Maximum Flood Prone Area Mapping using RADARSAT Images and GIS: Kelantan River Basin

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Abstract

This paper summarizes the findings of the maximum flood prone area mapping at Kelantan river basin, Malaysia, using multiple logistic regression model with the aid of GIS tools and remote sensing data. To map the maximum flood prone areas, at first the flood extent areas were extracted from RADARSAT 1 images and supported with ground data, existing reports and field notes. To evaluate the factors associated with flood prone areas, a spatial database was constructed from a topographical map, geological map, hydrological map, Global Positioning System (GPS) data, land cover map, SPOT 5 satellite image, digital elevation model (DEM), and precipitation data. Nine major parameters were extracted for the logistic regression analysis to determine each factor's rating, and the ratings were computed for flood prone area mapping analysis. Results indicate that flood prone area mapping which can be termed as susceptibility map can be performed at 1:25,000 which is comparable to some conventional medium scaled flood hazard map. The flood prone areas delineated on these map correspond to areas that would be inundated by significant flooding (approximately the 100 year flood). Qualitatively, the model seems to give reasonable results with accuracy observed was 84%.

1. Introduction

Floods are among the most frequent and costly natural disasters in terms of human and economic loss. As much as 90 percent of the damage related to natural disasters in Malaysia is caused by flood (Chan, 1995). According to Malaysian Department of Irrigation and Drainage, it has been estimated that more than 2.7 million people live in flood prone areas while the average annual flood damages have been estimated to be within the range of RM 200 to RM 300 million per year. These flooding have caused considerable damages to highways, settlements, agriculture and livelihood. In Malaysia, floods are caused by a combination of natural and human factors. Malaysians are historically river dwellers as early settlements grew on the banks of the major rivers in the peninsula. Coupled with natural factors such as heavy monsoon rainfall, intense convection rain storms, poor drainage and other local factors, floods have become a common feature in the lives of a significant number of Malaysians. Monsoon rains have a profound influence on many aspects of the lives of the people in the east coast of Peninsular Malaysia (Chan, 1995). While the rains are needed for agriculture, particularly wet rice cultivation, they are also largely responsible for bringing seasonal monsoon. Recently, accordingly to the local news paper reports (The Star) in the year 2006, 2007, 2008 and 2009 heavy monsoons rainfall have triggered floods along Malaysia's east coast as well as in southern state of Johor. The hardest hit areas are along the east coast of peninsular Malaysia in the states of Kelantan, Terengganu and Pahang. The flood cost nearly billion Ringgit of property and many lives. According to the daily news paper Utusan Malaysia dated on 27 February 2006, the flood occurred at Shah Alam on 26 February 2006 where water inundated 4000 houses and 1240 people have been evacuated to relief centers. Recently, the state news agency (Bernama, 2009) have reported that some 2,514 people have been evacuated after flooding in central and northern Malaysia causing nearly RM 300 Million property loss. The extent of damage could have been reduced or minimized if an early warning system would have been in place. Using GIS as the basic analysis tool for flood susceptibility mapping can be effective for spatial and data management and manipulation, together with some reasonable models for the analysis. In this regards, there have been many studies of flood susceptibility mapping using remote sensing data and GIS tools. Dewan and others (2006a) summarized many flood

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susceptibility studies. Also, recently there have been studies for flood susceptibility evaluation using GIS and many of their studies have used Radar remote sensing data using probabilistic methods (Hess et al., 1995, Hess et al., 1990, Dewan and Yamaguchi 2008b, Dewan et al., 2007a, Dewan et al., 2007b, Dewan et al., 2006b, Le Toan et al., 1997, Landau et al., 2000, Farajzadeh, 2001, 2002 and Horritt and Bates, 2002). Logistic regression model has also been applied to other natural hazard modeling such as landslide susceptibility mapping (Atkinson and Massari 1998, Pradhan et al., 2008 and Lee and Pradhan, 2007). Hydrological and stochastic rainfall methods for flood susceptibility mapping have been employed in other areas (Blazkova and Beven, 1997, Cunderlik and Burn, 2002, Ebisemiju, 1986, Haeng et al., 2001, Nageshwar and Bhagabat, 1997, Yakoo et al., 2001 and Villiers, 1986). Flood susceptibility mapping using GIS and neural network methods have been applied in various case studies (Honda et al., 1997, Islam and Sadu, 2001, 2002, Sanyal and Lu, 2004, 2005, Townsend and Walsh, 2005, Wadge et al., 1993, Tambunan, 2007, Profeti and Machintosh, 1997, Knebl et al., 2005, Masmoudi and Habajeb, 1993, Sinnakaudan et al., 2003, Merwade et al., 2008 and Zerger, 2002). The difference in this study is the application of GIS-based multiple logistic regression method to flood prone area mapping in the Malaysia situation. In this paper, remote sensing data coupling with other tabular and meta data were used to delineate the flood susceptibility mapping for the part of the Kelantan river basin. Terrain information such as historical flooded areas extracted from RADARSAT images, DEM, slope, aspect, curvature, distance from drainage, flow direction, flow accumulation, soil, land cover, soil texture, and precipitation information have been updated to enable the quantification of flood associated attributes. Flood susceptibility mapping has been performed using multiple logistic regression model in SPSS software.

