Flood Hazard Potential Mapping Using GIS: A Case Study in Sungai Besi Camp, Kuala Lumpur

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Abstract. During the last few decades, floods have been the most common natural disaster on the world. For flood management and mitigation, flood hazard potential mapping is required. The goal of this study was to create a flood hazard potential map by utilising the efficiency of the analytical hierarchical process (AHP) to identify potential flood hazard zones by comparing them to previous flood events that had been documented. Five parameters were used in the study area: distance from drainage, land use, elevation, land slope, and rainfall data. Ratings on the Saaty's scale were prepared to determine the weight of each effective factor. The normalised weights of criteria/parameters were determined using the AHP and eigenvector methods, based on Saaty's nine-point scale and its importance in specifying flood hazard potential zones. To generate a flood hazard potential map, the set of criteria was combined using the weighted linear combination method in ArcGIS 10.8 software. The flood hazard potential map was validated by comparing previous documented flood events that occurred in the study area. The results showed that the AHP technique has the potential to make accurate and reliable flood hazard potential. Hence, the AHP and geographic information system (GIS) techniques are recommended for assessing flood hazard potential, particularly in areas with limited data.

Keywords: Spring Water, Water Quality Monitoring, World Health Organisation (WHO), National Water Quality Standard for Malaysia (NWQS).

1 Introduction

Flood is a typical and natural phenomenon or occurrence when exaggerated water overflows or overhelm land that is normally dry. The term can also be applied to inflow of the tide in the sense of "flowing water". Flood are a field of research in the hydrology discipline and are of major concern in agriculture, civil engineering and public health. Human environmental changes also increase the severity and frequency of flooding such as deforestation and wetland removal, changes in waterway routes such as levees, and greater environmental concerns such as climate change and increase in sea level rise. According to [11], flooding is a natural disaster that frequently occurs and has had a serious effect on people, infrastructure and property, as well as an indirect impact on the economy of the country.

Nowadays, the traditional flood protection policy has now moved to a higher hazard potential-based flood management approachand and prespective to mitigate the effect of flooding. Two elements are related to flood hazard potential, i.e., flood vulnerability and flood hazard. Flood hazard can be ecplicate as possibility or probability of a flood event occurring. Meanwhile, the possible effect of flooding on society and properties that is typically correlated with property damage assessment can be define as flood vulnerability. Therefore, improving geographic information system (GIS) has encourage to explore alternative approach to flood hazard potential mapping in recent years. [1] stated that, the critical element of flood hazard potential mapping is the retrieval of geomorphological attributes using Geographic Information Systems (GIS) techniques.

Several studies [10], [2] have found that flood hazard potential mapping could help the the authorities to manage and mitigate the flood effect that bring damage to study area and there is several main criteria that are related to be include in flood hazard potential mapping: (i) elevation; (ii) land use; and (iii) soil. Most of the criteria stated could be found in most study area and should be the main criteria for every study. [9] considered another two criteria that are pertinent to flood hazard potential mapping which are water table and interval from water surface. Various of criteria could be chosen to adapt and significant to the study area. Selection of criteria is crucial due to different criteria selected extremely impact the mapping.

A critical element of flood hazard potential mapping in managing the consequences is the estimation of river flood levels. There are three common proposition to predicting flood: (i) analysis of flooding frequancy, by means analysis of statistic, makes it possible to assess the recurrence period for each year and for a given stream discharge (without necessarily classification of the flood zones); (ii) storm progress monitoring (e.g. the amount of precipitation) where it can be applied to forecast short-term flood events; and (iii) the flood hazard map: facilitates the size of flooded areas to be estimated for various return time depending on the predicted discharges [12]. A common approach to flood hazard potential mapping is the use of hydrological numerical models that replicate water height over different surfaces as a function of several factors [5].

Many flood hazard potential mapping methods have been implemented, and one of the most common methods is the Analytic Hierarchy Process (AHP), GISs and integration of remote sensing data. [12] stated that, analysis of the Geographic Information System (GIS) and visual features commonly used in recent years to forecast flood-prone areas and flood maps. The GIS have been shown to be successful in analysing the hydrological aspects, especially in the area of flood hazard potential mitigation. The GIS is capable of using maps to store attribute data and has a feature to organise resources for large database. The Analytic Hierarchy Process (AHP) technique is relatively simple to use, versatile and allows users to have less abilities skill compared to other tools for example Multi Attribute Utility Theory (MAUT).

