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Flood Risk Map Based on GIS, and Multi Criteria Techniques (Case Study Terengganu Malaysia)

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Abstract

The heavy floods in the Terengganu have showed an increasing trend in recent years. Terrain characteristics of land and meteorological properties of the region are main natural factors for this disaster. In this paper, Terengganu was selected as the case study for flood risk analysis. Geographical Information System (GIS) is integrated with Multicriteria Decision Analysis (MCDA) to evaluate the potential flood risk areas. Some of the causative factors for flooding in watershed are taken into account as annual rainfall, basin slope, drainage network and the type of soil. The spatial multi-criteria analysis was used to rank and display potential locations, while the analytical hierarchy process method was used to compute the priority weights of each criterion. Using AHP, the percentages derived from the factors were Rainfall 38.7%, Drainage network 27.5%, Slope of the river basin 19.8% and Soil type 14%. At the end of the study, a map of flood risk areas was generated and validated with a view to assisting decision makers on the menace posed by the disaster.

Keywords

Geographic Information System, Multi Criteria Decision Making, Analytical Hierarchy Process, Pairwise Comparison, Flood

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1. Introduction

In the years of 2006, 2007 and 2008, heavy monsoon rainfall seasons triggered floods along Malaysia's east coast as well as in different parts of the country. Terengganu was one of the hardest hit areas along the east coast of Peninsular Malaysia [1]. Terrain characteristics of land and meteorological properties of the region have been the main natural factors for causing flood disaster. Flood risk mapping using GIS and multicriteria methods has been applied in various case studies [2]-[6]. The selection of criteria that has spatial reference is an important step in spatial multicriteria decision analysis [7]. The criteria used in this study were selected due to their relevance in the study area.

The objective of this study is to determine flood potential areas using Spatial Multicriteria Evaluation technique, Pairwise Comparison (Analytical Hierarchy Process-AHP) and Ranking Method.

2. Materials and Method

2.1. Study Area

This study was conducted in the State of Terengganu, West Malaysia Terengganu is located at the east coast of Peninsular Malaysia, neighboring the State of Kelantan to the East, and the State of Pahang to the South (**Figure 1**). It is located between latitudes 05˚51'06"N and 03˚55'37"N and longitudes 102˚21'11"E and 103˚31'28"E. Terengganu today covers 12,995 square kilometers and comprises seven districts. It is generally hot and humid all year round, averaging from 28˚C to 30˚C in daytime and slightly cooler after sunset. Terengganu's average rainfall is 2575 mm to 2645 mm per year, with the most rain falling between November and January [8].

2.2. Data Source

The principle supporting the data for this study was provided in 2006 from department of agriculture and de-

Figure 1. Location of the study area (DID, 2006).

Table 1. List of data sets used in the study.

Type of Data	Description	Source
Soil chemical and physical values	Profile data for each type of soil	1992-2006 Department of Agriculture (DOA) Kuala Lumpur
Soil map	Soil semi detailmap,scale 1:25000	2006 DOA Kuala Lumpur
Terrain	The terrain value extracted from the topographic map for each soil type	2006 DOA Kuala Lumpur
Rainfall precipitation	Monthly rainfall from 34 stations during 10 years	1996-2006 Department of Irrigation and Drainage (DID)
Drainage network	Scale 1:25,000	2006 DOA Kula Lumpur
Flood map	Scale 1:30,000	2008 DID

partment of survey and mapping in Kula Lumpur. The selection of criteria that has spatial reference is an important step in spatial multicriteria decision analysis [7]. The spatial data and there description, are listed in **Table 1**. A number of procedures were followed in compiling the geographic and tabular data input: entering spatial data (digitizing). The criteria used in this study were selected due to their relevance in the study area, these are listed below.

2.2.1. Annual Precipitation

Climate information was obtained from 32 meteorological stations located within the study area (see **Figure 2**). The current data include the longitude and latitude for each station associated with monthly records available for 10 years rainfall data (1996-2006). The mean annual rainfall was estimated for each station. The rainfall interpolation surface was created based on Inverse Distance Weighted method (**Figure 3**).

2.2.2. Drainage Network of the River Basin

The drainage network data was converted into compatible GIS format, and created in layer using ArcGIS (**Figure 4**).

2.2.3. Topographic Criteria (Slope) and Soil

In the current study, the terrain value was extracted from the topographic map for each soil type and displayed in GIS layer. Soil was ranked based on expert opinion considering it is texture and structure for causing flood

2.3. Multi Criteria Analysis

Multi criteria analysis is applied and integrates with the spatial data in order to describe the causative factors of a phenomenon under concern. In this study, the risk areas were first produced by numerically overlaying soil, drainage network, slope and rainfall layers. The selection of these criteria was based on the expert's opinion and availability of data. This overlay was carried out as a Boolean overlay. All criteria are combined by logical operators such as intersection (AND) and union (OR).

