Flood Susceptibility Analysis (FSAn) Using Multi-Criteria Evaluation (MCE) Technique for Landuse Planning: A Case from Penampang, Sabah, Malaysia

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Abstract. Flooding is one of the main natural disasters in Sabah, Malaysia. Several current cases of disastrous flooding were recorded particularly in Penampang area, Sabah (e.g. July 1999; October 2010; April 2013; October & December 2014). Substantial downpour has triggered floods and caused extreme loss in Penampang area. The 2014 floods have affected 40,000 people from 70 villages. The objectives of this research are (i) To determine the factors contributing to the flood occurrences; (ii) To analyse the Flood Susceptibility Level (FSL); and (iii) to produce the flood hazard map for the study area. 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 Susceptibility Analysis (FSAn) map was produced based on the data collected from the field survey, laboratory analysis, high resolution digital radar images (IFSAR) acquisition, and secondary data in year 2014. FSL was defined using Multi Criteria Evaluation (MCE) technique integrated with GIS software. Based on the FSAn, approximately 3.17% of total study area classified as Very High Hazard (VHH), 4.55% as High Hazard (HH), 15.52% as Moderate Hazard (MH), 15.72% as Low Hazard (LH) dan 61.04% as Very Low Hazard (VLH) respectively. Based on the risk rate, requirements for the development procedure has been recommended in this paper. The map produced will be a very useful source for consulting, planning agencies and local governments in managing risk, land-use zoning and redressal efforts to mitigate risks. Besides, the method used in this study can easily be applied to other areas, where other factors may be considered, depending on the convenience of data.

1. Introduction
Flooding is one of the major natural disasters in Malaysia. Based on the results from Department of Irrigation and Drainage, it has been estimated that an area of 29,000 km² or 9 % of the total area in Malaysia are vulnerable to this disaster, a loss of RM 915.12 million and 4,915,000 people was evacuated in 2002 [1]. The Penampang District of Sabah, East Malaysia (Figure 1) has long been known as a flood prone area, is facing a rapid economic development which resulted in further pressure to utilize various purposes such as infrastructures, residential, commercial, tourism and...
agricultural activities in low lying area in Moyog river floodplain. The subsequent transition of land use from rural development and cultivation of rice paddy to intensive urban development presents a range of social and environmental issues. Of concern to the area are the issues associated with flooding.

Based on the flood histories in Kota Kinabalu vicinity from July 2005 until May 2015, a total of 38 flood cases and 5 deaths had been recorded (Table 1) that caused by the monsoon flood. In 2014 from October 7 to October 10, Penampang suffered its worse flood ever, since the last big flood in 1991 (Figures 2 & 3). According to the District Officer of Penampang as many as 40,000 people from 70 villages were affected by the flood. This catastrophic flood occurred coincidently with continuous heavy rainfall and affected by the tail of typhoon Phanfone and typhoon Vongfong. Another recent flood disaster in Penampang occurred in September 2007 and May 2013 which were also affecting several villages (Figure 3).

This research will focus on flood hazard assessment in Penampang low lying areas using Multi Criteria Evaluation (MCE) method and Geographic Information System (GIS). By the end of this research, several types of flood hazard severity maps will be produced. Although this approach looks like a general research, it is very practical and relevance to delineate a clear flood hazard situation. These maps can help the authorities to identify the most cost-effective measurement for flood mitigation development plan. Generally, this research approach is a compulsory way in early stage for any development purposes activities and to ensure the sustainability long-term development in low lying areas and to avoid over an unplanned and mismanagement development. It is hopes that the outcomes from this research can be an important reference document for the local authority and other relevant agencies for the purpose of urban planning and flood mitigation.

The main objectives of this study are to determine the factors contributing to the flood occurrences in the study area, to analyse the Flood Susceptibility Level (FSL) in the study area, and to produce the flood susceptibility map of the study area. This research concentrated in low-lying area which have contributes to most of the flood events. All the activities such as mapping, observation and monitoring is more focused on the low-lying area which have high inundation possibilities. An integration of Analytical Hierarchical Process (AHP) as a Multi-Criteria Evaluation (MCE) technique with GIS software mapping is used in this study to produce the flood hazard maps. Decision making is an alternative way of making choice in many disciplines. The unavoidable problems in these disciplines necessitated a detailed analysis considering many different criterions. All these criteria need to be estimated for decision making process [2-6]. For example, Multi Criteria Evaluation (MCE) methods has been used in various studies since most of the data used by decision makers are associated to geography [7,8]. When it comes to decision making, Geographic Information System (GIS) offers a finer and greater extent of information. This allows the decision makers to identify the criterion with a specified set for overlay process [9,10], and the multi-criteria decision analysis within GIS is used to develop and evaluate alternative plans that may enable compromise among the concerned parties [11].