According to the Malaysian Department of Drainage and Irrigation (DID), flood coverage in Malaysia was approximately over 4.82 million people and 29 800 km^2 of land area which consist of 22 percent of overall population are threatened per year, with resident area of lowlying especially near to riverbanks, being the most prone to flooding. Malaysia has been vulnerable throughout the whole year to the season of the monsoon and dense precipitation, resulting enormous runoff concentration exceeds the absorption competence of the system of natural drainage. [6] stated, heavy monsoon rainfall season in 2006, 2007 and 2008 caused flood along Malaysia's east coast and also various part of the country, and one of the hardest hit areas along the east coast of Peninsular Malaysia was Terengganu.

Malaysia has a year-round average monthly temperature ranging from 23°C to 34°C and relative humidity as high as 90 percent due to Malaysia are located in the equatorial zone. Malaysia has a very high intensity of rainfall, especially during 4 the monsoon seasons. The annual rainfall varies from 2000 mm to 2500 mm and the monthly average precipitation varies from 133 mm to 259 mm. Several states at east coast of Malaysia suffer major damage subsequence to flood that occurs during monsoon season. A lot of remedial action had been taken by the Malaysian authorities to forecast and manage the flood occurrence at the east coast.

In several state recently, flood have caused significant damage to its public and private properties. It was verified by the National Security Council (NSC) that the recent major flood that hits Pahang, Johor, and Terengganu is one of the worst in history of Malaysia. Heavy rain and continuos raining have caused the river in the particular state rise to its danger level from December 2020. According to Department of Irrigation and Drainage (DID) in December 2020, several district in Pahang, six major rivers in that state have rise to its danger limit which include Sungai Jelai, Jeram Bungor, Lipis; Sungai Pahang di Sungai Yap, Jerantut; Sungai Pahang (Lubuk Pasu), Temerloh; dan Sungai Pahang di Lubuk Paku, Maran.

Researchers, municipalities, and the private sector have developed numerous methods for producing flood maps to forecast hydraulic and hydrological modelling for flood hazard potential mitigation planning as well. Using InfoWorks River Simulation and LiDAR systems, Department of Irrigation and Drainage (DID) Sarawak has built a flood map in Sarawak, but the cost is higher due to time and labour costs for surveying a river cross-section. The Digital Elevation Model (DEM) is the lion's share feasible method obtained from the Earth Explorer website supported by the United States Geological Survey (USGS) for open access. Mapping is a tool for researchers to check databases to view, for example, flood hazard potential factors such as topographic, slopes, contours, or land use characteristics of an area. To estimate the region of flood hazard potential, GIS is combined with Multi-Criteria Decision Analysis (MCDA). To score and illustrate flood hazard potential area likelihood, Spatial multi-criteria analysis is used. Meanwhile to measure the priority weights of each factor, the Analytical Hierarchy Method (AHP) is used.

2 Material and Method

2.1 Study Area

The study area was in Universiti Pertahanan Nasional Malaysia (UPNM) which located in Kuala Lumpur at latitudes 3° 3" east and longitudes 101°43" north shown in Figure 1. Kuala Lumpur state is exposed and very vulnerable to flood event when heavy rain occurs. Throughout the year, it is normally hot and humid, averaging from

28°C to 30°C during the day and slightly cooler after sunset. According to Malaysian Department of Drainage and Irrigation (DID), Kuala Lumpur is influenced by strong and prolonged rainfall during the southwest monsoon from June to September and during the northeast monsoon from December to March. Generally, strong localised precipitation associated with short duration thunderstorm occurs throughout the year. The annual average rainfall varies from 1900 mm to over 2600 mm.

