Flood Susceptibility Analysis (FSA) Using Analytical Hierarchy Process (AHP) Model at The Kg. Kolopis area, Penampang, Sabah, Malaysia

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Abstract. Flooding is one of the major natural disasters in Sabah, Malaysia. Several recent cases of catastrophic flooding were recorded mainly in Kg. Kolopis area, Sabah. Heavy monsoon rainfall has triggered floods and caused significant damage in Kg. Kolopis area. The 2014 floods have affected 5,000 people. The objectives of this paper are (i) to determine the Flood Hazard Level (FHL) and (ii) to identify the factors contributing to the flood occurrences. In this study, eight (8) parameters were considered in relation to the causative factors to flooding, which are: rainfall, slope gradient, elevation, drainage density, land use, soil textures, slope curvatures and flow accumulation Flood Hazard Analysis (FHAn) map were produced based on the data collected from the field survey, laboratory analysis, high resolution digital radar images (IFSAR) acquisition, and secondary data in three (3) different periods (2002, 2008 and 2014). FHL was defined using Analytical Hierarchy Process (AHP) Model integrated with GIS software. The developed model will be a precious resource for consulting, planning agencies and local governments in managing risk, land-use zoning and remediation efforts to mitigate risks. Moreover, the technique applied in this study can easily be extended to other areas, where other factors may be considered, depending on the availability of data.

1. Introduction
Flood is a common disaster that is damaging and may have an impact on world societies [1]. In Malaysia, flooding is one of major natural disaster that often associated with heavy rainfall due to monsoon season and unplanned development. The effect of the rapid development activities that lead to expanding the river floodplain for infrastructure development and agricultural activities. The following land use transformation from rural development and farming businesses to concentrated urban development demonstrates a wide range of issues including social and environmental problems.

Several recent cases of catastrophic flooding were recorded primarily in Kg. Kolopis area, Penampang District of Sabah, Malaysia. This area has been known as a flood prone area. In 2014, around 5,000 people were affected by this event. Heavy monsoon rainfall which was influenced by the tail of typhoon Phanfone and typhoon Vongfong has triggered floods and caused significant damage in Kg. Kolopis area [2-4].
The objectives of this paper are (i) to determine the Flood Hazard Level (FHL) based on Flood Susceptibility Analysis (FSA) in three assessment years (2002, 2008 & 2014) and (ii) to determine the factors contributing to the flood occurrences. This research will focus on flood susceptibility assessment in Kg. Kolupis area using Multi-Criteria Evaluation (MCE) method and Geographical Information System (GIS). By the end of this research, there are three flood susceptibility maps will be produced according to the assessment years that is 2002, 2008 and 2014.

2. Setting of the Study Area
Kg. Kolopis situated at the Penampang district and partly Kota Kinabalu area. The location of the study area is shown in Figure 1. It is bounded between latitude line N 05° 53’ 25” to N 05° 58’ 3” and longitude line E 116° 02’ 20” to E 116° 11’ 52”. The topographic setting of this area is mainly controlled by its lowland in the western part and the mountainous region at eastern part.

3. Material and Methods
In this study, to produced flood susceptibility maps, integration of the Analytical Hierarchical Process (AHP) as a Multi-Criteria Evaluation (MCE) technique with GIS software mapping has been used. These techniques provide a systematic approach for assessing and integrating the impacts of various parameters which involved multi-levels of dependent or independent qualitative as well as quantitative information [5-6]. It comprises three significant steps of methodology to determine the flood susceptibility in the study area (Figure 2).

3.1 Selection and Evaluation of Parameter and Sub Parameter
The selection of parameter has been made based on observation, interview the expert and literature review from previous flood reports. These parameters were selected depends on the significance of each variable towards causing the flood. There are eight parameters were chosen in this study; rainfall,
slope gradient, topography, drainage system, land-use, soil textures, slope curvature, and flow accumulation. The sub-parameter in each parameter has been future breakdown according to their influence on flooding.

