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Detecting Flood Susceptible Areas Using GIS-based Analytic Hierarchy Process

Dano Umar Lawal[1+], Abdul-Nasir Matori[2], Ahmad Mustafa Hashim[3], Khamaruzaman Wan Yusof[4], Imtiaz Ahmed Chandio[5]

[1]PhD Student, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia
[2]Associate Professor, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia
[3]Associate Professor, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia
[4]Associate Professor, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia
[5]PhD Student, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia

Abstract. Speedy growth of the world's population has escalated both the frequency and severity of the natural catastrophes nowadays. Flood disaster has a very special place in natural catastrophes and its effect area is not bounded. It is the unusual event of river basins due to a prolonged rainfall and related humankind activities. Floods are the costliest types of natural catastrophes in the world and it accounts for 31% of the economic losses resulting from natural catastrophes. This paper is part of the ongoing project aimed at identifying the areas that are likely to be inundated by significant flooding based on the reviewed flood contributing factors of the study area. Multi-Criteria-based Evaluation (MCE) method is adopted in detecting the flood susceptible areas around the river basin of the study area of Perlis, Malaysia. The MCE method used is the pair-wise comparison methods of Analytical Hierarchy Process (AHP). Questionnaires were distributed to experts on hydrology and hydraulics in order to score each flood contributing factor used as criterion separately in their order of significance. Pair-wise comparison method was used in calculating the weights of each criterion. Some of these flood causative factors considered herein are the annual rainfall, capacity of the existing drainage, size of the watershed, land use, soil type and the slope. The weights derived shows C1= annual rainfall and C2= capacity of the existing drainage to be the most flood contributing factors based on the decision makers' preferences. However, the results of this analysis will further be overlaid for the flood susceptibility mapping for the presumptive flood areas around the river basin of Perlis into the GIS environment. This will be carried out in the subsequent study as this paper is part of the ongoing project. The flood vulnerable areas to be delineated will correspond to those areas that are likely to be inundated by significant flooding. Additionally, further risk analysis will be performed using Digital Elevation Model (DEM) data, distance from hazard zone, land cover map and potential damageable objects at risk. DEM will be used to delineate the catchments and serves as a mask to extract the highest hazard zones of the flood vulnerable area(s). The final results will be incorporated to Web-based GIS using Mash-up to serve as an interface.

Keywords: Flood Susceptible Areas, Geographic Information System, Multi-Criteria Evaluation

1. Introduction

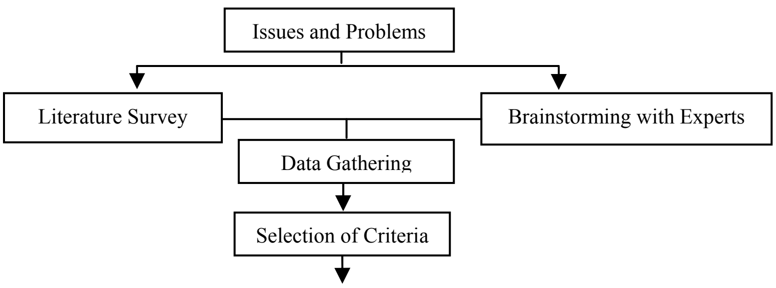
Several countries experience fatalities, injuries, property damage, economic and social disruption resulting from natural disasters. Natural disasters, such as earthquakes, hurricanes, flash floods, volcanic eruptions, and landslides have always constitute a major problem in many developing and developed countries. The natural hazards kill thousands of people and destroy billion of dollars worth habitat and property each year. The rapid growth of the world's population has escalated both the frequency and severity of the natural disasters. Flood disaster has a special place in natural hazards. Floods are the costliest

[+] Corresponding author: Dano Umar Lawal Tel.: +60177366200;
E-mail address: bblawaldano@gmail.com.