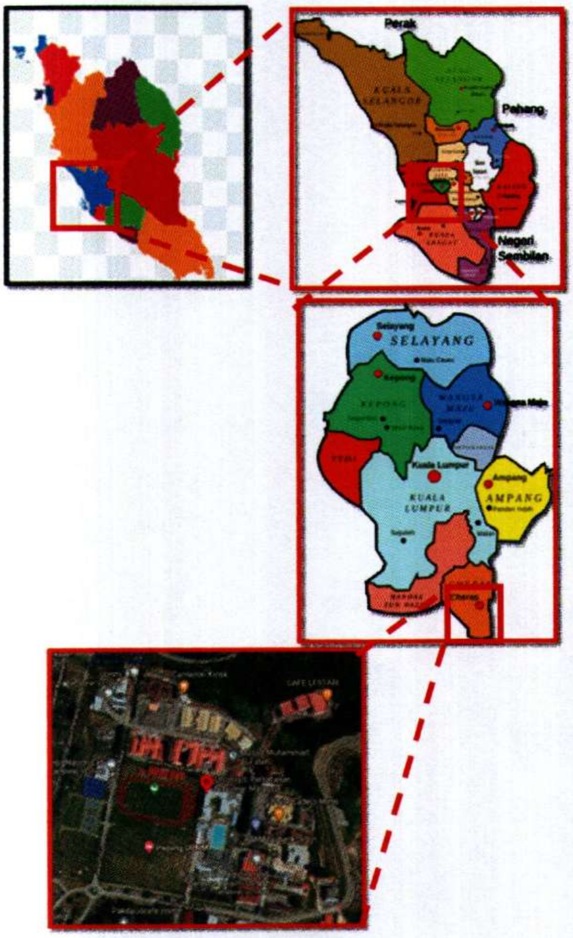

Fig. 1. Location of study area

2.2 Methodology

A multi-criteria GIS approach for flood hazard potential mapping based on the spatial intersection of six criteria was applied in this study which consist of slope percent, distance from drainage, land used and land cover, altitude, curve number and rainfall data. The AHP was chosen in the sense of MCDM as the criteria weighting process. The criteria used to assess the flood hazard potential are based on the factors that relate most to the flooding of rivers.

ArcMap (version 10.8), which is a popular GIS program that allows users to build, manipulate, and analyse geospatial data, is the software used in this research. The input data needed for all the maps to be generated were: the digital elevation model (DEM) map, land use/land cover map, the Malaysia boundary map, precipitation data from rainfall gauges and soil type map.

Each of the maps of the criteria was translated to the required predicted coordinate system and converted to the raster format. In addition, all maps were reclassified on a scale of 1 to 5 using the ArcMap reclassification method, where 1 refers to very low flood hazard potential (e.g., low flood hazard potential) and 5 refers to very high flood hazard potential levels. ArcMap's Weighted Overlay Tool was used to perform the spatial overlay of the maps after reclassification of the maps. Figure 2 show the research design procedure that had been conducted in this study.

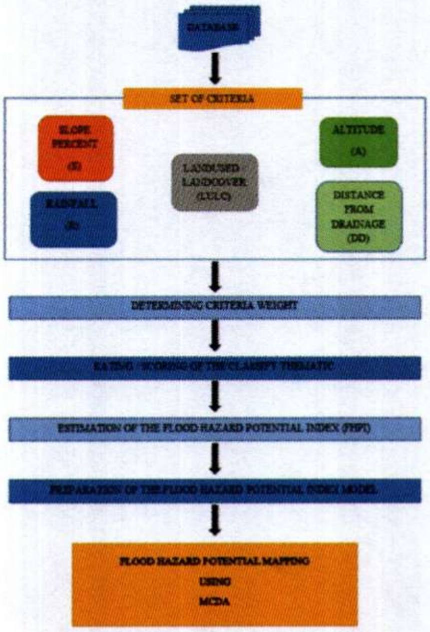

Fig 2. Research design and procedure

2.3 Selection criteria

There is no consensus on the criteria that should be used for creating the flood hazard potential mapping. According to [8], there is no precise agreement on which variables and criteria in flood hazard potential susceptibility assessments should be implemented. Nonetheless, some of the parameters used in many studies that relate to flood susceptibility are: slope, river distance, land use, and altitude. Plus, very few studies have used precipitation under the GIS-based multi-criteria study to chart flood susceptibility. According to [9], the slope and distance from rivers have been included in the current study. Recent research, on the other hand, have aimed to present models that use the least number of independent parameters while still producing very specific results. However, significant criteria were selected for the flood hazard potential mapping which consist of Slope percent (S), Distance from Drainage (DD), Land Used / Land Cover (LULC), Altitude (A) and Rainfall (R).

2.3.1 Slope Percent (S)

The percentage slope can be viewed as a surface predictor for flood susceptibility identification. This aspect must be included, in other words, as it plays an important role in deciding the velocity of surface runoff and vertical percolation, thus influencing the vulnerability of floods. The slope influences the velocity at which the drainage channel and the watershed transport water [2]. In addition, the steeper the slopes, the greater the runoff will be, and higher peak discharges will be created as a consequence. Using the Slope tool in ArcMap, the slope layer for the study area was derived from the DEM. It was reclassified to a scale from 1 to 5, where lower slopes were given a value of 5 and higher values were given a value of 1. Figure 3 shows the slope percent map.