3.2 Multi-Criteria Evaluation (MCE) Determination
To determine the weight of each parameter and sub parameter selected, a pair-wise comparison method, which is one of the AHP processes that was introduced by [7] has been applied. The parameter pair-wise comparison matrix has been estimated by pair-wise comparisons as input and produced the relative weights as output. Each comparison was rated by a group of experts using the scale for a pair-wise comparison technique to calculate the importance of every parameter and sub-parameters.

This technique involves the comparison of the parameter and allows one to compare the importance of two parameters at a time using the Saaty’s [7] relative scale. This method provides relative range consists of integer numbers from 1 to 9, whereby one means that the factors are equally important with the compared parameter and the higher the scale value indicates that the parameter is hugely more important than another. Pair-wise comparison was also carried out and applied to the sub-parameter.

The consistency ratio (CR) must be computed to verify the disagreement between the pair-wise comparisons and the dependable of the obtained weights. These are necessary to determine the consistency of the evaluation by calculating the consistency ratio (CR) before a final decision is made. The consistency ratio (CR) has been used in AHP to build a matrix, and [7] suggested that the CR must below 0.1 to be accepted. Otherwise, if the ratio exceeds 0.1, the set of judgements may be too inconsistent to be reliable. When the evaluation is inconsistent, the procedure is repeated until the CR is within the desired range.

3.3 Flood Susceptibility Analysis (FSAn)
The thematic maps have been produced based on primary data. These thematic maps then were analysed through the spatial analyst technique using the raster calculator. The thematic maps that have been given the weight such as rainfall map, drainage map, flow accumulation map, land use map, elevation map, slope gradient map, soil texture map, and slope curvature map then were calculated based on (2) for flood susceptibility level estimation and classification (Table 1). The flood susceptibility calculation was carried out through a combination of parametric input maps with the GIS operations using the grid base.

\[ \Sigma[(32.53 \times \text{Rainfall}) + (22.74 \times \text{Drainage Density}) + (15.84 \times \text{Flow Accumulation}) + (11.08 \times \text{Landuse}) + (7.19 \times \text{Elevation}) + (4.89 \times \text{Slope Gradient}) + (3.35 \times \text{Soil Textures}) + (2.38 \times \text{Slope Curvatures})] \] (1)

4. Results
There are eight thematic maps were produced based on the causative factors, which are rainfall, slope gradient, topography, drainage density, land use, soil textures, slope curvatures and flow accumulation as shown in Figure 3.

4.1 Rainfall
One of the major causes of floods is heavy rainfalls. Heavy rainfalls tend to cause flooding when natural watercourses cannot convey excess water. In this study, a rainfall map was developed based on daily rainfall intensity. This information was obtained from the Meteorological Department Malaysia (MetMalaysia) and the Sabah Department of Irrigation and Drainage (DID). The rainfall intensity map was calculated based on four rainfall station; Ulu Moyoq station, Inanam station, Kota Kinabalu International Airport station, and Babagon station.

A mean annual rainfall was considered and interpolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within the study area. There are five classes to classify the
intensity of the rainfall using equal interval. The reclassified rainfall was given a value <40mm (weight = 0.0624) for least rainfall to >300mm (weight = 0.4162) for highest rainfall.

| 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 |             |
|                     |                | Agricultural & Forestry | 0.1380         |
| 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 (°)            | 0.0623          |
|                     |                | 6 – 15 (°)           | 0.0986          |
|                     |                | 16 – 30 (°)          | 0.1611          |
|                     |                | 31 – 60 (°)          | 0.2618          |
|                     |                | > 60 (°)             | 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          |
4.2 Drainage Density
Drainage densities are one of the critical keys that control the hazards by indicating the nature of soils and its properties. The higher the drainage density, the higher the catchment area that prone to erosion, resulting in sedimentation at the lower ground [8]. Drainage density map could be derived from the drainage map. The drainage density was calculated based on the total length of drainage channel in watershed divided by the entire area of the watershed. For the study area, higher value (0.4162) were assigned to poor drainage density area, and lower weighted value (0.0624) were assigned to the area which has a dense amount of drainage. Then the drainage density was reclassified into five classes using the standard classification schemes.