2. Study Area

The study (Figure 1) area is part of Kelantan state which is one of the 13 states of Malaysia. The Kelantan River emerges at the confluence of the Galas River and Lebir River near Kuala Krai and meanders over the coastal plain until it finally debauches into the South China Sea, about 12 kilometres north of Kota Bahru. The main reach of the Kelantan River has some further larger tributaries downstream. However, the Galas and the Lebir rivers themselves have many tributaries, which provide the majority of the flow in the main Kelantan River. These tributaries rise in the forested mountains of peninsular Malaysia. Four major towns are located on the river: Kota Bharu, Pasir Mas, Tumpat, and Kuala Krai. Kota Bharu is the main city and centre of commercial trade and administration in the Kelantan state.

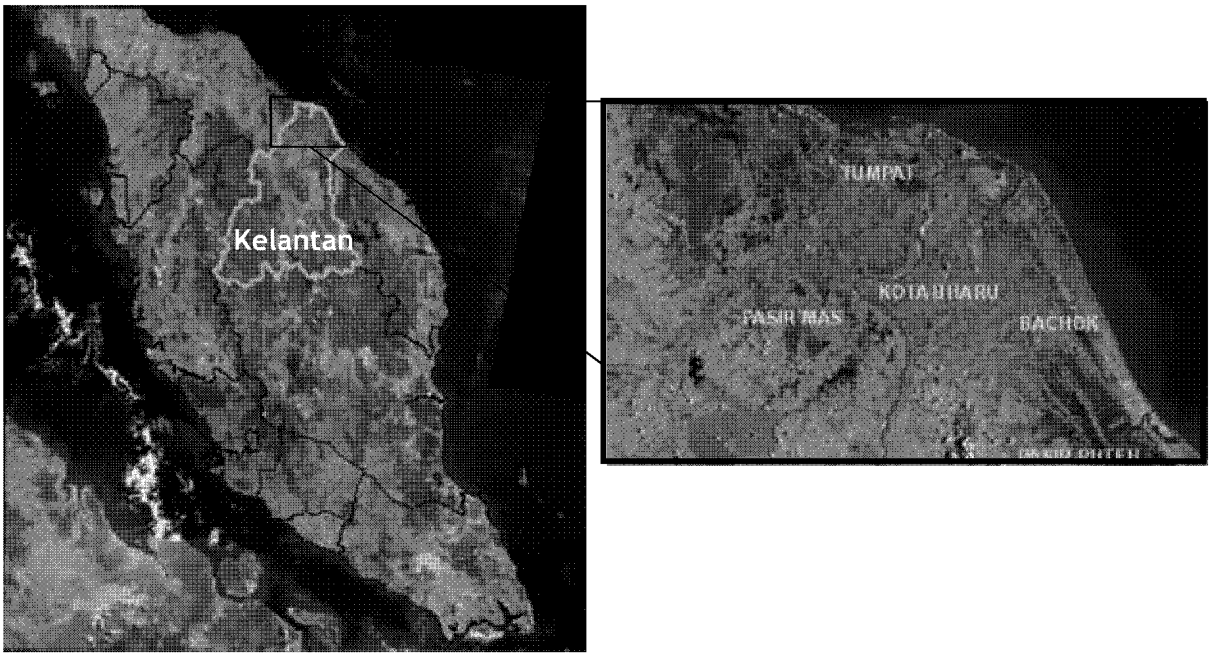


Figure 1: Study area and Kelantan river basin

Its ideal geographical location also makes it a gateway to the neighboring countries of southern Thailand, and is thus a city with high tourism potential for domestic and foreign tourists who visit year-around. Due to its geographical characteristics; unplanned urbanization; and proximity to the South China sea, Kota Bharu has become extremely vulnerable to monsoon floods every year. With its population density and as a commercial centre, the city has characteristics that can magnify the impact of flooding to which it is prone. The Kelantan river regularly floods during the months of November to February, due to the north-eastern monsoon. These flooding problems have given rise to the need for an efficient, cost-effective solution to flood forecasting and warning in the basin. Based on the reports from Malaysian Meteorological Department (MMD), the annual rainfall is very high averaging between 2,500 mm to 3,500 mm per year (Mardiana et al., 2000). Two pronounced wet seasons from September to December and February to May. Rainfall peaks between November to December and March to May. Peninsular Malaysia experiences a hot, wet humid equatorial climate regime in which the most distinguishing feature is its heavy year round rainfall ranging from 1,500mm to more than 3,500mm annually. More significant, however, is the occurrence of sustained heavy rain spells (sometimes for several weeks) during the monsoon season, from which a total rainfall of 610mm within a matter of 24 hours is not uncommon. The seasonal floods in the East Coast are therefore a natural consequence of these heavy rains occurring over a short period of time. During these north-east monsoon months, a monthly rainfall total of 500mm is not uncommon. According to the reports of department of irrigation and drainage, the soil cover varies between 1 to 18 meters (Mardiana et al., 2000). A fine sandy loam soil is found in the extreme east and west of the southern half of the basin. Its depth seldom exceeds a few meters. The remaining portion, comprising almost one-third of the catchment, is cloaked by a variable soil cover that varies in depth, from a few meters to more than 9 meter. The cultivation is relatively good, limited to the plains only. From a hydrological point of view, the Kelantan River Basin is made up of flat slope and moderately sloping areas. There are large level plains on the southern side and also in the south west. The steep scraps and the high slopes in the southern part of the river basin can be contributed to the major run-off zone to the Kelantan river. The drainage of the area shows a dendritic pattern in most part of the region.

3. Data and Materials

To apply the multiple logistic regression model, a spatial database that considers flood-related factors should be first designed and constructed (Townsends and Walsh, 1998). Some studies indicate that various factors are effective in the flood susceptibility mapping. Slope gradient, basin shape, aspect, curvature, geological conditions, rainfall regime, vegetation cover are some of the factors that control runoff volume (Wadge et al., 1993). Some of these data were available in Malaysia either as paper or as digital maps. The list of remote sensing data and the thematic layers used in the analysis is shown in Table 1 and Table 2 respectively.