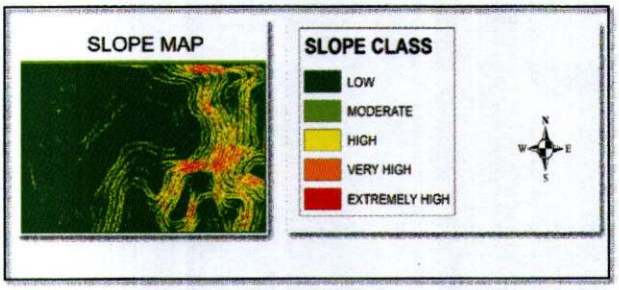

Fig 3. Slope Percent map

2.3.2 Distance from Drainage (DD)

In deciding the flood hazard potential area, the distance from drainage and river factor plays an important role Since near-lying land adjacent to streams is more likely than further land to be flooded. According to previous research by [3], as a consequence of overflow, the areas most affected during floods are those along these rivers. This map was created using the ArcGIS 10.2 software buffer tool, and five categories of buffers were produced. The intervals used for the distance were: <100; 100-200; 200-300; 300-400 and 400-500 m. Figure 4 shows the distance from drainage map.

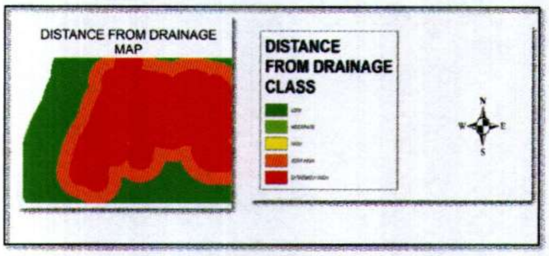

Fig 4. Distance from Drainage Map

2.3.3 Land used/Land Cover (LULC)

A significant factor in determining areas that have demonstrated high vulnerability to flooding is land use/land cover. Due to the negative relationship between flooding and vegetation density, vegetated regions have low flooding potential. Residential areas and highways, which are often made of impermeable surfaces, on the other hand, and bare land increase the runoff of the storm [14]. Five land use groups have been defined in the LULC map: residential areas and road, forest, drainage zone, cropland, and bare land. Figure 5 illustrates the land used/ land cover map.

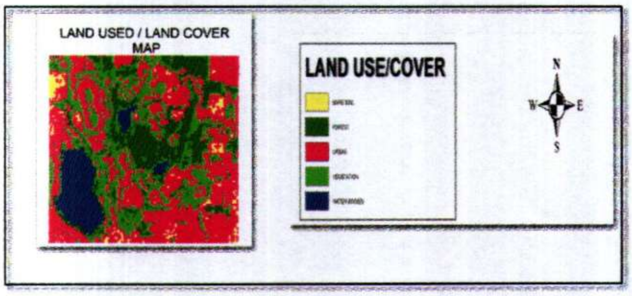

Fig 5. Land Used/Land Cover map

2.3.4 Elevation (E)

The elevation has a big effect on the proliferation of flooding in the study area. This parameter also has a crucial role in monitoring the motion of the overflow path and the flood depth [4]. The altitude map of the study area was generated using ArcGIS 10.8 software from an ASTER DEM image of the area. The resulting map was divided into five groups: < 1700; 1700 - 1725; 1725 - 1750; 1750 - 1775 and > 1775 m, respectively, representing classes 1 – 5 as shown in Figure 6.