In the second phase, Ranking Method was used, where every criterion under consideration was ranked in the order of the decision maker's preference. Each factor was weighted according to the estimated significance for causing flooding. The inverse ranking was applied to these factors. Factor of rank 1 is the least important and 8 is the most important factor. In the third phase, Pairwise Comparison Method which was developed by Saaty [9] was used to determine the weight of each criterion. **Figure 5** illustrates the general procedure used to create flood risk map for the study area.

Pairwise Comparison Method

This method involved the comparison of the criteria and allows the comparison of two criteria at a time. It can convert subjective assessments of relative importance into a linear set of weights. This method could estimate the weight of the following criteria:

C1 = Rainfall (Precipitation);

C2 = Slope of the basin;

C3 = Soil type;

C4 = Drainage network.

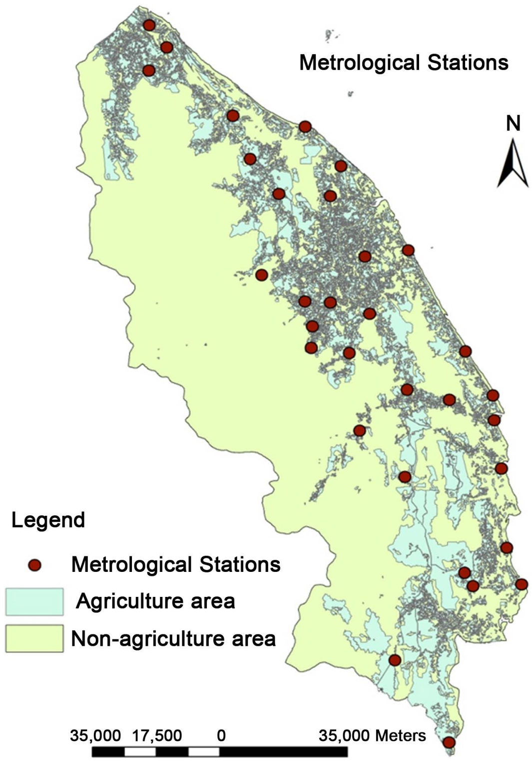

Figure 2. Metrological stations.

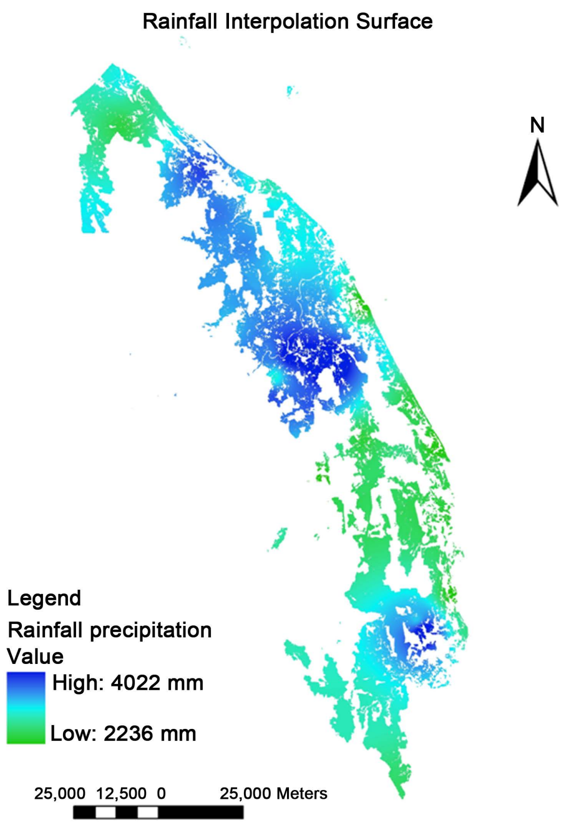

Figure 3. Rainfall interpolation surface.

