ASM Sc. J., 11, Special Issue 3, 2018 for SANREM, 104-122

Flood Hazard Analysis (FHAn) using Multi-Criteria Evaluation (MCE) in Penampang Area, Sabah, Malaysia

Rodeano Roslee[1,2*] Felix Tongkul[1,2] Syalini Mariappan[1,2] and Norbert Simon[3]

[1]*Natural Disaster Research Centre (NDRC), University Malaysia Sabah (UMS) Jalan UMS, 88400 Kota Kinabalu, Sabah, Malaysia*

[2]*Faculty of Science and Natural Resources (FSSA), University Malaysia Sabah (UMS), JalanUMS, 88400 Kota Kinabalu, Sabah, Malaysia*

[3]*Faculty of Science and Technology (FST), University Kebangsaan Sabah (UKM), 83600 Bangi, Selangor, Malaysia*

Flooding is one of the major natural disasters in Sabah, Malaysia. Several recent cases of catastrophic flooding were recorded especially in Penampang area, Sabah (e.g. July 1999; October 2010; April 2013; October & December 2014). Heavy monsoon rainfall has triggered floods and caused great damage in Penampang area. The 2014 floods has affected 40,000 people from 70 villages. The objectives of this paper are (i) to determine the Flood Hazard Level (FHL) and (ii) to determine the factors contributing to the flood occurrences. In this study, eigth (8) parameters were considered in relation to the causative factors to flooding, which are: rainfall, slope gradient, elevation, drainage density, landuse, 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) acquisation, and secondary data in three (3) different period (2002, 2008 and 2014). FHL were defined using Multi Criteria Evaluation (MCE) technique integrated with GIS software. As a result of the calculation and interpretation, the average ratio of the areas under the curve was 0.839, and thus can be argued that validation prediction accuracy was 83.90%. The developed model will be a very valuable 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.

Keywords: Flood Hazard Analysis (FHAn); Multi-Criteria Evaluation (MCE); Sabah, Malaysia

*Corresponding author's e-mail:

I. INTRODUCTION

LoremThe Penampang District of Sabah, East Malaysia (Figure 1) is subjected to development pressure as the urban centre of Kota Kinabalu expands onto the Sungai Moyog 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 particular concern to the area are the issues associated with flooding. In 2014 from October 7 to October 10, Penampang suffered its worse flood ever, since the last big flood in 1991 (Figure 2 and 3).

Figure 1. Location of the study area

According to the District Officer of Penampang as many as 40,000 people from 70 villages were affected by the flood. The flood coincided with continuous heavy rainfall due to typhoon Phanfone and typhoon Vongfong. Another recent flood disaster in Penampang occurred on September 2007 and May 2013, affecting several villages (Figure 3).

Figure 2. Some cases of flash flood in Penampang, Sabah (Sources: Pejabat Daerah Penampang)

The main objectives of this study are: a) to determine the Flood Hazard Level (FHL); b) to determine the factors contributing to the flood occurrences; and c) to recommend mitigation measures in order to minimize flood vulnerability & risk. It is hopes that the outcomes from this study can be an important reference document for the local authority and other relevant agencies for the purpose of urban planning and flood mitigation. An ad hoc, or reactive, approach to floodplain management has previously been standard practice. Insufficient control over floodplain development practice has led to a worsening of the flood problem. Until recently, floodplain management has only involved structural approaches to

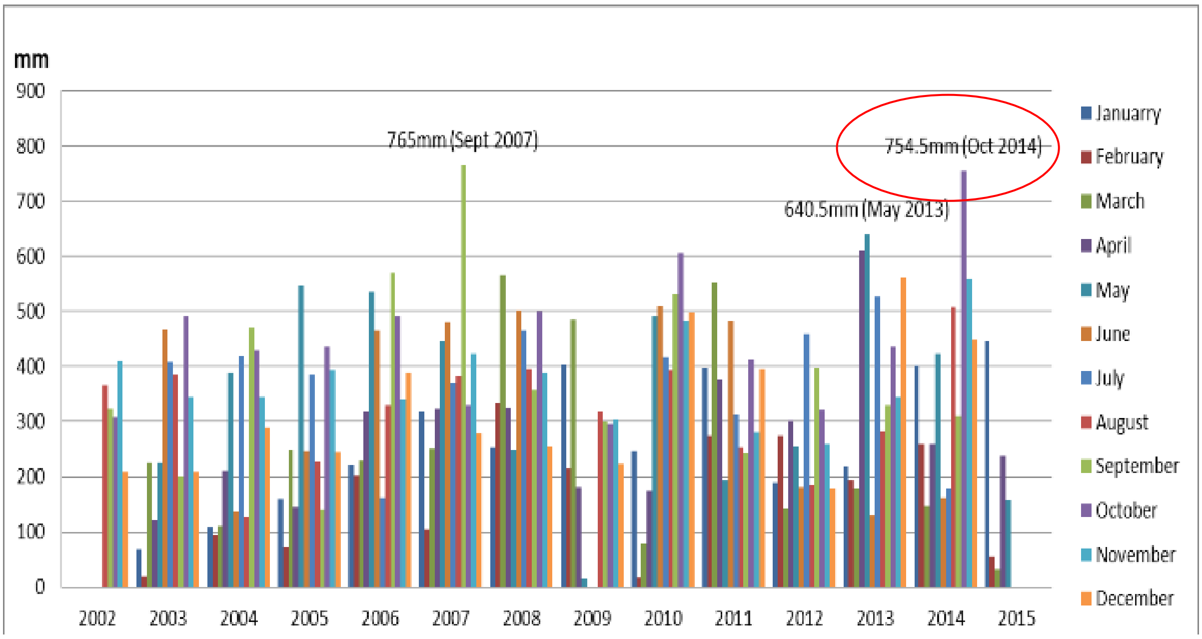

Figure 3. Daily recorded rainfall of Babagon Agriculture Station from year August 2002 – May 2015 (Department of Drainage and Irrigation, 2015)

modifying flood behaviour. However, without planning, the structural flood modification only compensates for the poor development practice by restoring the flood behaviour to pre-development conditions. Ultimately, there is no net benefit (Caddis et al., 2011).

