Research Journal of Applied Sciences, Engineering and Technology 7(22): 4638-4644, 2014
DOI:10.19026/rjaset.7.845
ISSN: 2040-7459; e-ISSN: 2040-7467

Submitted: April 11, 2013 Accepted: June 08, 2013 Published: June 10, 2014

Research Article

Flood Susceptibility Modeling: A Geo-spatial Technology Multi-criteria Decision Analysis Approach

[1]Dano Umar Lawal, [1]Abdul-Nasir Matori, [1]Khamaruzaman Wan Yusof, [1]Ahmad Mustafa Hashim, [1]Mansir Aminu, [2]Soheil Sabri, [1]Abdul-Lateef Balogun, [1]Imtiaz Ahmed Chandio and [1]Munirah Radin Mohd Mokhtar
[1]Department of Civil Engineering, Universiti Teknologi PETRONAS, Malaysia
[2]Department of Urban and Regional Planning, Universiti Teknologi Malaysia, Malaysia

Abstract: Understanding the surface and subsurface condition can immensely enhance the availability of accurate flood susceptibility maps for effective management of flood catastrophe. In this study, remote sensing and Geographic Information System-based (GIS-based) Multi-Criteria Decision Analysis (MCDA) based on experts' opinions has been adopted to carry out the preparedness phase of flood management. Establishing a link between the surface/subsurface conditions and flood occurrence is the major objective of this study. The surface/subsurface investigations showed that the lowland areas of the study area are characterized by the presence of flat slope, alluvium deposits and low humid clay soil composition. The GIS-based Analytic Hierarchy Process (AHP) model was adopted in simulating the flood susceptible zones map of the study area. Finally, the result revealed that flood generation in the area immensely relied on slope, geology and soil type along with rainfall as the key catalyst.

Keywords: Flood susceptibility mapping, GIS-based multi-criteria decision analysis, remote sensing, surface/ subsurface factors

INTRODUCTION

Natural catastrophes such as earthquakes, tornados, floods, volcanic outbreaks and landslides have constantly make-up an issue in most developing and developed nations. It kills million and destroys billions of dollars yearly. The rapid increase of the world's population has escalated equally the number and rigorousness of the natural catastrophes. Flood tragedy possesses a very special place in natural hazards (Lim, 2008). Media has a tremendous significance in presenting the news and serious flood incidents every now and then make the headlines. Vast majority of the news relates to fairly smaller incidents, which usually cause little injury and which can be soon forgotten apart from the individuals whom were directly affected. Some, however, exhibit serious calamities involving loss of lives along with the deterioration of properties and convey in their wake hardship, suffering, ailment and also starvation.

Flood is defined as a scenario during which water temporarily goes over an area of land where it usually does not. The water arises from the sea, lakes, streams, waterways or sewers; it can as well be rainwater. Even though flood is triggered by nature, it impacts places where people reside and can bring serious destruction and agony to people who live in the area. Flood can consequently be seen as an event that leaves social, cultural as well as economic impacts on the people it afflicted.

Floods account for around 90% of the overall natural catastrophes associated injuries in Malaysia (Adiat *et al*., 2012). The average yearly flood damage is as huge as 100 million dollars (Pradhan and Shafie, 2009). Floods have grown to be a typical characteristic in the lives of a substantial number of Malaysians. Perlis State is among the Malaysian States suffering from flood. Similarly, the State was adversely afflicted with flood during the last quarter of the year 2010. The impacts of the flood left untold hardship on the individuals of the impacted areas. Therefore, this study simulated the flood susceptible areas of the study area using geo-spatial technology.

DESCRIPTION OF THE STUDY AREA

Location of the study area: The State of Perlis is bounded by Thailand in the north, Kedah in the south, while its western coastline borders the Straits of Malacca as illustrated in Fig. 1.