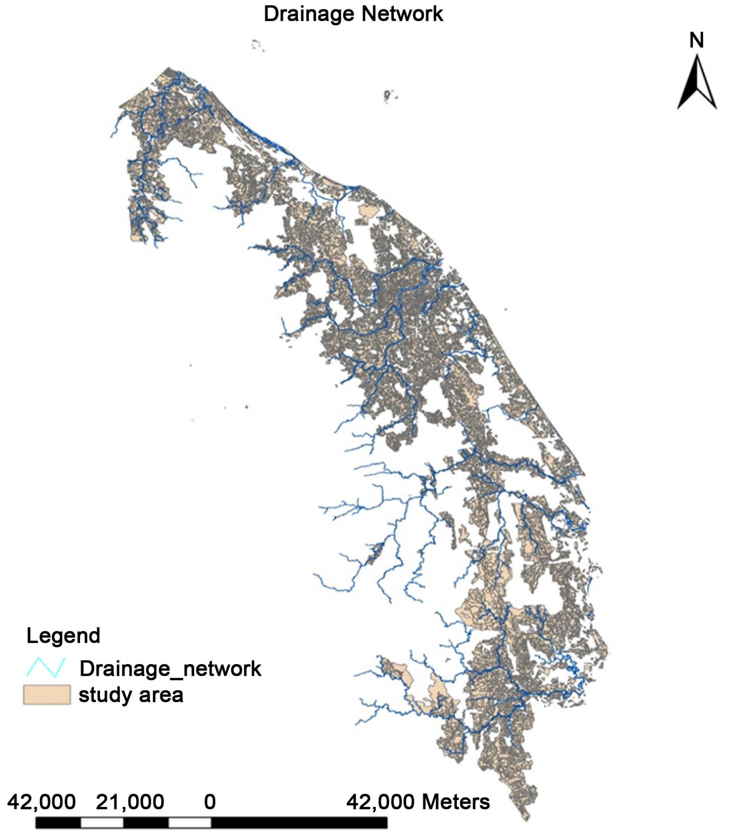

Figure 4. Drainage network layer for the study area.

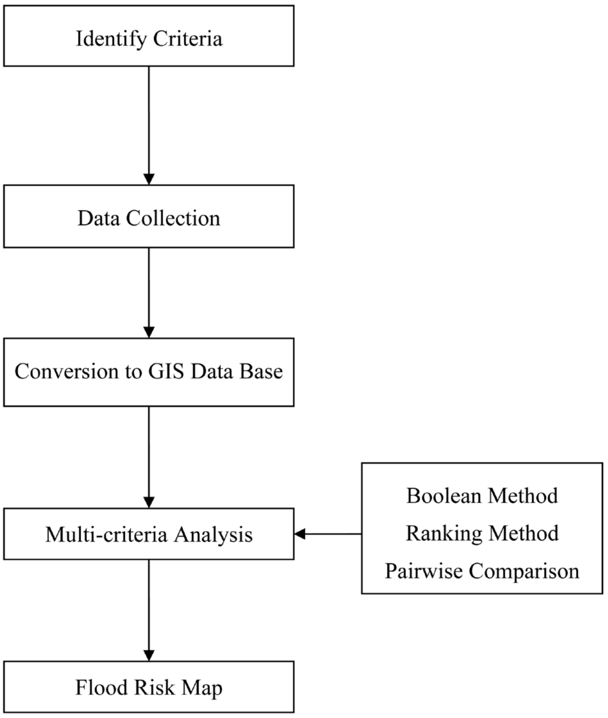

Figure 5. General procedure undertaken to develop flood risk map in GIS for the study area.

The square pair-wise comparison matrix is presented in **Table 2**. To generate the criterion values for each evaluation unit, each factor was weighted according to the estimated significance for flood potential project. The normalized matrix is presented in **Table 3**. Meanwhile, the individual judgment, which never agreed perfectly with the degree of consistency achieved in the ratings, was measured by using Consistency Ratio (CR), indicating the probability that the matrix ratings were randomly generated. The Random Indices for matrices are listed in **Table 4**. The rule of thumb is that a CR less than or equal to 0.1 indicates an acceptable reciprocal matrix, while a ratio over 0.1 indicates that the matrix should be revised.

Table 2. Pairwise comparison matrix for flood risk parameters.

	C1	C2	C3	C4
C1	1	2	2	2
C2	0.5	1	2	0.5
C3	0.5	0.5	1	0.5
C4	0.5	2	2	1
	2.5	5.5	7	4

Table 3. Normalize matrix.

	C1	C2	C3	C4	Priority Vector
C1	0.4	0.36	0.29	0.5	0.387337662
C2	0.2	0.18	0.29	0.125	0.198133117
C3	0.2	0.09	0.14	0.125	0.139691558
C4	0.2	0.36	0.29	0.25	0.274837662
Total	1	1	1	1	1

Table 4. Random indices for matrices of various sizes (n).