In the recent years, there have been many studies on flood susceptibility/hazard/risk mapping using GIS tools (Hess *et al.*, 1990; 1995; Le Toan *et al.*, 1997) and many of these studies have applied using probabilistic methods (Landau *et al.*, 2000 (Landau *et al.*, 2000; Farajzadeh, 2001; 2002; Horritt and Bates, 2002; Pradhan and Shafie, 2009). In different ways, hydrological and stochastic rainfall method has also been employed in other areas (Blazkova and Beven, 1997; Cunderlik and Burn, 2002; Ebisemiju, 1986; Heo *et al.*, 2001; Nageshwar and Bhagabat, 1997; Yakoo *et al.*, 2001; Villiers, 1986). Likewise neural network methods have been applied in various case studies (Kute, 2014; Honda *et al.*, 1997; Islam and Sadu, 2001; 2002; Sanyal and. Lu, 2004; 2005; Townsend and Walsh, 1998; Wadge *et al.*, 1993; Profeti *et al.*, 1997; Knebl *et al.*, 2005; Masmoudi and Habaieb, 1993; Merwade *et al.*, 2008; Zerger, 2002.

Determining the flood susceptible/vulnerable areas is very important to decision makers for planning and management of activities. Decision making is actually a choice or selection of alternative course of action in many fields, both the social and natural sciences. The inevitable problems in these fields necessitated a detailed analysis considering a large number of different criteria. All these criteria need to be evaluated for decision analysis (Sinha *et al.,* 2008; Yahaya, 2008; Chen *et al.,* 2011; Lawal *et al.* 2012; Saini and Kaushik, 2012). For instance, Multi Criteria Evaluation (MCE) methods has been applied in several studies since 80% of data used by decision makers are related geographically (Istigal, 1997; Siddayao *et al.,*2014). Geographic Information System (GIS) provides more and better information for decision making situations. It allows the decision makers to identify a list, meeting a predefined set of criteria with the overlay process (Ho *et al.,* 2002; Ouma and Tateishi, 2014), and the multi-criteria decision analysis within GIS is used to develop and evaluate alternative plans that may facilitate compromise among interested parties (Collins, *et al.,* 2001).anim id est laborum.

II. MATERIALS AND METHODS

Figure 4 shows the framework model used in this study. There are four (4) main phases involved, namely: a) Phase I: Selection and evaluation of criteria; b) Phase II: Multi-Criteria Evaluation (MCE); c) Phase III: Flood Susceptibility Analysis (FSAn); and d) Phase IV: Flood Hazard Analysis (FHAn)

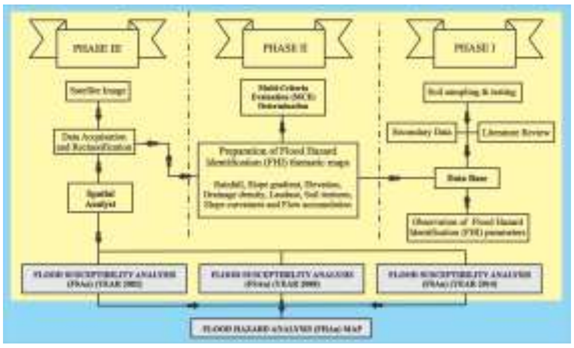

Figure 4. The proposed developed model for Flood Hazard Assessment (FHAs) in the study area

A. Selection and evaluation of criteria

The main purpose in Phase I are database development. Firstly, soil samples were collected from the field will be analyzed their types in accordance with BS1377-1990. The next step is secondary data compilation and literature review. Lastly observation of Flood Hazard Identification (FHI) parameters was conducted through the fieldwork study (Figure 4). study area

B. Multi-Criteria Evaluation (MCE) technique

In Phase II, the choice of criterions that has a spatial reference is an important and profound step in Multi-Criteria Evaluation (MCE) technique.

Hence, the criteria consider in this study is based on their significance in causing flood in the study area. Eigth factors are considered in relation to the causative factors, which are rainfall, slope gradient, topography, drainage density, landuse, soil textures, slope curvatures and flow accumulation (Figure 4).

Several questionnaires were distributed among experts in hydrology and hydraulics. The inputs obtained from those experts were further used in carrying out the pair-wise comparison technique in order to calculate the weights of each criterion. Pair-wise comparison is more appropriate if accuracy and theoretical foundations are the main concern (Malczewski, 1999). The technique involves the comparison of the criteria and as allows one to compare the importance of two criteria at a time. This very technique, which was proposed and developed by Saaty (1980) within the framework of a decision making process known as Analytical Hierarchy Process (AHP) is capable of converting subjective assessments of relative importance into a linear set of weights. 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 rule-of-thumb is that a CR less than or equal to 0.10 signifies an acceptable reciprocal matrix, and ratio over 0.10 implies that the matrix should be revised, in other words it is not acceptable (Saaty, 1980; 2008).