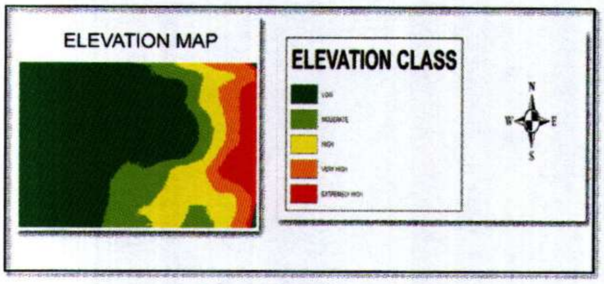

Fig 6. Elevation map

2.3.5 Rainfall (R)

River floods are mostly caused by precipitation. When streams can no longer carry surplus water due to heavy rain, flooding can occur. Because runoff is proportional to precipitation, more precipitation results in more runoff. As a result, increased precipitation increases flood susceptibility. The precipitation-isohyet map was created by interpolating the maximum precipitation data for the yearly event from January to December using the inverse distance weighted (IDW) interpolation method using daily precipitation data from several rain gauge stations in the Selangor watershed which include the rain gauge station of study area from 2015 to 2020. According to [7], flooding is not always a result of increased rainfall, although it does raise the hazard of flooding. Even small quantities of rainfall, especially in areas where urban flooding is on the rise, can inflict significant harm. Figure 7 points the rainfall map that had been created using the software.

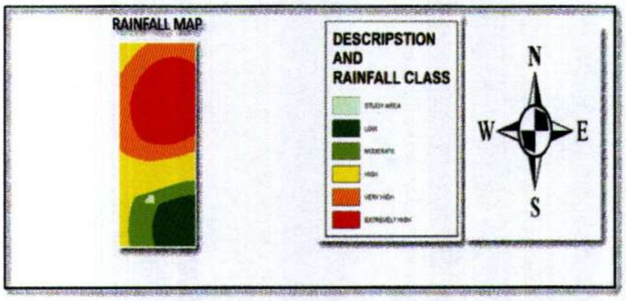

Fig 7. Rainfall map

2.4 Determining criteria weights

MCDA is an approach which allows the weighting of map layers to represent their relative influences. In this case, AHP was chosen to determine the weights of the variables/criteria over a range of MCDA methods. In natural hazard estimation, this approach has acquired wide applications. The numerical ratings and its verbal judgement of preferences based on [13] has shown in Table 1.

Table 1. Saaty's scale for weight assignment [13]

Numerical rating	Verbal judgment of preferences
9	Extremely preferred
8	Very strongly to extremely
7	Very strongly preferred
6	Strongly to very strongly
5	Strongly preferred
4	Moderately to strongly
3	Moderately preferred
2	Equally to moderately
1	Equally preferred

In order to determine each parameter's weight, a review various of previous study on comparison rating on a scale of 1-9 will be prepared. The number of scale values is based on Saaty (1980) method. A matrix of pairwise comparisons of the criteria for the AHP process was determined based on the previous study data according to this scale. The pairwise comparisons of all the parameters were taken in the AHP process as the inputs while the outputs were the relative weights of the parameters. In addition, the final weightings for the parameters are the normalized values of the eigenvectors, which are aligned with the overall values of the (reciprocal) matrix ratio.

2.5 Rating/scoring of the classified thematic layers

The thematic layer is classified for each parameter. The rate provides the flood susceptibility ranges within each parameter. Ranks (R) are allocating to each class accordingly to the class's order of impact on the potential flood hazard. Ranks (R) 1-7 are adopt reflect to very very low, very low, low, medium, high, very high, very very high flood hazard potential, respectively. The ranks (R) values will be followed previous study by [8]. The estimation of the Normalized Rate (NR) is based on the sum of the rates assigned to each parameter. Table 2 shows Rahmati's rating and score that will be used in the study.

Table 2. Rahmati's rating and score [8]

Ranks	Verbal judgement
1	very very low
2	very low
3	low
4	medium
5	high
6	very high
7	very very high

2.6 Estimation of the flood hazard potential index (FHPI)

To estimate the flood hazard potential index (FRI), the weighted linear combination (WLC) approach is use. For each parameter, WLC is normally defined in terms of normalized rates for all options relative to each of parameters. The final utility U for each option Oi is then calculated using the following formula:

$$U\ (O_i) = \sum_{R=1}^{R=n} Z_R\ (O_i) X\ W(C_R) \tag{1}$$

where ZR(Oi) is the normalized rate of option Oi under criterion CR, and W(CR) is the normalized weighting for each criterion CR.

Replacing the left-hand side (LHS) of equation U(Oi) above with FRI and the righthand side (RHS) to be replace with the sum of the products of the normalized weights (W) and normalized ratings (NR) of each parameter, the FRI for each cell was computed using equation:

$$FRI_i = S_W\ S_{NR} + DD_W\ DD_{NR} + LULC_W\ LULC_{NR} + A_W\ A_{NR} + CN_W\ CN_{NR} + R_W\ R_{NR} \tag{2}$$

where SW is weighted of slope, SNR is normalized rank of slope, DDW is weighted of distance from river/drainage, DDNR is normalized rank is distance from river/drainage, LULCW is weighted of land use/cover, LULCNR is normalized rank of land use/cover, AW is weighted of altitude, ANR is normalized rank of altitude, CNW is weighted of curve number, CNNR is normalized rank of curve number, RW is weighted of rainfall and RNR is normalized rank of rainfall respectively.