Climate: The climate, which is usually hot and wet, is basically controlled by the annual fluctuations in position of the inter tropical convergence zone as it follows the apparent movement of the sun north and south of the equator. This results in two distinct rainy

Corresponding Author: Dano Umar Lawal, Department of Civil Engineering, Universiti Teknologi PETRONAS, Malaysia

Fig. 1: Map of Peninsular Malaysia showing the study area, http://www.royalpcg.com/sites

periods and a drought period. It experiences a monsoon tropical climate and "winter winds" (east coast wind from Teluk Siam). The drought period spanning the months of December to March is associated with the north-eastern monsoon. The two periods of rainfall are associated with the advance and retreat of the south-western monsoon in April-May and September-October. The latter period produces greater depths of rainfall. The annual range of the temperature is from 21 to 32°C while the mean annual rainfall is between 2000 to 3000 mm. The rainfall has peaks during both the post-equinoctial transition periods between the monsoons. Analysis of rainfall data indicates higher mean monthly rainfall occurs between May and November, while less rainfall in December to March. Less rainfall occurs to coastal areas compared to the interior areas.

Geology: From the geology map of Perlis, alluvium covers a huge area of the central and southern regions of the state. This alluvium comprises unconsolidated sediments like sand as well as gravel. Paddy covers a significant part of the alluvium lying parts. Alluvium tends to be low-lying and can triggers flood during intense event; in fact, even the thinner alluvium tracts connected with smaller tributary valleys could be susceptible to flash-flood. The KubangPasu-Singa formation, which is made up of shale, mudstone, siltstone, flagstone, sub-greywacke, greywacke and quartzite covers most of the northern and central areas. There are actually two distinct limestone formations namely: the Chuping limestone that made up the central spine within the KubangPasu-Singa formation as well as the Setul limestone which is obtained in western Perlis bordering Thailand. The Bukit Arang formation which is actually a formation of semi-consolidated clays, sands and gravels along with some thin coal seams and oil shales are obtained only in the north-eastern region. Whilst a minute outcrop of granite is obtainable at the northern tip of Perlis bordering Thailand.

MATERIALS AND METHODS

Selecting the flood influencing criteria/factors in the study area: Some natural flood influencing factors were considered in this study in order to predict the flood susceptible zones in the study area. The factors considered herein are: rainfall, geology, slope gradient, land use and the soil type. These factors are therefore believed to be influencing flood generation in the area. Therefore, the following steps were adhered in coming up with the aforementioned data layers factors.

Scanning: A setback experienced when performing this study was that some of the spatial data used

Table 1: Interpretation of the Saaty's scale of measurement

Degree of importance	Definition	Interpretation
1	Equal importance	Two element making equal contribution to the goal
3	Somewhat more important	Moderate importance of element over the other element
5	Much more important	Essential or strong importance
7	Very much important	Very strong importance
9	Extremely important	Extreme importance
Scale, 2.4, 6 and 8	Intermediate values	These are require when comparison between two adjacent judgment is needed
Reciprocals	If v is the judgment value when i is compared to j, then 1/v is the judgment value when j is compared to i	

in this study were only available in the form of hardcopy or printed maps. These maps in hardcopy needed to be scanned and digitized in a GIS environment.

Digitization: Digitization was carried out in order to allow details of the scanned maps to be saved into the GIS database. All scanned maps were saved in jpg format. All plotting were completed using ArcGIS software which allowed the user access to both data formats. However, before plotting could be done, each of the scanned maps needed to be registered into the local coordinate system using ArcGIS software. Coordinate registration was achieved by reference to the coordinates of the satellite image.

Satellite image processing: The satellite image used in this study is SPOT (Systeme Pour l'Observation de la Terre) image. The SPOT image is a 3-band multi-spectral image dated 2005, covering the entire state of Perlis was procured from the Malaysian Centre of Remote Sensing (MACRES). The SPOT satellite image was chosen for this study since the resolution capability of SPOT's panchromatic (black and white) sensor was 10 m, while its multi-spectral sensor can have a resolution up to 20 m. Here the multi-spectral image of Perlis with a resolution of 20 m was chosen. The results suggested that a raster based GIS can facilitate the necessary digital analysis and manipulations, including data integration, geo-corrections and handling classification. Lastly, the land use map of this study was created based on Supervised Classification using ENVI 4.8 software.