C. Flood suceptibility Analysis (FSAn)

The initial step in Phase III is the delineation and conversion processes of data from the radar images (IFSAR). Phase III also covers the integration between criteria weights and maps, producing a Flood Susceptibility Analysis (FSAn) using spatial analyst, which determine the Flood Susceptibility Level (FSL) in different period (2002, 2008 and 2014).

All of the thematic maps produced were analyzed through the spatial analyst technique (raster calculator) based on Eq. (1) for LSL estimation and classification (Table 1). The FSL calculation was carried out through a combination of input parametric maps in Eq. (1) with the GIS operations using a grid base.

$\sum$ [(32.53*Rainfall) + (22.74*Drainage Density) + (15.84*Flow Accumulation) + (11.08*Landuse) + (7.19*Elevation) + (4.89*Slope Gradient) + (3.35*Soil Textures) + (2.38*Slope Curvatures)] (1)through the fieldwork study (Figure 4). study area

D. Flood Hazard Analysis (FHAn)

The last phase in LHAs is FHAn. This phase involves the combination of the three LSAn map for the year 2002, 2008 and 2014. The map overlaid was carried out using "Raster Calculator" in the Arc GIS software.

III. RESULTS AND DISCUSSIONS

A. Rainfall

Heavy rainfalls are one of the major causes of floods. Flooding occurs most commonly from heavy rainfall when natural watercourses do not have the capacity to convey excess water. Floods are associated with extremes in rainfall, any water that cannot immediately seep into the ground flows down slope as runoff. The amount of runoff is related to the amount of rain a region experiences. The level of water in rivers rises due to heavy rainfalls. When the level of water rises above the river banks or dams, the water starts overflowing, hence causing river based floods. The water overflows to the areas adjoining to the rivers or dams, causing floods (Ouma and Tateish, 2014).

In the study, a rainfall map was developed based on the daily rainfall values (short-term intensity rainfall) for the study area (Figure 3 and 5). Based on the information obtained from the Metrology Department of Malaysia (MetMalaysia) and the Sabah Department of Irrigation and Drainage (DID), a total of four (4) stations were identified, i.e. the Ulu Moyog station, Inanam station, Kota Kinabalu International Airport (KKIA) station and Babagon station.

A mean annual rainfall for fourteen (14) years (2002–2015) was considered and interpolated using Inverse Distance Weighting (IDW) to create a continuous raster rainfall data within and around municipality boundary. The resulting raster layer was finally reclassified into the five classes using an equal interval. The reclassified rainfall was given a value < 40 mm (weighted = 0.0624) for least rainfall to > 300 mm (weighted = 0.4162) for highest rainfall (Table 1 & Figure 5).

B. Drainage density

Drainage is an important ecosystem controlling the hazards as its densities denote the nature of the soil and its geotechnical properties. This means that the higher the density, the higher the catchment

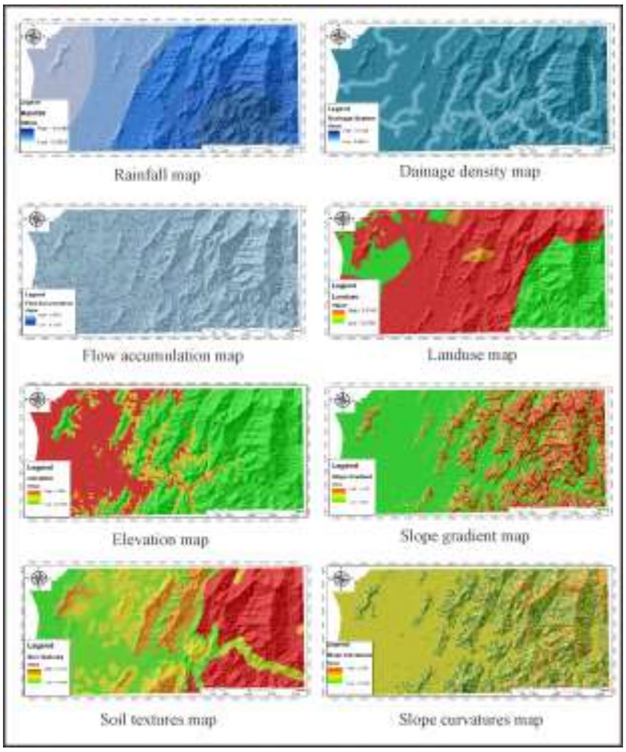

Figure 5. Thematic maps for Flood Hazard Analysis (FHAn) in the study area

area is susceptible to erosion, resulting in sedimentation at the lower grounds (Ouma and Tateishi, 2014). The first step in the quantitative FSAn is designation of stream order. The Stream ordering in the present study area was done using the method proposed by Strahler (1964).

Drainage density map could be derived from the drainage map. *i.e.*,drainage map is overlaid on watershed map to find out the ratio of total length of streams in the watershed to total area of watershed and is categorized. The drainage density of the watershed is calculated as: $D=L/A$, where, D = drainage density of watershed; L = total length of drainage channel in watershed (km); A = total area of watershed (km^2).