Table 1: List of remotely sensed data used in the analysis

Type of Images	Sensors/Model	Acquisition Date	Flood Situation	Resolution (meter)
RADARSAT	Standard 6	8 August 2004	Before Flood	25
	Extended High 6	11 December 2004	During Flood	25
	Extended High 3	03 December 2003	Before Flood	25
	Wide 2	06 December 2003	During Flood	30
	Extended High 4	10 December 2003	During Flood	25
	Extended High 6	17 December 2003	During Flood	25
	Wide 2	21 December 2003	After Flood	30
	Standard 1	18 December 1998	During Flood	25
	Standard 7	22 December 1998	During Flood	25
	Wide 2	23 December 1998	During Flood	30
	Standard 2	25 December 1998	During Flood	25
	Extended High 3	29 December 1998	During Flood	25
SPOT 5		4 September 2004	Before	20

Table 2: Thematic data layers used in the analysis

Classification	Sub-Classification	GIS Data Type	Scale
Historical flooded areas	**Flood extent**	**Polygon coverage (Derived from RADARSAT images)**	**10 m x 10m**
Basic Map	Topographic Map (DEM)	Line and Point coverage	1:25,000
	Slope	GRID	10 m x 10m
	Curvature	GRID	10 m x 10m
	Flow direction	GRID	10 m x 10m
	Flow accumulation	GRID	10 m x 10m
	Land Cover	GRID	10 m x 10m
	Soil (1:63,360)	GRID	10 m x 10m
	Precipitation	GRID	10m×10m

In this study, there were nine factors (slope, DEM, curvature, flow direction, flow accumulation, distance from drainage, landcover, soil and precipitation), considered in calculating the probability, and the factors were extracted from the constructed spatial database. The factors were transformed into a grid spatial database, and flood-related factors were extracted using the database. A key assumption using the multiple logistic regression approach is that the potential (inundated areas due to future flood) of future flooding areas will be comparable to the actual frequency and extent of previous historical floods. Historical flooded areas were detected from RADARSAT images of the year 1998, 2003 and 2004. A historical flooded map was prepared from RADARSAT images coupling with the field data and existing reports, in combination with the GIS, and this were used to evaluate the frequency and extent of future floods in the area. The detail of the RADATSAT data used in this study is shown in Table 1. Topography and lithology databases were constructed and lineament, land cover, vegetation index value extracted from SPOT 5 satellite image and precipitation distribution from the meteorological data for the analysis. Then, the calculated and extracted factors were converted to a 10m × 10m grid (ARC/INFO GRID type). Statistical based multiple logistic regressions were applied using the database. Further the spatial relationships between the historic flooded areas and each flood-related factor were analyzed. Using the logistic regression model, the relationship was used as each factor's rating in the overlay analysis and a formula of flood extent possibility was extracted using the relationships. This formula as shown in Equation 6 was used to calculate the flood susceptibility index and the index was mapped to represent flood prone areas. Finally, the map was verified and compared using known 2007 flood extent and success rates and ratio areas were calculated for quantitative validation. In the study, Geographic Information System (GIS) software, ArcGIS 9.2 version; Erdas Imagine 9.1 package and SPSS 12.0 statistical program were used as the basic analysis tools for spatial management and data manipulation. Most of the thematic GIS data layers have been prepared in ArcGIS 9.2 while the satellite images such as RADARSAT and SPOT 5 were processed in ERDAS Imagine 9.1. In addition, the multiple regression model was performed using the SPSS 12.0 statistical package.