types of natural hazards in the world and constitute 31% of the economic losses resulting from natural catastrophes [1]. In Malaysia, it has been documented that since circumstances change the flood behavior [2, [3]. Flood associated with so-called “flash floods” is common in Malaysia. Most of the major urban areas experienced flash floods, which normally occurred during monsoon seasons from November to March (North-East monsoon) and May to September (South-West Monsoon) [2]. The basic cause is the incidence of heavy monsoonal rainfall and the resultant large concentration of run-off, which exceeds river systems [4]. Rapid urbanization within urban river catchments have also served to compound the problem with higher run-off and deteriorated river capacity that have resulted in increased flood frequency and magnitude. Urban activities are causing more and more urban areas becoming sensitive to short duration with high intensity rainfall that leads to flash flood (2 to 5 hours) [2]. With heavy rain between 2000mm to 3000mm a year, flash floods are one of the most common hazards after monsoon floods [2]. The hazard brought much disruption to the livelihood of the urban people. In many incidents, homes were flooded and residents were forced to evacuate. In addition, traffic flows were disrupted and occasionally, some lives were lost due to drowning. However, flood related problems and many other applications proved that these problems could be solved through planning studies and detailed projects in the floodplain areas. Determining the flood susceptible 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. For instance, Multi-Criteria Evaluation (MCE) methods has been applied in several studies since 80% of data used by decision makers are related geographically [5]. 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 [6], and the multi-criteria decision analysis within GIS is used to develop and evaluate alternative plans that may facilitate compromise among interested parties [7]. Moreover, Multi-Criteria Evaluation (MCE) method was used in analyzing and finding the flood vulnerable areas in west of black sea of the northern Turkey (Ho et al, 2002). Another study in Nigeria presented a GIS-based multi-criteria evaluation approach in analyzing flood vulnerable areas. It applied the multi-criteria analysis framework to incorporate the obtained weights of each factor into GIS environment in determining the vulnerable areas [8]. The approach proposed here allows planners and housing developers to examine the susceptible areas for information about the risk areas likely to be flooded and for development control in floodplain areas. Therefore, the actual purpose of this study is to identify the flood susceptible areas based on the flood contributing factors and to painstakingly identify the most contributing ones based on experts' preference.

2. Methodology

Actually, in determining the flood susceptible areas in the study area two stages were undertook. First of all 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 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. Figure 1 illustrates the methodological flowchart of the study.



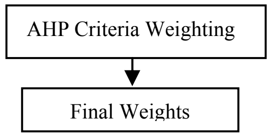


Figure 1: Methodology Flowchart

2.1. Selection and Evaluation of Criteria

According to [9], the choice of criterions that has a spatial reference is an important and profound step in multi-criteria decision analysis. Hence, the criteria considered in this study were chosen due to their significance in causing flood in the study area. The factors considered are:

Annual rainfall,

Capacity of the existing drainage,

Size of the watershed,

Land use,

Soil type, and

Slope.

2.2. Multi Criteria Analysis

First and foremost, few 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. Though, this method is much more complicated than ranking and rating methods, it has been criticized by the way of receiving the ratios of importance. But reference [10] states that pair-wise comparison is more appropriate if accuracy and theoretical foundations are the main concern. The technique involves the comparison of the criteria, which as well allows one to compare the importance of two criteria at a time. This very technique, which was proposed and developed by Saaty in 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 [12]. The computation of Consistency Ratio herein was carried out in a few steps as illustrated he; the weighted sum vector was determined by multiplying the matrix by the vector of the criterion weights (each column was multiplied by the corresponding criterion weights and the products were summed over the rows).

3. Results and Discussion

3.1. Computation of the Pair-wise Comparison Matrix and Consistency

Pair-wise comparison matrix is created by assigning weights by experts. The weights are further evaluated in finding alternatives and estimating associated absolute numbers from 1 to 9 in fundamental scales of the AHP [12]. These weights can be computed automatically in IDRISI (Eastman 1995), Microsoft Excel as well as in Expert Choice (Expert Choice Quick Start Guide, 2000-2004) software called Multi-Criteria Decision Analysis (MCDA) tool. Hence, the results of relative weights of C1= Annual rainfall, C2= Capacity of the existing drainage, C3= Size of the watershed, C4= Land use, C5= Soil type, and C6= Slope are shown in Table 1. So, pair-wise comparison matrixes are calculated herein using the Microsoft Excel in determining priority weightages in this manuscript. Furthermore, the obtained results will be incorporated into ArcGIS software for spatial flood susceptibility mapping for the presumptive areas around the study area.