Table 1. 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 Infrastructures	0.1380
		Agricultural & Forestry	0.0756
Elevation	0.0719	< 5 m	0.2940
		6 – 10 m	0.2681
		11 – 20 m	0.2113
		21 – 30 m	0.1507
		> 30 m	0.0759
Slope Gradient	0.0490	0 – 5 (°)	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

For the study area, higher weighted value (0.4162) were assigned to poor drainage density areas and lower weighted value (0.0624) were assigned to areas with adequate drainage. The drainage density layer were reclassified in five sub-groups using the standard classification Schemes. Areas with very low drainage density are > 200 mm and those with very high drainage density with value of < 50 mm as depicted in the results Table 1 and Figure 5.

C. Flow accumulation

Flow accumulation is where water accumulates from precipitation with sinks being filled. From the flow accumulation of the study area, two (2) main rivers in the study area were derived: Moyog, and Babagon Rivers (Figure 5). For the study area, higher weighted value (0.3612) were assigned as highest flow accumulation areas and lower weighted value (0.1238) were assigned as lowest flow accumulation. The flow accumulation layer were reclassified in five sub-groups using the standard classification Schemes (very low to very high as shown in the results Table 1 and Figure 5.

D. Landuse

The land-use of an area is also one of the primary concerns in FSAn because this is one factor which not only reflects the current use of the land, pattern and type of its use but also in relation to infiltration. Land-cover like vegetation cover, whether that is permanent grassland or the cover of other crops, has an important impact on the ability of the soil to act as a water store (Ouma and Tateishi, 2014). Impermeable surfaces such as concrete, absorbs almost no water at all. Land-use like buildings and roads, decreases penetration capacity of the soil and increases the water runoff. Land-use types work as resistant covers and decrease the water hold up time; and typically, it increases the peak discharge of water that enhances a fastidious flooding. This implies that land-use and land-cover are crucial factors in determining the probabilities of flood (Ouma and Tateishi, 2014; Collins et al., 2009).

In this study area, land use map shows a few sectors such as the residential sector, commercial sector, public infrastructure sector, the industrial sector, the higher education institutions and schools sector, and the agriculture, forestry and others sector (Figure 5 & Table 1). Based on the results of the GIS spatial analyst conducted, it was found that the agriculture, forestry and others sector cover the widest 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 sector (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% as a whole for development and agricultural activities. Exploration mass without control/enforcement of the activities of slope cutting can trigger the occurrence of flash flood.

E. Elevation

A digital elevation model (DEM) of the slope conditions provided by raster datasets on morphometric features (altitude, internal relief, slope angle, aspect, longitudinal and transverse slope curvature and slope roughness) and on hydrologic parameters (watershed area, drainage density, drainage network order, channel length, etc.) were automatically extracted from the DEM (Figure 5). In addition, the slope angle is also considered as an index of slope stability caused by the presence of a digital elevation model (DEM) which is evaluated numerically and is illustrated by the spatial analysts (Yalcin and Bulut, 2007).

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) (Figure 5 & Table 1). Almost 16.01% of the study area consists of lowland areas (<10 m). Lowland areas were concentrated in the southwestern and northern parts of the study area with little hills. This region includes the alluvial plains and areas which have undergone a process of cut and fill slopes activities for urbanization, housing, manufacturing and other infrastructure construction. From the satellite images observations, lowland areas have brighter tone, incorporeal arise and flat. The directional trend of lineaments is northeast-southwest. Short and intermittent drainages often found in lowland areas and mostly dried during the dried season. In lowland areas also have several small lakes such Taman Tuan Fuad and Bukit Padang area.

Moderately highland areas (11-30 m) covered about 42.38% of the entire study area (Figure 5). It is located in the northeastern and southwestern parts of the study area. 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. Moderately highland areas were produced by the process of adoption or folding of the Crocker Formation. In this area there are many rivers flowing along the valley.

Hilly areas (> 30 m) that extends in the northwestern and southeastern parts covered about 41.60% of the entire study area (Figure 5). This area is 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. There are several residential areas (villages) built in this area. Infrastructure and utilities are very limited and not as good as lowland or moderately highland areas.

F. Slope Gradient

Elevation and slope play an important role in governing the stability of a terrain. The slope influences the direction of and amount of surface runoff or subsurface drainage reaching a site. Slope has a dominant effect on the contribution of rainfall to stream flow. It controls the duration of overland flow, infiltration and subsurface flow. Combination of the slope angles basically defines the form of the slope and its relationship with the lithology, structure, type of soil, and the drainage. Steeper slopes are more susceptible to surface runoff, while flat terrains are susceptible to water logging. Low gradient slopes are highly vulnerable to flood occurrences compared to high gradient slopes (Ouma and Tateishi, 2014).

In terms of slope gradient in the study area, the results suggest that 48.37% of the area can be categorized as 0^o - 5^o, 28.45% as a 6^o - 15^o, 22.41% as 16^o - 30^o, 0.75% as 31^o - 60^o and 0.01% in excess of 60^o (Figure 5 & Table 1). Rain or excessive water from the river always gathers in an area where the slope gradient is usually low. Areas with high slope gradients do not permit the water to accumulate and result into flooding. If the main concern is river caused flood, elevation difference of the various DEM cells from the river could be considered, whereas for pluvial flood local depressions, *i.e.*, DEM cells with lower elevation than the surrounding would be more important. This implies that the way in which elevation could be associated with risk is important.

G. Soil Textures

Information on soil types explaining the diversity of physical characteristics for unconsolidated deposition and weathering production. Soil texture and moisture are the most important components and characteristics of soils. Soil textures have a great impact on flooding because sandy soil absorbs water soon and few runoffs occurs. On the other hand, the clay soils are less porous and hold water longer than sandy soils. This implies that areas characterized by clay soils are more affected by flooding.