4.3 Flow Accumulation
Flow accumulation is where water accumulates from precipitation with sinks being filled. From the flow accumulation of the study area, two main rivers in the study area were derived: Moyog and Babagon Rivers. For the study area, higher weighted value (0.3612) were assigned as highest flow accumulation areas whereas 0.1238, a lower weighted value was designated as lowest flow accumulation. The flow accumulation layer was reclassified in five classes using the standard classification scheme.

4.4 Land use
One of the significant concerns in flood susceptibility analysis is land use. It reflected the current use of the land and related to infiltration. One of the examples is like vegetation land-cover, it has an essential impact on the ability of the soil to act as a water store [8]. In this study area, land use map

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**Figure 3.** Thematic maps for Flood Susceptibility Analysis (FSAn) in the study area.
shows a few sectors such as the residential sector, commercial sector, public infrastructure sector, the industrial sector, the higher education institutions and schools’ sector, the agriculture, forestry, and other sectors.

Based on the results of the GIS spatial analyst conducted, it was found that the agriculture, forestry and other sector cover the most extensive area in the study area (53.92%). This was followed by the residential sector (32.98%), the commercial sector (6.00%), water body (2.34%), the higher education institutions and schools’ industry (2.27%), the industrial sector (1.68%), and the public infrastructure sector (0.82%). In terms of the progress of the diversity of land use, this means that the study area has been explored for more than 70% for development and agricultural activities. Exploration mass without control/enforcement of the actions of slope cutting can trigger the occurrence of the flash flood.

4.5 Elevation
Raster datasets on slope condition like morphometric features and hydrologic parameters, were automatically extracted from the Digital Elevation Model (DEM). The elevation of topography in the study area can be divided into three main areas: lowland areas (<10 m), moderately highland areas (11-30 m) and hilly areas (>30 m). Almost 16.01% of the study area consists of lowland areas (<10 m). Moderately highland areas (11-30 m) covered about 42.38% of the entire study area whereas hilly regions (>30 m) that extend in the northwestern and southeastern parts covered about 41.60% of the whole study area.

4.6 Slope Gradient
Low gradient slopes are highly prone to flood occurrences compared to high slopes gradient [8]. Rain or excessive water from the river always gather in an area where the slope gradient is usually low. In terms of slope gradient in the study area, the results suggest that 48.37% of the area can be categorized as 0° - 5°, 28.45% as a 6° - 15°, 22.41% as 16° - 30°, 0.75% as 31° - 60° and 0.01% in excess of 60°.

4.7 Soil Textures
Soil types define the variety of physical characteristics for unconsolidated deposition and weathering product. Soil textures and moistures play an essential role in causing a flood as it is controlled the amount of water that infiltrate into the ground and hence the amount of water which become surface runoff [9, 10]. Based on the soil types map derived from the Agriculture Department of Sabah (JPNS), the soils association in the study area can be grouped into ten (10) categories, namely the Weston association (very silty sand-textured, SM) (5.47%), the Tanjung Aru association (sand with little silty textured, SW) (2.98%), the Tuaran association (very silty sand-textured, SM) (2.03%), the Kinabatangan association (very clayey sand-textured, SC) (1.28%), the Sapi association (peat textured, Pt) (1.28%), the Klias association (organic textured, O) (1.69%), the Brantian association (clay textured, C) (1.07%), the Dalit association (very clayey sand-textured, SC) (8.89%), the Lokan association (very silty sand-textured, SM) (26.23%), and the Crocker association (clayey sand-textured, S-C) (49.07%).