Building the database: The satellite images that had been processed through the classification process now had to be processed using ArcGIS software to create the land use map. In ArcGIS various data formats were available. Some of the data needed in this study were only available in the form of printed or hardcopy maps. These maps first had to be scanned with a digital scanner and saved into the GIS system together with all spatial and attribute data. After scanning of all maps, registration to the local coordinates system had to be carried out before spatial analysis was done.

Assigning weights to the flood influencing criteria/factors: Using the technique of the Multi-Criteria Decision Analysis (MCDA), weights were calculated and assigned to each factor under consideration. According to Eastman (1996) and Navalgund (1997) defined MCDA as a technique that allows each factor to be weighted in accordance to its relative importance/influence. Experts' opinions were employed in evaluating the weight of each factor. The experts used in this study are geologists. Therefore, in this study the AHP model proposed by Saaty (1980) was employed in determining the relative weights of each flood influencing factor considered herein. It was basically based on the Saaty's scale of preference 1 to 9 as illustrated in Table 1.

Table 2: Pair wise comparison (step I)

	C1	C2	C3	C4	C5
C1	1.00	1.15	2.73	1.22	1.57
C2	0.87	1.00	0.48	0.47	0.60
C3	0.37	2.09	1.00	0.78	0.80
C4	0.82	2.13	1.28	1.00	0.84
C5	0.64	1.66	1.25	1.18	1.00
Sum	3.70	8.03	6.74	4.65	4.81

Table 3: Determining the relative criterion weights (step II)

C1	C2	C3	C4	C5	Weight
0.27	0.14	0.41	0.26	0.33	0.28
0.24	0.12	0.07	0.10	0.12	0.13
0.10	0.26	0.15	0.17	0.17	0.17
0.22	0.27	0.19	0.22	0.17	0.21
0.17	0.21	0.19	0.25	0.21	0.21
1.00	1.00	1.00	1.00	1.00	1.00

Pair wise comparison matrix was used in calculating the weights, where two factors were compared and scored at a time according to their degrees of influence in flood generation based on the experts opinions gathered in the course of the AHP survey questionnaires administered. A matrix of pair wise comparisons of the factors for the AHP model was determined as illustrated in Table 2. In AHP, the pair-wise comparisons of all the criteria/factors are considered as the inputs whilst the relative weights of the factors are the outputs. The factors final weightings are the normalized values of the eigenvectors that is basically associated with the maximum eigenvalues of the ratio (reciprocal) matrix. According to Saaty (1980), this particular way is the best approach of minimizing the effect of the inconsistencies in the ratios. Table 3 illustrates the weights of the factors generated based on the steps described by Malczewski (1999). Moreover, in order to check the consistency of the responses given by the experts, Consistency Ration (CR) was calculated as shown in Table 4. In generating the weight of each factor; email-based questionnaire on comparison ratings on a scale of 1-9 (Table 1) was prepared and administered on thirteen (13) experts (geologists) within and outside Malaysia. The experts'

Table 4: Calculating the consistency ratio

Step I:										
C1	1.00	1.15	2.73	1.22	1.57					
C2	0.87	1.00	0.48	0.47	0.60					
C3	0.37	2.09	1.00	0.78	0.80					
C4	0.82	2.13	1.28	1.00	0.84					
C5	0.64	1.66	1.25	1.18	1.00					
			*					Step II: sum 1/weight		
	0.28	0.13	0.17	0.21	0.21					
			=			SUM1				
C1	0.28	0.15	0.46	0.26	0.32	1.48		0.28		5.24
C2	0.24	0.13	0.08	0.10	0.12	0.68	/	0.13	=	5.18
C3	0.10	0.27	0.17	0.17	0.16	0.88		0.17		5.21
C4	0.23	0.28	0.22	0.21	0.17	1.11		0.21		5.21
C5	0.18	0.22	0.21	0.25	0.21	1.07		0.21		5.19
									Sum 2	26.04