Table 1. Summarization of flood histories in Kota Kinabalu vicinity from July 2005 until May 2015 (Source from NDRC-UMS website).

| No. | Locations            | Total Occurrences | Deaths |
|-----|----------------------|--------------------|--------|
| 1   | Telipok, Sepanggar   | 10                 | 3      |
| 2   | Inanam, Menggatal    | 8                  | 1      |
| 3   | Penampang, Kepayan   | 14                 | 1      |
| 4   | Kota Kinabalu        | 4                  | 0      |
| 5   | Putatan              | 2                  | 0      |
|     | **Total**            | **38**             | **5**  |
2. Material and Methods
In this study, in determining the flood susceptible areas in the study area two stages were undertook. First is determining the causative factors causing flood in the study area; secondly, is applying the Multi-Criteria Evaluation technique in finding the flood susceptible areas based on the flood related factors of the study area and thirdly, Flood Susceptibility Analysis (FSAn). Figure 4 illustrates the methodological flowchart of the study.
2.1 **Scope of the Study**
The study area 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”. It has covered around 151 km² which is mostly the Penampang district and partly Kota Kinabalu area (Figure 1). The topographic setting of this study area is mainly controlled by its flat land in western part and mountainous region at eastern part. This geographical and geomorphological setting encourages the opening of development projects in low-lying areas and near to the rivers. This research concentrated in low-lying area which have contributes to most of the flood events. All the activities such as mapping, observation and monitoring is more focused on the low-lying area which have high inundation possibilities. An integration of Analytical Hierarchical Process (AHP) as a Multi-Criteria Evaluation (MCE) technique with GIS software mapping is used in this study to produce the flood hazard maps.

2.2 **Desktop Study**
Desktop study involves the revision of previous studies such as assessment reports, journals, proceedings, photographs and any related documents. All these activities need to be done to get understanding about the geomorphological and flood behavior in the whole study area. Several maps and images were also referred which include topographic maps from different eras published by the Survey and Mapping Department (JUPEM), landuse maps from different eras provided by Department of Agriculture Sabah, digital elevation model from Interferometric synthetic aperture radar (IFSAR) and the Google Earth images referred online. All this information provided essential information on elevation, geomorphology, landform and land use in study area, particularly in areas where the physical condition is not clearly visible from the ground due to the obstruction of view by vegetation or buildings.

2.3 **Field Observation**
Field observation in the study area is a compulsory activity to implement to get the real situation related to the studies such as river morphology, settlements in low lying areas, etc. All the field observation was carried out by using 1:50,000 scale base maps for 72 grids. The equipment used during the field observation were camera, Brunton compass, global positioning system (GPS) and tape.
measures. An Unmanned Aerial Vehicle (UAV) survey had also been carried out in the field to obtain the aerial photographs. The field observations were made along the roads, tracks, streams and covered the whole study area especially in the low-lying areas.

2.4 Data Interpretation & Analysis

The generation of 1 meter contour from DEM IFSAR was carried out by using Global Mapper V. 10. The contour then stored in shapefile format and transferred to ArcGIS V.10.0. All the topographic maps, land use maps, imageries and the generated contour were integrated on the ArcGIS V.10.0 files, together with the waypoints and traverses downloaded from the GPS during field observation. By the end of the results, GIS generated various thematic maps such as rainfall map, drainage density map, flow accumulation map, land use map, elevation map, slope gradient map, soil textures map and slope curvatures map. All these maps were used to identify the hazard in the respective area and produce the flood hazard maps.

2.5 Flood Susceptibility Assessment

In this study, in determining the flood susceptible areas in the study area two stages were undertook. First is determining the causative factors causing flood in the study area and secondly, is applying the Multi-Criteria Evaluation technique in finding the flood susceptible areas based on the flood related factors of the study area. In evaluating the flood susceptible areas, Pair-wise Comparison Method was used. It is an integral part of Analytical Hierarchy Process (AHP) proposed by Saaty in 1980 [12] for tackling sophisticated problems. This helps in detecting the flood susceptible areas in the study area by identifying the most flood significant criteria based on the decision makers’ preferences. An integration of Analytical Hierarchical Process (AHP) (Figure 5) as a Multi-Criteria Evaluation (MCE) technique with GIS software mapping is used in this study to produce the flood hazard maps.