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%) (Figure 5 & Table 1).

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 (Nicholls and Wong, 1990). 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 (Lowery et al., 1996).

H. Slope curvatures

Slope shape has a strong influence on flood occurrences in by concentrating or dispersing surface and primarily subsurface water in the landscape. There are three basic slope curvature units: convex, straight and concave. Convex landform is most stable in steep terrain, followed by concave hillslope segment and straight hillslope (least stable). The main reason is related to landform structure affecting largely the concentration or dispersion of surface and subsurface water. Convex and concave hillslopes tend to concentrate subsurface water into small areas of the slope, thereby generating rapid pore water pressure increase during storms or periods of rainfall. Whereas a straight hillslope /flat surface that allows the water to flow quickly is a disadvantage and causes flooding, whereas a higher surface roughness can slow down the flood response.

In this study, the slope curvatures map (Figure 5) was prepared using the digital elevation model (DEM) and surface analysis tools in ArcGIS software. The slope curvatures classes having less values was assigned higher weighted value due to almost flat terrain while the class having maximum value was categorized as lower weighted value due to relatively high run-off (Figure 5 & Table 1). Most of the entire flooding area lies in a straight or flat elevation. This implies that slope curvatures may not be the predominant factor in ranking FSL classes.

I. Flood susceptibility level (FSL)

Figure 6 shows the results of Flood Susceptibility Level (FSL) data in year 2002, 2008 and 2014.The results of the FSL level for the Penampang suggest that in 2002, 65% of the area have very low susceptibility (VLS), 17% as low susceptibility (LS), 6% as moderate susceptibility (MS), 11% as high susceptibility (HS) and 1% as very high susceptibility (VHS). While in 2008, 62.74% of the area have VLS, 15.62% as LS, 15.49% as MS, 3.57% as HS and 2.58% as VHS. In year 2014, 40.49% of the area can be categorised as having VLS, 35.08% as LS, 18.21% as MS, 5.50% as HS and 0.71% as VHS.

In general, the VLS to LS areas refer to stable conditions from flood vulnerability/risk. In contrast, MS to HS areas are basically not recommended to be developed due to high flood vulnerability/risk. However, if there is no choice or the developer or the local authorities really want to develop these areas, some mitigation procedures to be introduced. VHS areas are strictly not recommended to be developed and provisions for suitable structural and non-structural works planning controlare recommended.

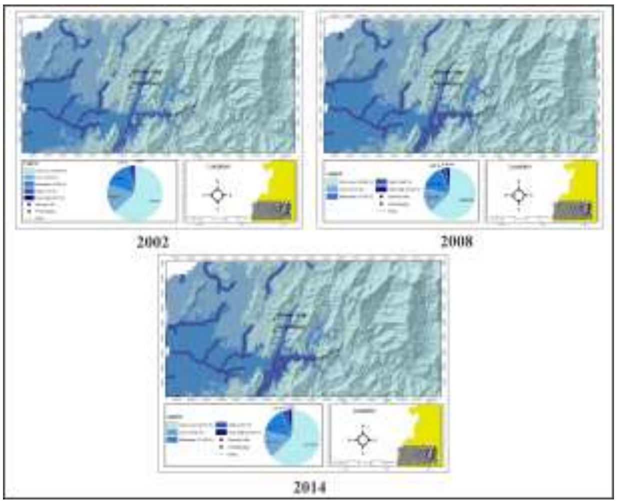

Figure 6. Flood Susceptibility Analysis (FSAn) Maps of the study area (Year 2002, 2008 and 2014)

J. Flood Hazard Analysis (Fhan)

Flood Hazard Analysis (FHAn) is important for planning development activities in an area and can be used as supplementary decision making tools. Rainfall, elevation, slope, drainage density, flow accumulation, land use, soil texture, slope gradient and slope curvature were chosen as the most influential factors for evaluating the flood hazard to the municipality.

Figure 7 shows the FHAn map of the study area. The map was prepared by overlaying the flood susceptibility maps in year 2002, 2008 and 2014 (Figure 6). Based on the map, approximately 3.69% of total study area classified as very high hazard (VHH), 2.38% as high hazard (HH), 15.93% as moderate hazard (MH) and 15.16% as low hazard (LH), as vey low hazard (VLH) respectively.

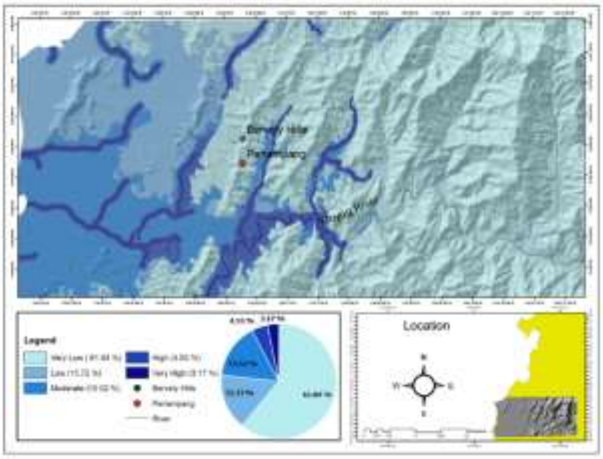

Figure 7. Flood Hazard Analysis (FHAn) map of study area

The Sg. Moyog catchment covers an area of approximately 295km². The upper reaches of the catchment extend into the Crocker Range, with elevation exceeding 1,800m. From the headwaters, the Sg. Moyog meanders in a westerly direction through steep mountainous terrain, until it reaches the expansive lower floodplain at Dongongon. Fig. 8 shows the floodplain map of the study area. From this figure, most of the floodplain area is located at the western part of the study area. Across the Sg. Moyog floodplain, the main towns are Dongongon and Putatan. The largest village is Kampung Petagas with 3,500 people. Any kind of development and activities should be minimizes as the area is more prone to flood disaster.