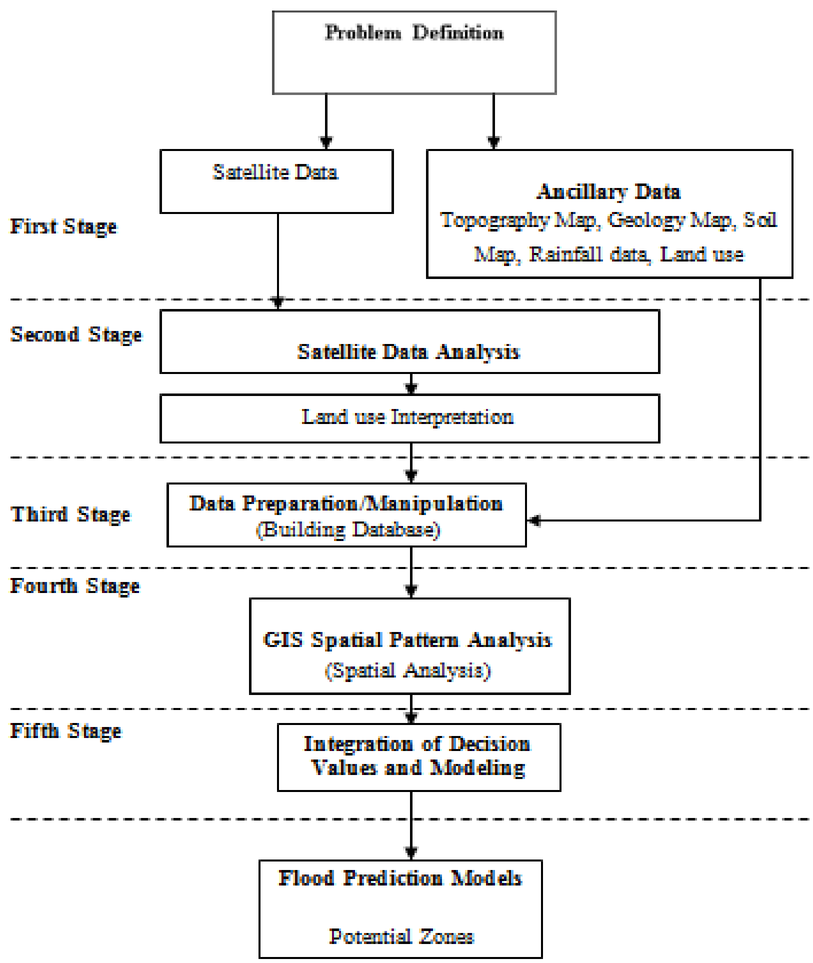

Fig. 2: Flowchart of the study methodology

preferences were aggregated using a Geometric Mean method as follows:

$$\text{Geometric Means} = ((X_1)\ (X_2)\ (X_3)\ \ldots.\ (X_N))^{1/N}$$

where, X is individual score and N is sample size (Number of scores). Therefore, the experts preferences combined with other field investigations and related studies helped in carrying out the pair wise comparison matrix illustrated in Table 2.

Integration of the AHP model into GIS system: This stage involved integration of the AHP model into GIS system. It involved combining all the thematic layers using the Weighted Linear Combination (WLC) method based on the computed weights generated from the

AHP method into GIS. The weighted linear combination, or simple additive weighting, depends upon the theory of a weighted average in which continuous criterions are standardized to a collective numeric range and then combined by means of a weighted average (Drobne and Lisec, 2009). These thematic layers were overlaid to obtain the final flood prediction map in accordance with the AHP model developed. The result of the final analysis managed to indicate the potential areas of flood. Figure 2 shows the methodology flowchart used in this study.