2.7 Preparation of the flood potential index model map

In the GIS setting, all thematic layers will be aggregated using the WLC method based on equations (2). The FRI will subsequently be obtained for all the pixels within the area of study. In other words, for each pixel, the FRI will be obtained, and the map will be classified based on the same interval method as: < 0.1 (low), 0.1 – 0.2 (moderate), 0.2 – 0.3 (high) and >0.3 (very high). The classification is according to [21].

3 Results and Discussion

3.1 Preparation of FHP map

Using Saaty's AHP, the pairwise comparison matrix and normalised weight - according to theory eigenvectors - were considered for parameters and are shown in Table 3. The analysis of linear transformations heavily relies on eigenvalues and eigenvectors. According to [2], if the inconsistency is less than or equal to a desirable value, the primary eigenvector is required to reflect the priorities associated with that matrix.

Table 3. Pair-wise comparison matrix and normalized weights for parameters

	Parameter					
Parameter	Slope percent (S)	Elevation (E)	Distance from Drainage (DD)	Land Used/ Land Cover (LULC)	Rainfall (R)	Normalized weight
S	1	2	4	2	2	0.134
E		1	3	3	4	0.232
DD			1	3	3	0.446
LULC				1	5	0.104
R					1	0.084

Consistency Ratio (CR) = 0.02

Also shown were the ranks (R) assigned to different classes of the individual parameter, as well as their normalised ranks (NR) in Table 4. The FHPI map was created using the WLC technique.

Table 4. Assigned and normalized ranks for individual classes.

Parameter	Class	Assigned Rank (R)	Normalized Ranked (NR)
Slope	0-10	9	9/45 = 0.200
	10-20	8	8/45 = 0.178
	20-30	7	7/45 = 0.156
	30-40	6	6/45 = 0.133
	50-60	5	5/45 = 0.111
	60-70	4	4/45 = 0.089
	70-80	3	3/45 = 0.067
	80-90	2	2/45 = 0.044
	> 90	1	1/45 = 0.022
Total		45	
Distance from Drainage	0-20	9	0.200
	20-40	8	0.178
	40-60	7	0.156
	60-80	6	0.133
	80-100	5	0.111
	100-120	4	0.089
	120-140	3	0.067
	140-160	2	0.044

	> 160	1	0.022
Total		45	
Elevation	< 160	9	0.200
	160-150	8	0.178
	150-140	7	0.156
	140-130	6	0.133
	130-120	5	0.111
	120-110	4	0.089
	110-100	3	0.067
	100-90	2	0.044
	< 90	1	0.022
Total		45	
Land Use / Land Cover	Water Bodies	6	0.316
	Urban	5	0.263
	Bare soil	4	0.211
	Vegetation	3	0.158
	Forest	1	0.053
Total		19	
Rainfall		9	0.200
		8	0.178
		7	0.156
		6	0.133
		5	0.111
		4	0.089
		3	0.067
		2	0.044
		1	0.022
Total		45	

3.2 Identification of flood hazard potential zones

Individual thematic layers and their classes were given to varied weightages based on the previous study in order to identify flood danger potential zones. Given its lesser significance to favourability evaluation, the land use component earned a low weightage percentage of 10% based on these criteria or variables. It is followed by two additional variables, slope and elevation, both of which have a weightage percent of 15%. Rainfall and distance to drainage, on the other hand, are given a high priority and each factor is given a 30% weighting due to the most previous study consider these two factor very favourable to produce and generate flood hazard map. Higher values for variables and their classes indicate the most suitable zones for flood hazard potential. Then, using the Arc toolbox in the ArcGIS software 10.8, weighted linear combination was used to produce flood hazard potential zones for the study area.