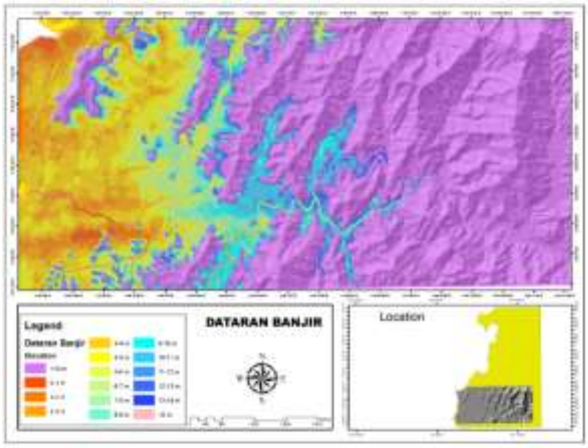

Figure 8. Floodplain map of study area (Department of Drainage and Irrigation, 2015)

K. Validation For Flood Hazard Analysis (Fhan)

For validation of flood hazard models, two basic assumptions are needed. One is that flooded areas are related to spatial information, and the other is that future flooded areas will affected by a specific factor such as rainfall. In this study, the two assumptions are satisfied because the flooded areas were related to the spatial information and the flooded areas were triggered by heavy rainfall in the study area. The Flood Hazard Analysis (FHAn) result was validated using the Floodplain map (Figure 8). The validation process is carried out by comparing the floodplain data with the Flood Hazard Analysis

(FHAn) map (Figure 7) through the Prediction Rate Curve (PRC) (Figure 9). In order to create PRC, the flood index values in FHAn were calculated and all its cells were sorted in decreasing order. Then, the ordered cell values were divided into 100 classes. All of these 100 classes were weighted and were overlaid with the floodplain map data and then converted into the percentage format for each class (Table 2). As a result of the calculation and interpretation, the average ratio of the areas under the curve was 0.839, and thus can be argued that validation prediction accuracy was 83.90% (Figure 9 & Table 2). This means that the FHAn result that were carried out in this study have a good reliability (0.8 < AUC < 0.9) (Zhu et al. 2010) (Table 3).

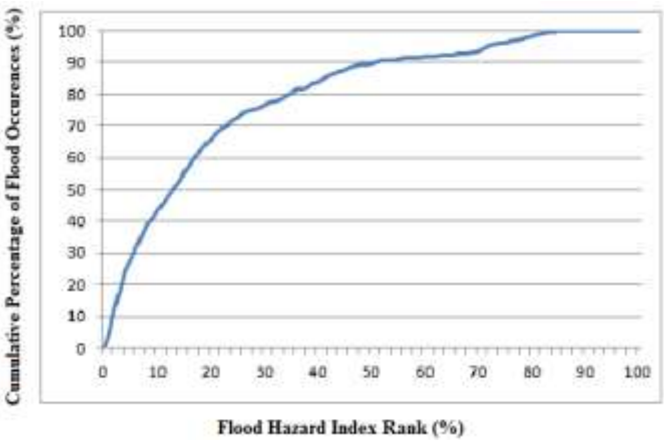

Figure 9. Illustration of cumulative frequency showing flood hazard index rank (y-axis) occurring in cumulative percentages of flood occurrences (x-axis)

Table 2. Calculation of the ratio of the average area under the curve

Cumulative Value	**Class**	**Area Ratio**
90-100%	10%	0.40
80-100%	20%	0.65
70-100%	30%	0.78
60-100%	40%	0.82
50-100%	50%	0.90
40-100%	60%	0.92
30-100%	70%	0.94
20-100%	80%	0.98
10-100%	90%	1.00
0-100%	100%	1.00
Average		**0.839**

Table 3. Classification for Area Under the Curve, AUC (Zhu et al, 2010)

AUC Value	**Classification**
0.9 < AUC < 1.0	High
0.8 < AUC < 0.9	Good
0.7 < AUC < 0.8	Moderate
0.6 < AUC < 0.7	Low

iv. CONCLUSIONS

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 use of MCE for different factors is also demonstrated to be useful in the definition of the risk areas for the flood mapping and possible prediction. In overall, the case study results show that the GIS-MCE based category model is effective in flood risk zonation and management.

The developed framework model (Figure 4) will be a very valuable 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.

The main causes of flooding in the study area are: a) Increased runoff rates due to the urbanisation; b) Loss of flood storage – development in flood plains and drainage corridors; c) Inadequate drainage systems; d) Constriction at bridges; e) Undersized culverts; f) Siltation in waterway channels from indiscriminate land clearing operations; g) Localised continuous heavy rainfall; h) Tidal backwater effect; and i) Inadequate river capacity.

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 public and private sectors. Whilst 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.

I. ACKNOWLEDGMENT

Deep gratitude to Universiti Malaysia Sabah (UMS) for providing easy access to laboratories and research equipment. Highest appreciations also to the Ministry of Higher Education of Malaysia (MOHE) for the fundamental research grant award (FRG0410-STWN-1/2015) to finance all the costs of this research.