RESULTS AND DISCUSSION

AHP pair wise comparisons of the natural flood influencing factors: Multi-Criteria Decision Analysis (MCDA) techniques are numerical algorithms that define suitability of a particular solution on the basis of the input criteria and weight together with some mathematical or logical means of determining trade-offs when conflict arise. Using this technique, a weight value ranges from 1 to 9 was assigned to the data layers by the experts to reflect their relative importance. All the map layers were combined together in the final GIS analysis using a method called the 'Weighted Linear Combination (WLC)'. The WLC technique can be carried out using any type of GIS system possessing the overlay. This permits the evaluation criterion map layers to be overlaid in order to obtain the composite map layer which is output. Therefore, the output of this WLC method gave a map which simulated the most potential flood susceptible zones of Perlis. Figure 3 shows the flood prediction model. For comparison, analysis was carried out based on AHP pair wise comparisons. This study had earlier proposed the AHP Flood Prediction Model as computed below:

where,
RF = Rainfall
GL = Geology
ST = Soil type
SG = Slope gradient
LU = Land use

Step III: The Consistency Index (CI), which is a measure of departure from consistency, was calculated using the formula:

$$CI = \frac{\lambda - n}{n - 1} \quad (1)$$

where,
n = Number of factors (i.e., 5)
λ = Average value of the consistency vector determined in step II above:

λ = 5.24 + 5.18 + 5.21 + 5.21 + 5.19 = 26.04/5 = 5.21
Based on Eq. (3), CI = 5.21-5/5-1 = 0.05

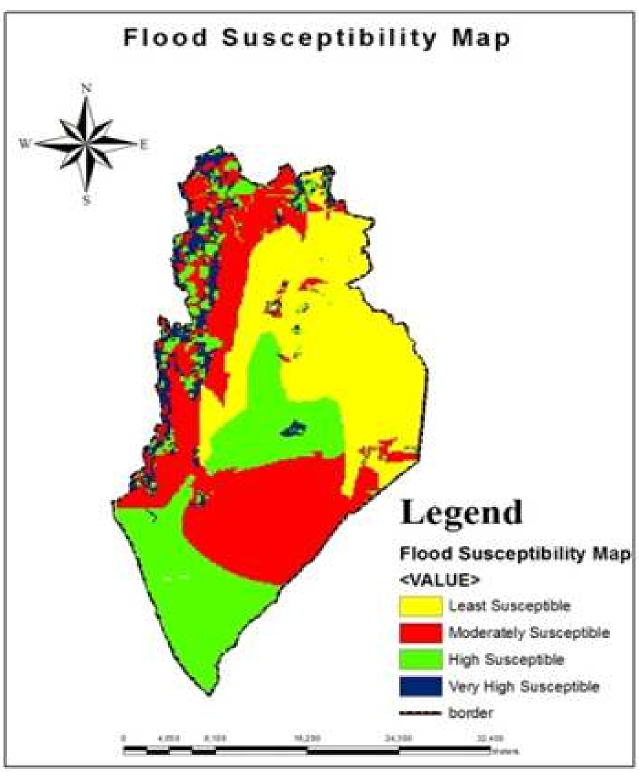

Fig. 3: Map of predicted flood susceptible zones in perlis based on spatial Analytic Hierarchy Process (AHP) model produced in this study

Table 5: Random inconsistency indices

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

Step IV: Calculating the Consistency Ratio (CR). The consistency ratio is defined as:

$$CR = CI/RI \quad (2)$$

where, RI is the random inconsistency index whose value depends on the number (n) of factors being compared; for n = 5, RI = 1.12 as illustrated in Table 5 (Saaty, 1980).
Using Eq. (2):

$$CR = 0.05/1.12 = 0.04$$

Therefore, since 0.04<0.1, it indicates that there is a realistic degree of consistency in the pair wise comparison and as a result, the weights 0.28, 0.13, 0.17, 0.21 and 0.21 (i.e., 28, 13, 17, 21 and 21% respectively) can be assigned to rainfall, geology, soil type, slope gradient and land use respectively.