2.6 Flood Susceptibility Analysis (FSAn)

The initial step in this section is the delineation and conversion processes of data from the radar images (IFSAR). This section also covers the integration between criteria & sub criteria weights and maps, producing a Flood Susceptibility Analysis (FSAn) using spatial analyst, which determine the Flood Susceptibility Level (FSL). All of the thematic maps such as rainfall map, drainage density map, flow accumulation map, land use map, elevation map, slope gradient map, soil textures map and slope curvatures map were analyzed through the spatial analyst technique (raster calculator) based on Equation (1) for FSL estimation and classification (Table 2). The FSL calculation was carried out through a combination of input parametric maps in Equation (1 and 2) with the GIS operations using a grid base.

\[
FSI = \sum_{j-1}^{n} W_jw_{ij}
\]  

(1)

Where:

- FSI: Flood susceptibility index
- \(W_j\): Weight value of criteria \(j\)
- \(w_{ij}\): Weight value of class \(i\) in criteria \(j\)
- \(n\): Number of Criterion

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

(2)
Table 2. The weighted value of the factor in the final result.

| 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 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 (°)      | 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          |
|                 |                | Tuaran         | 0.0323          |
|                 |                | Kinabatangan   | 0.0433          |
|                 |                | Tuanan         | 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          |
3. Results and Discussion

Eight (8) parameters were considered in this study in relation to the factors of flooding, which are: rainfall, slope gradient, elevation, drainage density, land use, soil textures, slope curvatures and flow accumulation. The result and discussion on the causative factors in flood occurring and the flood susceptibility level in the study area are as follows:

3.1 Rainfall

High intensity of rainfall can trigger flooding especially if the drainage systems do not have the capacity to cope with the flows. Floods are related with excesses rainfall, any water that cannot immediately leak into the ground flows down slope as runoff. The amount of runoff is associated to the amount of rain an area experience. The water level in rivers increases because of heavy rainfalls. When the water level increases above the riverbanks or dams, the water start to overflow, hence cause river-based floods. The water runoffs to the areas attached to the rivers or dams, triggering floods [10].

In this study, a rainfall map was produced based on the daily rainfall amounts for the study area (Figure 3). According to the information received from the Metrology Department of Malaysia (MetMalaysia) and the Sabah Department of Irrigation and Drainage (DID), a total of four (4) stations which are the Ulu Moyog station, Inanam station, Kota Kinabalu International Airport (KKIA) station and Babagon station were recognized. A mean annual rainfall for fourteen years (2002–2015) was took into account and interpolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within and around the municipality boundary of the study area. The interpolated raster layer was categorised into the five classes using an equal interval. The categorised rainfall was given a value < 40 mm (weighted = 0.0624) for the smallest amount to > 300 mm (weighted = 0.4162) for the highest amount of rainfall as shown in Table 2 and Figure 6.
3.2 Drainage Density

Drainage density or stream density is one of significant characteristics for evaluating potential runoff. It depends on climate and physical characteristics of the drainage basin. Rivers that have a high drainage density indicate a greater flood risk. The results show that the higher weightage value is 0.4162 while the lower weightage value is 0.0624. Higher weightage value refers to lower drainage density and lower weightage value refer to high drainage density (Table 2 and Figure 7).

Based on map in Figure 7, it was shown that the study area does not have large number of tributaries. This indicates that the drainage basin of the area has lower drainage density. Lower drainage density means a deep, well-developed soil. In this case, water will infiltrate into the soil rather than become surface runoff and enter into the channel network. The drainage density layer was categorised into five sub-groups using the standard classification Schemes. Areas with very little drainage density are > 200 mm and those with very high drainage density are with value of < 50 mm as shown in Table 2 and Figure 7.

3.3 Flow Accumulation

Flow accumulation represents the drainage network and its water accumulation potential. An increase in flow accumulation means an increase in flood susceptibility [13]. The output of flow accumulation would represent the amount of rain that would flow into each cell, assuming that all rain became runoff and there was no interception, evapotranspiration, or loss to groundwater. This could also be viewed as the amount of rain that fell on the surface, upslope from each cell.