N	**R1**
1	0
2	0
3	0.58
4	0.9
5	1.12
6	1.24
7	1.32
8	1.4
9	1
10	1.49
11	1.51
12	1.48
13	1.56
14	1.57
15	1.59

Calculating Consistency Ratio (CR)

$$CR = CI/RI$$

where $CI = (\lambda_{max} - n)/(n - 1)$;

RI = Random Consistency Index;

n = Number of Criteria;

λ_{max} is the priority vector multiplied by each column total;

$\lambda_{max} = 4.13526786$;

$CI = 0.04508929$;

$CR = 0.0500992$.

3. Result and Discussion

3.1. Flood Risk Map

Figure 6 shows the flood risk map created based on GIS and multicriteria method. The criterion maps were combined by logical operations and criterion values were generated based on ranking method for each evaluation unit. Using pair wise compression the normalized criterion weights were calculated as 0.387, 0.198, 0.14 and 0.275, respectively for annual rainfall, basin slope, soil type and drainage network of the river basin. The significant findings showed a Consistency Ratio (CR) value of 0.05, which fell much below the threshold value of 0.1 and it indicated a high level of consistency. Hence, the weights are acceptable.

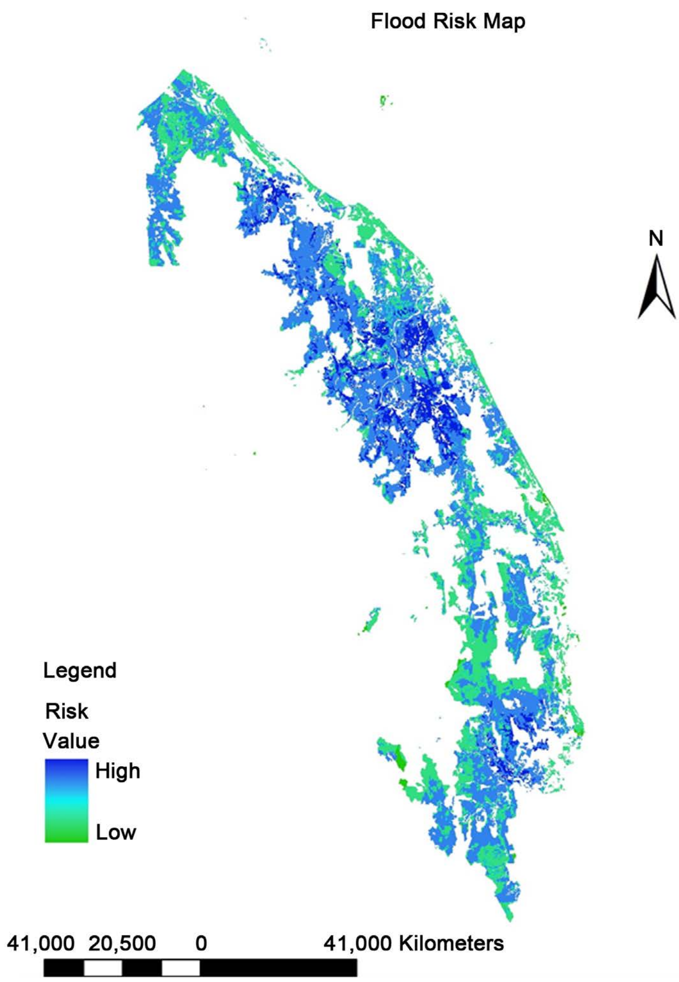

Figure 6. Flood risk map.

3.2. Flood Map Validation

The flood potential map which resulted from multi criteria analysis was compared with the original flood map of 2008/2009 obtained from DID in Terengganu for the purpose of validation. The original flood map is shown in **Figure 7**. The flood potential map was classified based on flood vulnerability, such as:

a) 4 for the highly more to flooding;
b) 3 for the moderately more to flooding;
c) 2 for the less more to flooding;
d) 1 for the no flooding area.

The raster flood potential map was converted into feature map in which, all features take the grid code values from the raster pixel values. Each polygon has one grid value (*i.e.* 1, 2, 3 or 4) based on the corresponding cell value at the same location in the raster. This step made the polygon with same value to dissolve in one polygon feature, resulting in generating four polygons; one polygon for each flood suitability level. Then each flood class was converted into external shape file (*.shp) and the external image was compared with the original flood map.

The extracted flood map from overlaying the original and potential flood maps had been analyzed and it was noticed that the no flooding area (class 1) did not exist in the original flood map. **Table 5** summarizes the overlayed result for the other classes (class 2 - 4). The total of area of original flood map was 66742705.182035 m^2 (66.742 km^2). Around 90% of the original flood area was covered by the class 4 and 3 which indicate the high flood potential area and moderate flood potential area. The remaining areas were covered in class 2 as shown in **Figure 8**.