The AHP spatial flood prediction model: Based on the derived weights calculated from the AHP analysis, the combination of all parameters was carried out in GIS using the Weighted Linear Combination (WLC) method. The Weighted Linear Combination (WLC) formula is shown below:

$$FSZ = \sum w_i x_i$$

Where, *FSZ* is the Flood Susceptible Zones; w_i is the factors weights which must sum of to 1 and x_i is the criterion score i. All these relevant data were uploaded into the GIS system before analysis was carried out using a total of five thematic maps: land use, geology, rainfall distribution, slope gradient and soil type. Figure 3 presents the result of the model, where the areas highlighted in dark blue forms the very high susceptible areas, lemon green represents high susceptible, red color signifies moderately susceptible, while least susceptible areas were presented in a yellow color.

CONCLUSION

GIS and remote sensing tools proved profound potentials in combating flood catastrophes. In this study, the efficiency of GIS-based AHP and remote sensing as a spatial multi-criteria prediction tools was discovered. In achieving the set objectives, spatial prediction of flood susceptible zones in a particular study area was used as a case study. Total of five natural flood influencing factors believed to be influencing flood generation potential in the area were chosen. Each factor was assigned suitable weight based on Saaty's scale of preference given by the experts during the AHP survey. The weights were further normalized through the Analytic Hierarchy Process (AHP). The flood susceptible areas prediction map of the study area was developed. It was confirmed in this study that the ability of the technique used to come up with accurate prediction is reliant on the exhaustiveness of a set of factors employed. Similarly, it has been confirmed in this study that GIS-based AHP technique has the capability of developing accurate and reliable hazards predictions. The approach can therefore be used in other studies.

ACKNOWLEDGMENT

This project was funded by the Universiti Teknologi PETRONAS Short Term Internal Research Fund (STIRF) under the project leadership of Associate Professor Dr. Kamaruzaman Wan Yusof. I would therefore like to acknowledge his support and guidance as well as my supervisors Associate Professor Dr. Abdul-NasirMatori and Associate Professor Mustafa Ahmad Hashim for their support.

REFERENCES

Adiat, K., M. Nawawi and K. Abdullah, 2012. Assessing the accuracy of GIS-based elementary multi criteria decision analysis as a spatial prediction tool-A case of predicting potential zones of sustainable groundwater resources. J. Hydrol., 440-441: 75-89.

Drobne, S. and A. Lisec, 2009. Multi-attribute decision analysis in GIS: Weighted linear combination and ordered weighted averaging. Nature, 4(26): 28.

Eastman, J.R., 1996. Multi-criteria Evaluation and Geographical Information Systems. In: Longley P.A., M.F. Goodchild, D.J. Magurie and D.W. Rhind, (Eds.), 2nd Edn., John Wiley and Sons, New York, 1: 493-502.

Lim, K., 2008. Methodology for evaluating flood damage reduction alternatives using a GIS-based MCDA interactive model. Ph.D. Thesis, Colorado State University Fort Collins, Colodado.

Malczewski, J., 1999. GIS and Multicriteria Decision Analysis. John Wiley and Sons, Inc., United States of America, pp: 177-192.

Navalgund, R.R., 1997. Revised development plan of Ahmedabad urban development authority area-2011. Ahmedabad Urban Development Authority and Space Applications Centre, Ahmedabad, India, Technical, Report No: 1 SAC/RSAG/TR/12/ AUG/1997, pp: 142.

Pradhan, B. and M. Shafie, 2009. Flood hazard assessment for cloud prone rainy areas in a typical tropical environment. Disaster Adv., 2(2): 7-15.

Saaty, T.L., 1980. The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation. McGraw-Hill, New York.