As shown in Table 2 and Figure 8, higher weighted value (0.3612) were assigned as highest flow accumulation areas and lower weighted value (0.1238) were assigned as lowest flow accumulation. Cells with a high flow accumulation are areas of concentrated flow. While cells with a flow accumulation of zero are local topographic highs.
3.4 Land Use
Land use is considered as another important factor that affects the flood risk in the study area. Construction of roads and buildings involve removing vegetation and soil from the land surface. The permeable soil is replaced by impermeable surfaces like road, parking lot or sidewalk. Impermeable surfaces store little water that reduce infiltration of water into ground and accelerate runoff. As a result, peak discharge, volume and frequency of floods increase in nearby streams. From the land use maps shown in Figure 9 and Table 2, the higher weightage value (0.3163) refer to residential sector while the lower weightage value (0.0756) refer to agricultural and forestry sectors. It can be seen that from the map in 2014, the agriculture, forestry and others sector cover the broadest area in the study area (53.92%). Next is the residential sector (32.98%), then the commercial sector (6.00%), water body (2.34%), the higher education institutions and schools’ sector (2.27%), the industrial sector (1.68%), and the smallest area is the public infrastructure sector (0.82%).

3.5 Elevation
Elevation plays an important part in the horizontal movement of water across the landscape, with water tending to collect in the lower and flatter areas. The study area has three types of topography which are lowland areas (<10 m), moderately highland areas (11-30 m) and hilly areas (> 30 m) (Tab. 2). The highest point (1350 m) is located in the northwestern and southeastern of the area while the lowest part (<10 m) is located in the southwestern and northern parts of the area (Figure 10). Most of the development that takes place in this area is located in lowland region. This area also has high population. Lowland areas have risk of flooding associated with the elevation variables. When heavy rain occurs, water from higher region will tend to accumulate in the lower elevation because of gravity. Lowland areas were concentrated in the southwestern and northern parts of the study area with little hills. From the satellite images observations, lowland areas have brighter tone, incorporeal arise and flat. Moderately highland areas most widespread has changed from its original height due to the activities of urbanization. From the satellite images observations, moderately highland areas have medium dark tone, incorporeal arise with lineaments trends at northeast southwest. Hilly areas are part
of the Crocker range that forms a ridge nearly parallel to the strike of the bedding planes of the Crocker Formation sedimentary rocks in the northeast southwest.

![Elevation map](image)

**Figure 10.** Elevation map.

### 3.6 Slope Gradient
Slope gradient involves the velocity of runoff water. The energy of flow is determined by the slope of the surface. In a flat area, runoff water is retained for longer time and increase the damage. Lower slope gradient is highly vulnerable to flood occurrences compared to high gradient slopes. This is because rain or excessive water from the river always gathers in an area where the slope gradient is usually low. Also, areas with high slope gradients do not permit the water to accumulate and this result into flooding. Based on Figure 11, most of the area falls in the category of lower slope gradient (0° - 5°). This indicates that the place had undergone a process of cut and fill slopes activities for urbanization, housing, manufacturing and other infrastructure construction. That is why flooding occur in this area.

![Slope gradient map](image)

**Figure 11.** Slope gradient map.

### 3.7 Soil Texture
In Soil is an important geographical factor which has a direct influence on the drainage process because of its characteristics like texture, permeability degree and structure [14]. Generally, water will move slowly in the soil that has higher clay content. Besides, any impermeable layers in the subsoil such as natural clay will impede the drainage. Floods are more likely to occur in the areas that have clayey texture because clay can hold water at longer time than sand. The soil types in an area is important as they control the amount of water that can infiltrate into the ground, and hence the amount of water which becomes flow [15]. The structure and infiltration capacity of soils will also have an important impact on the efficiency of the soil to act as a sponge and soak up water. Different types of soils have differing capacities. The chance of flood hazard increases with decrease in soil infiltration capacity, which causes increase in surface runoff. When water is supplied at a rate that exceeds the soil’s infiltration capacity, it moves down slope as runoff on sloping land, and can lead to flooding [16]. As shown in Figure 12, the higher weighted value is 0.0199 which refer to Lokan association...
characterized by very silty sand (SM) soil texture. While the lower weighted value is 0.2716 which refer to Klias association characterized by an organic (O) soil texture.

![Soil texture map.](image1)

**Figure 12.** Soil texture map.

### 3.8 Slope Curvature

Slope curvature indicates where the surface is concave or convex [17]. It can cause acceleration or deceleration of the flow. Slope curvature has a strong influence on flood occurrences in by concentrating or dispersing surface and primarily subsurface water in the landscape. Based on Figure 13, the higher and lower weighted value is 0.1636 which means that the area is almost a flat terrain while the lower weighted value is 0.539 which refer to convex in slope curvature (Table 2). Areas of convex curvature indicate where acceleration of flow occurs17. The stream gains energy and its ability to transport particles increase. Therefore, areas of convex curvature indicate areas of erosion. While areas of concave or straight curvature is where the flow rate decreases, and the stream loses energy. Therefore, those areas indicate areas of deposition.