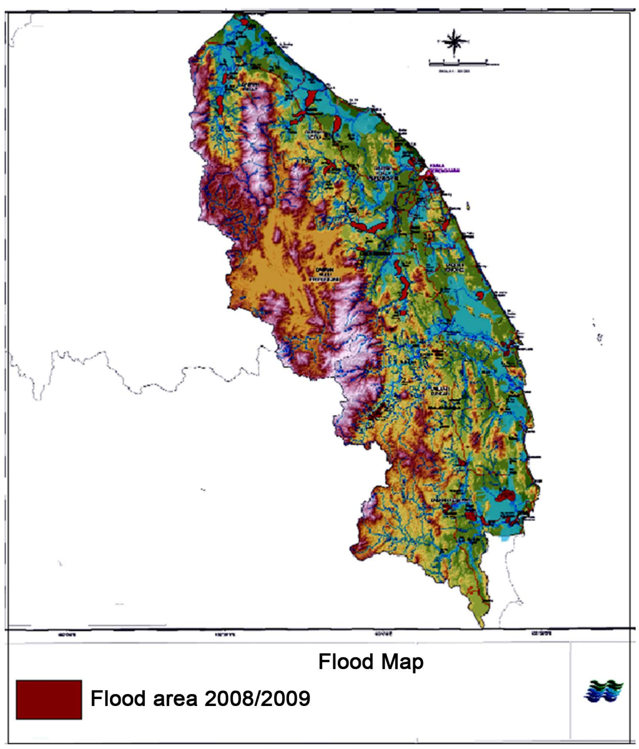

Figure 7. The original flood (DID, 2009).

Table 5. Overlayed from features.

Potential Flood Layers Class	Common Overlaid Area (M^2)	% Within Original Flood Area
2	6830837.9	**10.35**
3	38047426.99	**57.94**
4	20866752.92	**31.61**

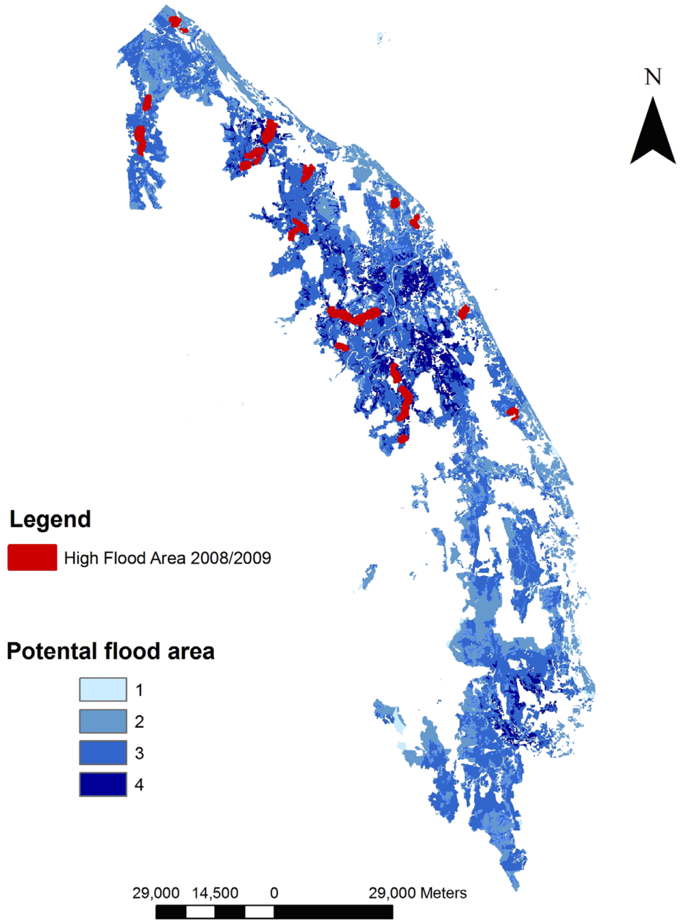

Figure 8. Original flood areas 2008/2009 overlayed with potential flood areas.

4. Conclusion

The study area (presented with the darkest area, as shown in **Figure 6**) was the high potential area for flood. However, the potentiality of flood decreased as the areas became lighter. Further validation was done to ensure the result. This result could be a valuable tool for assessing flood risk. The study also reviewed the role of GIS in decision-making and then outlined the evaluation approach for many criteria in decision process.

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