[1] Blazkova, S. & Beven, K. (1997). Flood Frequency Prediction for Data Limited Catchments in the Czech Republic using a Stochastic Rainfall Model and TOPMODEL. Journal of Hydrology. 195 (1-4): 256-278.

[2] Caddis, B., Hong, W. & Nielsen, C. (2011). The Challenges of Floodplain Management in Malaysian Borneo. 2011 Floodplain Management Conference, Tamworth, NSW. 22-25 February 2011. 1-11.

[3] Chen, Y. R., Yeh, C. H. & Yu, B. (2011). Integrated Application of the Analytic Hierarchy Process and the Geographic Information System for Flood Risk Assessment and Flood Plain Management in Taiwan. Natural Hazards. 59 (3): 1261-1276.

[4] Collins, M. G., Steiner, F. R. & Rushman M. J. (2001). Land-Use Suitability Analysis in the United States: Historical Development and Promising Technological Achievements. Environ. Manage. 28 (5): 611–621.

[5] Cunderlik, J. M. & Burn, D. H. (2002). Analysis of the Linkage Between Rain and Flood Regime and its Application to Regional Flood Frequency Estimation. Journal of Hydrology. 261 (1-4): 115-131.

[6] Ebisemiju. F. S. (1986). Environmental Constrains of the Interdependent of Drainage Basin Morphometeric Properties. Proc. of the First International Conf. on Geomorphology. Manchester, UK. Part 2: 3- 19.

[7] Farajzadeh, M. (2001). The Flood Modeling using Multiple Regression Analysis in Zohre & Khyrabad Basins. 5th International Conference of Geomorphology. Tokyo, Japan. August.

[8] Farajzadeh, M. (2002). Flood Susceptibility Zonation of Drainage Basins using Remote Sensing and GIS, Case Study Area: Gaveh Rod_ Iran

[9] Heo, J. H., Salas, J. D. & Boes, D. C. (2001). Regional Flood Frequency Analysis Based on a Weibull Model, Part 2 Simulations and Applications. Journal of Hydrology. 242 (3-4): 171-182, IAHS Publ., UK.

[10] Hess, L. L., Melack, J. M. & Simonett, D. S. (1990). Radar Detection of Flooding Beneath the Forest Canopy: A Review. International Journal of Remote Sensing. 11: 1313-1325.

[11] Hess, L. L., Melack, J., Filoso, S. & Wang, Y. (1995). Delineation of Inundated Area and Vegetation along the Amazon Floodplain with the SIR-C Synthetic Aperture Radar. IEEE Transactions on Geoscience and Remote Sensing. 33: 896-903.

[12] Ho, K. H., Ghazali, A. H. & Chong, S. F. (2002). Calibration and Evaluation of Modified Tank Model (Flood Forecasting Model) for Kelantan River Basin Malaysia. Proceeding of the Water Engineering. 23-24 July. Conference Malaysia. Kuala Lumpur. 231-245.

[13] Honda, K. C., Francis, X. J. & Sah, V. P. (1997). Flood Monitoring in Central Plain of Thailand using JERS-1 SAR Data. Proc. 18th Asian Conference of Remote Sensing. Malaysia.

[14] Horritt, M. S. & Bates, P. D. (2002). Evaluation of 1D and 2D Numerical Models for Predicting River Flood Inundation. Journal of Hydrology. 268: 87–99.

[15] Islam, M. M. & Sadu, K . (2001). Flood Damage and Modeling using Satellite Remote Sensing Data with GIS: Case

[16] Study of Bangladesh. In: Remote Sensing and Hydrology 2000, Edited by R. Jerry et al., IAHS Publication, Oxford. 455-458.

[17] Islam, M. M. & Sadu, K. (2002). Development Priority Map for Flood Countermeasures by Remote Sensing Data with Geographic Information System. Journal of Hydrologic Engineering. September-October 2002. 346-355.

[18] Istigal, A . (1997). Land and Agrometeorological Information for Agricultural Development. In: M.V.K. Sivakumar, U.S. De, K.C. Sinharay, M. Rajeevan (Eds). User Requirement for Agrometeorological Services Proceedings of an International Workshops Rune, India. 241 – 257.

[19] Knebl, M. R., Yang, Z. L., Hutchison, K. & Maidment, D. R. (2005). Regional Scale Flood Modeling using NEXRAD Rainfall, GIS, and HEC-HMS/RAS: A Case Study for the San Antonio River Basin Summer 2002 Storm Event. Journal of Environmental Management. 75: 325–336.

[20] Kute, S., Kakad, S., Bhoye, V. & Walunj, A. (2014). Flood Modelling of River Godavari using HEC-RAS. IJRET: International Journal of Research in Engineering and Technology. 03 (09): 81-87.

[21] Landau, S., Mitchell, R. A. C., Barnett, V., Colls, J. J., Craigon, J. & Payne R. W. (2000). A Parsimonious, Multiple-Regression Model of Wheat Yield Response to Environment. Agricultural and Forest Meteorology. 101 (2-3): 151-166. Elsevier Publi., USA.

[22] Lawal, D. U., Matori, A. N., Hashim, A. M., Yusof, K. W. & Chandio I. A. (2012). Detecting Flood Susceptible Areas using GIS-based Analytic Hierarchy Process. 2012 International Conference on Future Environment and Energy. IPCBEE vol.28. IACSIT Press, Singapore.