Table 1: Criteria Weighting Calculation for Flood Susceptible Areas

STEP I							STEP II						STEP III
	C1	C2	C3	C4	C5	C6	C1	C2	C3	C4	C5	C6	WEIGHT
C1	1.00	2.00	3.00	3.00	4.00	3.00	0.36	0.47	0.28	0.38	0.24	0.20	0.32
C2	0.50	1.00	3.00	3.00	3.00	4.00	0.18	0.24	0.28	0.38	0.18	0.27	0.25
C3	0.33	0.33	1.00	0.33	4.00	2.00	0.12	0.08	0.09	0.04	0.24	0.13	0.12
C4	0.33	0.33	3.00	1.00	4.00	3.00	0.12	0.08	0.28	0.13	0.24	0.20	0.17
C5	0.25	0.33	0.25	0.25	1.00	2.00	0.09	0.08	0.02	0.03	0.06	0.13	0.07
C6	0.33	0.25	0.50	0.33	0.50	1.00	0.12	0.06	0.05	0.04	0.03	0.07	0.06
SUM	2.74	4.24	10.75	7.91	16.50	15.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

Table 2: Consistency Ratio (CR) Calculation

STEP IV :

C1	1.00	2.00	3.00	3.00	4.00	3.00
C2	0.50	1.00	3.00	3.00	3.00	4.00
C3	0.33	0.33	1.00	0.33	4.00	2.00
C4	0.33	0.33	3.00	1.00	4.00	3.00
C5	0.25	0.33	0.25	0.25	1.00	2.00
C6	0.33	0.25	0.50	0.33	0.50	1.00

*

0.32	0.25	0.12	0.17	0.07	0.06

=

							SUM1
C1	0.32	0.51	0.35	0.52	0.28	0.18	2.17
C2	0.16	0.25	0.35	0.52	0.21	0.24	1.75
C3	0.11	0.08	0.12	0.06	0.28	0.12	0.77
C4	0.11	0.08	0.35	0.17	0.28	0.18	1.18
C5	0.08	0.08	0.03	0.04	0.07	0.12	0.43
C6	0.11	0.06	0.06	0.06	0.03	0.06	0.38

STEP V : SUM1/WEIGTH

SUM1	÷	WEIGHT	=	
2.17		0.32		6.72
1.75		0.25		6.87
0.77		0.12		6.49
1.18		0.17		6.77
0.43		0.07		6.16
0.38		0.06		6.29
			SUM2	39.29

STEP VI : λ = Sum2 and n = number of criteria

λ = SUM2/n = 6.55

STEP IV : CONSISTENCY INDEX (CI) = $\frac{\lambda - n}{n-1}$,

where λ = Summation of sum2 and n = number of criteria

$$CI = \frac{\lambda - n}{n-1} = 0.11$$

STEP V : CONSISTENCY RATIO (CR)

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

,Where CI= Consistency Index and RI= Random Inconsistency Index

n	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
RI	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49

$$CR = \frac{0.11}{1.24} = 0.09$$

,CR < 0.1 : REASONABLE

4. Conclusion

Actually, detecting the flood susceptible areas is quite imperative in determining risk areas that are likely to be flooded and in floodplain development control measures. The end results which will be in maps format showing the susceptible/risk areas will as well serve as valuable tools to planners, insurers, and emergency services in assessing flood risk. Therefore, pair-wise comparison matrix was designed using AHP method and priority weights were equally calculated in Microsoft Excel, which shows C1= Annual rainfall and C2= Capacity of the existing drainage to be the most significant factors liable to cause flooding in the study area. In addition, the Consistency Ratio which shows an acceptable level of 0.09 was equally calculated to validate the strength of the aforementioned technique adopted herein. Finally, the subsequent study will include the integration of these weights into GIS environment for spatial flood susceptibility mapping, risk areas map as well as potential damageable objects map. So, at the last phase, the generated maps will be converted by inculcating the ideation of the Web-based GIS integrating with Mashup Application to serve as an interface.

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