4.8 Slope Curvatures
Slope curvature has a substantial impact on flooding by dispersing surface and subsurface water in the landscape. There are three classes of slope curvature; convex, concave and straight surface. Most of the entire flooding area lies in a straight or flat elevation. In this study, the slope curvatures classes having fewer values were assigned higher weighted value due to almost flat terrain while the class having maximum value was categorised as lower weighted value due to relatively high run-off. This implies that slope curvatures may not be the predominant factor in ranking flood susceptibility level classes.
4.9 Flood Susceptibility Level (FSL)

The results for the Flood Susceptibility Level (FSL) analysis at the Kg. Kolopis area suggests that 40.49% of the area can be categorised as having very low susceptibility (VLS), 35.08% as low susceptibility (LS), 18.21% as moderate susceptibility (MS), 5.50% as high susceptibility (HS) and 0.71% as very high susceptibility (VHS). Figure 4 shows the results of the Flood Susceptibility Level (FSL) data in the year 2002, 2008 and 2014.

![Maps of the study area](image)

Figure 4. Flood Susceptibility Analysis (FSAn) Maps of the study area (Year 2002, 2008 and 2014).

5. Discussion

The FSL in the study area was analysed by using eight (8) parameters that were considered concerning the factors of flooding, which are: rainfall, slope gradient, elevation, drainage density, land use, soil textures, slope curvatures, and flow accumulation. In general, the Very Low Susceptibility to Low Susceptibility areas refers to stable conditions from flood hazards. In contrast, Medium Susceptibility to High Susceptibility areas is not recommended to be developed due to high flood hazards. However, if there is no choice or the developer or the local authorities want to develop these areas, some mitigation procedures to be introduced. Very High Susceptibility areas are strictly not recommended to be prepared and provisions for suitable structural and non-structural works planning control are supported.

Area of low-level flood susceptibility decreases across the year. On the other hand, a very high level of flood susceptibility increases across the year. Generally, areas with high to a very high level of flood susceptibility were found to be near the drainage system. Areas with moderate flood susceptibility level were located at the low-lying area. Meanwhile, those areas having low flood susceptibility occupy the high elevation region. Land use development in the low-lying area would be a significant factor that contributes to the higher level of flood susceptibility in this area. It is undeniable that low-lying area is more prone to flooding, but that depends on the texture of the soil whether it eases the infiltration of water or inhibits it. Land use development on this low-lying area such as the construction of buildings or roads makes the situation worse because it involves the clearing of vegetation, cutting of slope and the surface is covered with impervious material. That is why the level of flood susceptibility in this area is getting high.

6. Conclusion

The results of this study indicate that the integration of MCE and GIS techniques provides a powerful tool for decision-making procedures in FSL mapping, as it allows a coherent and efficient use of spatial data. The purpose of MCE for different factors is also demonstrated to be useful in the
definition of the risk areas for flood mapping and possible prediction. In overall, the case study results show that the GIS-MCE based category model is useful in flood risk zonation and management.

The developed framework model (Figure 4) will be a precious resource for consulting, planning agencies and local governments in managing hazard/risk, land-use zoning, damage estimates, good governance and remediation efforts to mitigate risks. Moreover, the technique applied in this study can easily be extended to other areas, where other factors may be considered, depending on the availability of data. Recognition that unplanned and uncontrolled development can increase the risk to life and damage to property is fundamental to successful floodplain management. Awareness of this issue is not just the responsibility of the local authorities, but all stakeholders, covering both the public and private sectors. While the land developer has the social responsibility for flood compatible development, the approving agencies share a portion of that responsibility through effective floodplain management, excised in a transparent, impartial manner.

7. References
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Acknowledgment
Deep gratitude to Universiti Malaysia Sabah (UMS) for providing easy access to laboratories and research equipment. Highest appreciations also to UMS for the research grant award (Priority Field Research Scheme, SPBK) (SBK0335-2017) and UMGreat: GUG0077-STWN-2/2016 to finance all the costs of this research.