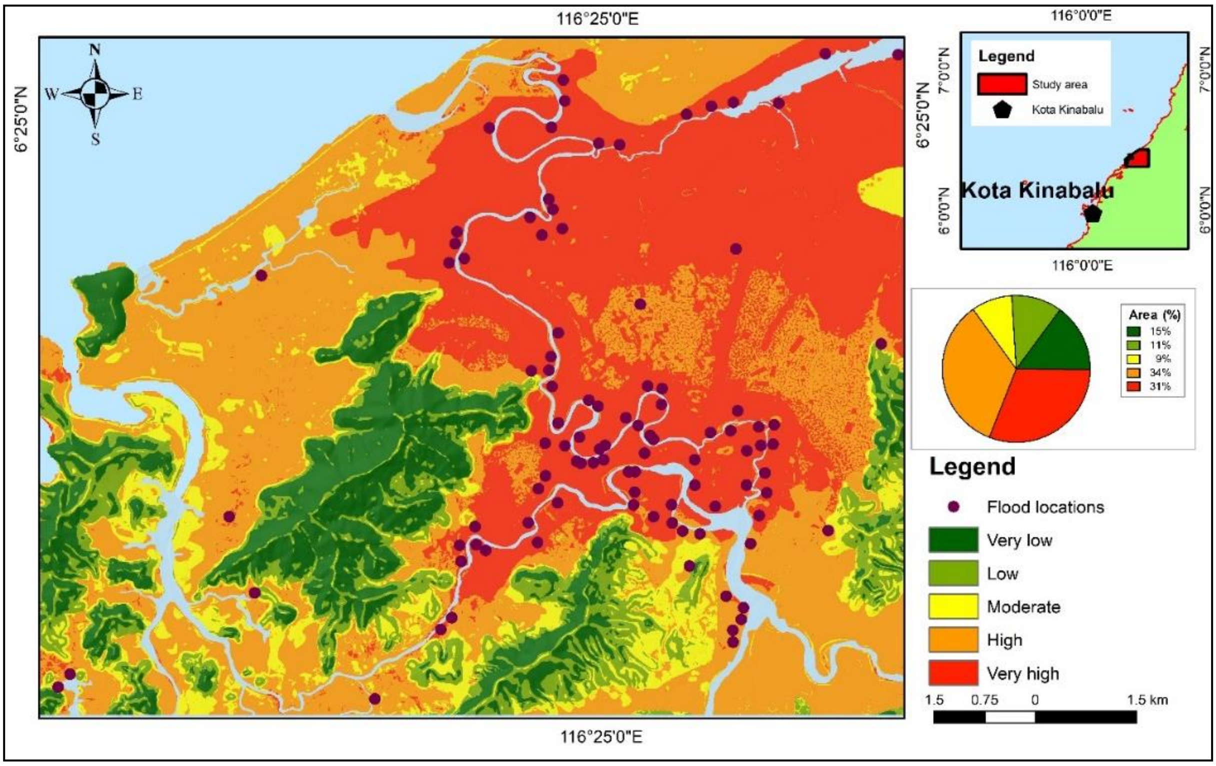

Figure 6. Flood susceptibility map using AHP model.

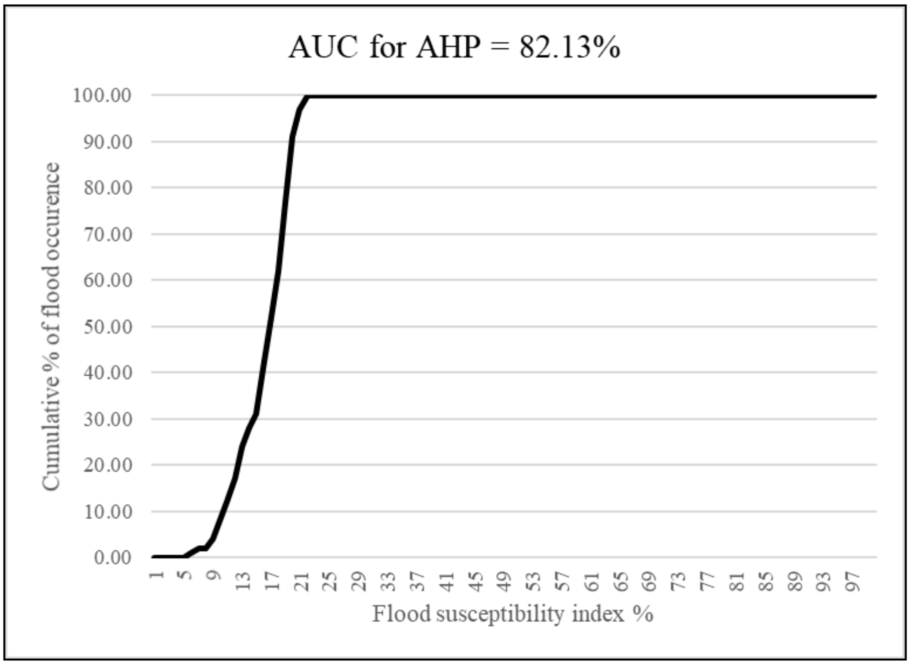

Figure 7. Validation of flood susceptibility.

5. Conclusion

The primary purpose of the present study is to model the flood susceptibility areas in Kota Belud area, Sabah, Malaysia. A comparison of the relative significance by pair matrix was made to determine a weightage value of eight physical parameters. The result indicates that the lowland area of the study area is susceptible to flood occurrences that mainly cause by elevation, slope angle and land use factors. However, other causative factors such as Drainage Proximity (DP), Drainage Density (DD), Soil Type (ST), Topographic Wetness Index (TWI) and Slope Curvature (SC) also contribute to the occurrence of floods in the study area based on the evidence of field work that has been carried out.

Future work will be investigating on inclusions of other physical factors. Also, the weighting of the comparative parameter must be flexibly amended based on the changes of relevant parameters. Therefore, this AHP model is suitable for the selection of land use suitability, control and manage the flood hazard/risk in the study area and potentially to be extended with different background environments.

Strict measure needs to be taken concerning the uncontrolled urbanization and the occupation of areas that has proximities to the rivers in order to prevent more significant damage. The identified of highly prone areas require more detailed mapping with the use of the latest technologies like high spatial resolution satellite images to create a research prospective that can improve the result obtained..

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