![Slope curvature.](image2)

**Figure 13.** Slope curvature.

### 3.9 Flood Susceptibility Level (FSL)

The percentage of the flood susceptibility level in the study area. According to the flood susceptibility map shown in Figure 14, areas with high to very high level of flood susceptibility were found to be near the drainage system and 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 the major 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 construction of buildings or roads makes the situation worse because it involves 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. Table 3 shows the requirements for development procedure according to the risk rate in the area concerned [18-19].
Figure 14. Flood susceptibility map.

Table 3. Land use suitability classes

| Risk Rate       | Requirements for development procedure                                                                 |
|-----------------|----------------------------------------------------------------------------------------------------------|
| **Very low (VLS)** | - Development highly recommended.                                                                     |
|                  | - Environmental Impact Assessment (EIA) must be conducted followed by suitable procedural guidelines or acts available (Handbook of EIA Guidelines, 2001 (DOE), Pindaan Akta Perancangan Bandar dan Desa, Akta A933 (1995), Garis Panduan DBKK, etc). |
|                  | - Detailed engineering geological and geotechnical reports.                                              |
|                  | - Conduct flood hazard assessment (FHA) – hazard identification & hazard analysis.                      |
| **Low (LS) to Moderate (MS)** | - Development slightly recommended.                                                                   |
|                  | - Environmental Impact Assessment (EIA) must be conducted followed by suitable procedural guidelines or acts available (Handbook of EIA Guidelines, 2001 (DOE), Pindaan Akta Perancangan Bandar dan Desa, Akta A933 (1995), Garis Panduan DBKK, etc). |
|                  | - Detailed engineering geological and geotechnical reports.                                              |
|                  | - Suitable structural control works planning (stabilization and mitigation).                           |
|                  | - Conduct flood risk analysis (FRAn) – FHA, consequence analysis & risk estimation.                    |
| **High (HS)**    | - Development to be allowed.                                                                            |
|                  | - Environmental Impact Assessment (EIA) must be conducted followed by suitable procedural guidelines or acts available (Handbook of EIA Guidelines, 2001 (DOE), Pindaan Akta Perancangan Bandar dan Desa, Akta A933 (1995), Garis Panduan DBKK, etc). |
|                  | - Detailed engineering geological and geotechnical reports.                                              |
|                  | - Suitable structural control works planning (stabilization and mitigation).                           |
|                  | - Conduct flood risk assessment (FHAs) – FHA, FRAn & risk evaluation.                                 |
| **Very high (VHS)** | - Basically, development is not recommended. However, if there is no alternative or the developer or the local authorities really want to develop this area, some procedures to be observed are as follows: |
|                  | - Environmental Impact Assessment (EIA) must be conducted followed by suitable procedural guidelines or acts available (Handbook of EIA Guidelines, 2001 (DOE), Pindaan Akta Perancangan Bandar dan Desa, Akta A933 (1995), Garis Panduan DBKK, etc). |
|                  | - Detailed engineering geological and geotechnical reports.                                              |
|                  | - Suitable structural control works planning (stabilization and mitigation).                           |
|                  | - Conduct flood risk management (FRM) – FHA, FRAn, FRAs & risk treatment.                             |
| **Extremely high (EHS)** | - Development is not recommended.                                                                      |
|                  | - Suitable non-structural control works planning: Regulatory measures, public awareness, disaster preparedness, behavioral modification and early warning system) |
4. Conclusion
Multi-criteria analysis (AHP) adopted for this study within Penampang district facilitated multi-source data combinations, which constituted a real advantage. The parameters used in the flood risk map include rainfall, slope gradient, topography, drainage system, land use, soil textures, slope curvatures and flow accumulation. Results indicated that AHP can be used as an efficient method to assess and map flood risk in GIS environment.

This resultant map can serve as a guideline to decision makers for potential anticipatory measures, better land use planning and flood risk management under climate change. Strict measures need to be taken concerning the uncontrolled urbanization and the occupation of areas that has proximities of rivers and places of clogged water passages to be implemented by policy makers in order to prevent more significant damages. This study also shows reliability and the indisputable role play by geoinformation techniques in natural disaster assessment which requires the contribution of multi-source data. The flood hazard map produced in this study should be renewed periodically whenever new data are available since they are very general and represent a static view of reality.

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