Figure 8 show the flood hazard potential map that have been produced in this study. Each potential zone was divided into four categories based on previous research, where it consists of low, moderate, high, very high and extremely high. Next, each of the zone where interpreted by percentage over the whole study area respectively. The extremely high flood hazard potential zones make up just 25.43% of the flood hazard potential zones, according to the analysis. Extremely high flood potential zone was located on the far west of the study area. Meanwhile, only less than 1% of the zone that are high flood hazard potential zone which located in between the extremely high potential zone. A very high flood hazard potential zone immerse the largest zones which estimated about 41.72% of the total study area. High zone immerse in the middle of study area and partially separated by the moderate zone in the south of the map. The moderate flood hazard potential zone was estimated about 25.15% of the study area which located at east of the map. Furthermore, the rest of the part were engross as low flood hazard potential zone which constituting about 6.85% located in between the moderate zone of flood hazard zone.

This study can explicate that the region with extremely high flood hazard potential contained flat areas of slope class, very low elevation, and a low density of distance from drainage, according to a map overlay between anticipated flood hazard potential map and flood hazard potential parameters. Because of the high infiltration rate, flat regions with a low slope class and a very low elevation class are prone to flooding. Very high flood hazard potential zones can also be found in low slope classes with a low density of distance from drainage. Low slope and low density of distance from drainage were discovered to be two characteristics linked to a significant potential for flood hazard. High slope class, land use type of building, significant elevation class, and high density of distance from drainage describe zones with high flood hazard potential. Finally, LULC type of denudational hill and water body, primarily high elevation and extremely high slope class, are included in moderate and low flood hazard potential zones. Due to heavy runoff and limited infiltration, areas with a high slope class are adverse to flood hazard potential. Because of the runoff zones and low rate of infiltration, a denudational hill has a low flood danger potential. Because of their sluggish permeability and poor hydraulic conductivity, buildings are characterised as having a high potential.

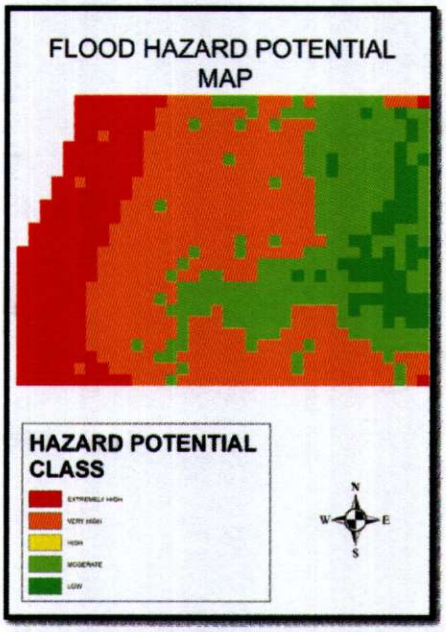

Fig 8. Flood Hazard Potential Map

4 Conclusion & Recommendation

Flooding is a natural hazard that poses a threat to both people and property in flood-affected regions. With the use of a geographical evaluation, flood hazard potential may be better recognized. In terms of time and resources, using advanced geospatial techniques to evaluate and map flood hazard potential is cost effective. Thus, in this study, the main objective was to generate a slope percent map, distance from drainage map, land use map, altitude map, rainfall map and to determine flood hazard potential map based on the study area. This paper attempted to establish and map the UPNM campus's flood hazard potential. Slope, elevation, LULC, distance from drainage, and rainfall were considered as the most important variables affecting flood hazard potential control.

However, because all of these factors are not equally important in determining flood hazard potential, a weighted value determination was performed after all the thematic maps were organized. As a result, the most significant factors were found to be distance from drainage and rainfall, each with a weighted percent of value of 30%. Flood hazard potential zones with low slope angle and elevation are found within low slope angle and elevation zones, respectively.

The rest of the factors, such as elevation (15%), slope (15%), and LULC (10%), were found to be the least important factors controlling flood hazard potential occurrence. The least potential areas are found in the study area, according to the spatial distribution of the flood hazard potential zone map. These are characterised by steep slopes and high elevations, which facilitate runoff and thus low flood hazard potential zones. Water bodies were an important factor in flood hazard potential for the LULC map, while urban areas and vegetation had low flood hazard potential. Flood hazard potential map areas with very high and high potential account for a small area coverage in general. As a result, when compared to its total area coverage, the study area has little flood hazard potential suitability. Therefore, the results showed that the AHP technique has the potential to make accurate and reliable flood hazard potential. In addition, the AHP and geographic information system (GIS) techniques are recommended for assessing flood hazard potential, particularly in areas with limited data.

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