[23] Le Toan, T., Ribbes, F., Wange, L. F., Floury, N., Ding, N. & Kong, K. H. (1997). Rice Crop Mapping and Monitoring using ERS-1 Data based on Experiment and Modeling Results. IEEE Transactions on Geoscience and Remote Sensing. 35: 41-56.

[24] Malczewski, J. (1999). GIS & multipleYork: John Wiley & Son.

[25] Masmoudi, M. & Habaieb, H. (1993). The Performance of Some Realtime Statistical Flood Forecasting Models Seen Through Multicriteria Analysis. Water Resources Manegement. 7: 57–67.

[26] Merwade, V., Cook, A. & Coonrod, J. (2008). GIS Techniques for Creating River Terrain Models for Hydrodynamic Modeling and Flood Inundation Mapping. Environmental Modelling and Software. 23 (10): 1300-1311.

[27] Nageshwar, R. B. & Bhagabat, P. (1997). Flood Estimation for Ungauged Catchments using the GIUH. Journal of Water Resources Planning and Management. 228-238, Elsevier Publi., USA.

[28] Nicholls N. & Wong, K.K. (1990). Dependence of Rainfall Variability on Mean Rainfall, Latitude, and the Southern Oscillation. J. Clim. 3, 163–170.

[29] Ouma, Y. O. & Tateishi, R. (2014). Urban Flood Vulnerability and Risk Mapping Using Integrated Multi-Parametric AHP and GIS: Methodological Overview and Case Study Assessment. Water 2014. 6 (6): 1515-1545.

[30] Pradhan, B. & Shafie, M. (2009). Flood Hazard Assessment for Cloud Prone

Rainy Areas in a Typical Tropical Environment. Disaster Advances. 2 (2): 7-15.

[31] Profeti, G. & Machintosh, H. (1997). Flood Management Though Landsat TM and ERS SAR Data: A Case Study. Hydrological Processes. 11: 1397–1408.

[32] Saaty, T. L. (1980). The Analytic Hierarchy Process. New York: Mc Graw Hill.

[33] Saaty, T. L. (2008). Decision Making with the Analytic Hierarchy Process. Int. J. Services Sciences. 1 (1).

[34] Saini, S. S. & Kaushik, S. P. (2012). Risk and Vulnerability Assessment of Flood Hazard in Part of Ghaggar Basin: A Case Study of Guhla Block, Kaithal, Haryana, India. International Journal of Geomatics and Geosciences. 3 (1): 42-54.

[35] Sanyal, J. & Lu, X. X. (2004). Application of Remote Sensing in Flood Management with Special Reference to Monsoon Asia – A Review. Natural Hazards. 33, Kluwer Academic Publishers.

[36] Sanyal, J. & Lu, X. X. (2005). Remote sensing and GIS-Based Flood Vulnerability Assessment of Human Settlements: A Case Study of Gangetic West Bengal, India. Hydrological Processes. 19: 3699-3716.

[37] Siddayao, G. P., Valdez, S. E. & Fernandez, P. L. (2014). Analytic Hierarchy Process (AHP) in Spatial Modeling for Floodplain Risk Assessment. International Journal of Machine Learning and Computing. 4 (5): 450-457.

[38] Sinha, R., Bapalu, G. V. , Singh, L. K. & Rath, B. (2008). Flood Risk Analysis in the Kosi River Basin, North Bihar using Multi-Parametric Approach of Analytical Hierarchy Process (AHP). Journal Indian Society Remote Sensing. 36: 335-349.

[39] Strahler, A.N. (1964). Quantitative Geomorphology of Drainage basins and Channel

[40] network. In Handbook of Applied Hydrology; Mc Graw Hill: New York, NY, USA. 39–76.

[41] Townsend, P. A. & Walsh, S. J. (1998). Modelling Flood Plain Inundation using Integrated GIS with Radar and Optical Remote Sensing. Geomorphology. 21 (98): 295-312.

[42] Villiers, A. B. (1986). A Multivariate Evaluation of a Group of Drainage Basin Variables, African Case Study. Proc. of the First International Conf. on Geomorphology. Manchester, UK. Part 2: 21-33.

[43] Wadge, G., Wislocki, A. P., Pearson, J. & Whittow J. B. (1993). Mapping Natural Hazards with Spatial Modeling System. In: Geographic Information Handling Research and Applications, edited by P.M. Mather, John Wiley and Sons Inc., New York.

[44] Yahaya, S. (2008). Multicriteria Analysis for Flood Vulnerable Area in Hadejia-Jama'are River Basin, Nigeria. ASPRS 2008 Annual Conference Portland, Oregon. April 28 - May 2.

[45] Yakoo, Y., Kazama, S., Sawamoto, H. & Nishimura M. (2001). Regionalization of Lumped Water Balance Model Parameters based on Multiple Regression. Journal of Hydrology. 246 (1-4): 209-222, IAHS Publ., UK.

[46] Yalcin A. & Bulut, F. (2007). Landslide susceptibility mapping using GIS and digital photogrammetric techniques: a case study from Ardesen (NE-Turkey). Nat Hazards 4: 201-226.

[47] Zerger, A. (2002). Examining GIS Decision Utility for Natural Hazard Risk

Modeling. Environmental Modelling and Software. 17 (3), 287-294.

[48] Zhu, W., Zeng, N. & Wang, N. (2010). Sensitivity, specificity, associated confidence interval and ROC analysis with practical SAS implementation. NESUG.