3.1 Flood Water Extraction from RADARSAT Images

"Before_flood" and "after_flood" RADARSAT images were acquired for wide-area flood extent mapping (Table 1). The water body extraction from RADARSAT images during flood includes the normal water extent including water filled paddy fields and the mountain shadow extent. RADARSAT images contain shadows; therefore, these shadows must be extracted from the image in the very first step. Shadow(s) occur in radar images due to the side looking geometry of the radar sensor. These shadow areas normally occur at the mountainous areas and give low or no backscatter. They appear as dark patches or spots in the image and pose a problem for water information extraction as they share the same dynamic range with water digital number in radar image. Therefore, shadow extraction using DEM simulation and visual interpretation was performed to reduce the effect of shadows. More focus was given at the southern part of study area as there were more changes on landform which can cause shadow occurrence. The results are shown in Figure 3. After shadow extraction, the mountain area delineation was performed using visual interpretation to get a mask for shadow reduction. Water extent extraction of RADARSAT image was carried out using the threshold method.

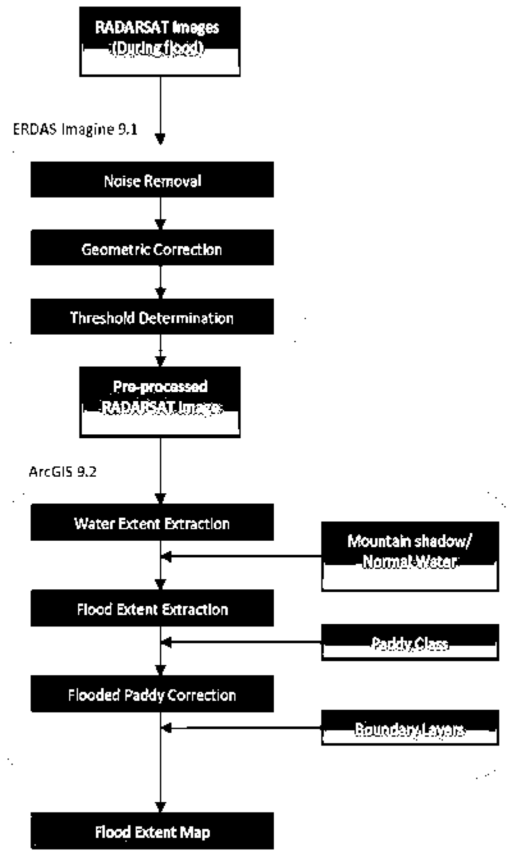


Figure 2: Flow chart for the extraction of flood extent from RADARSAT images

The geometrically corrected SAR image is used to perform the spectrum analysis in order to determine the threshold value of the water. The threshold value can be identified and verified using the spatial profile display function of ERDAS Imagine 9.1 software. There are two different regions, i.e. the low grey values region is just water bodies, while the high grey values region is non-water bodies. Therefore, the threshold value for water is easily identified by visual interpretation. The threshold was determined using the logical Equation 1 and 2.

$$If\ DN_{value} < K = "Water"$$

Equation 1

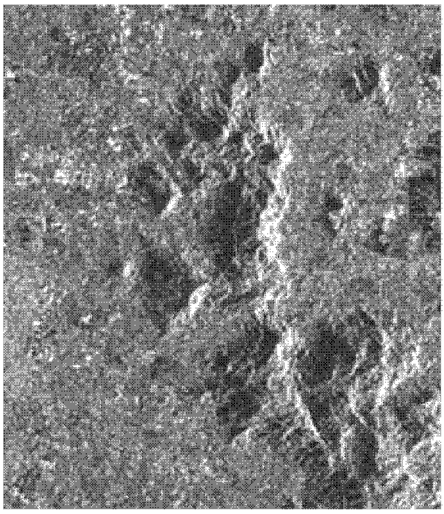
$$If\ DN_{value} \geq K = "Non-water"$$

Equation 2

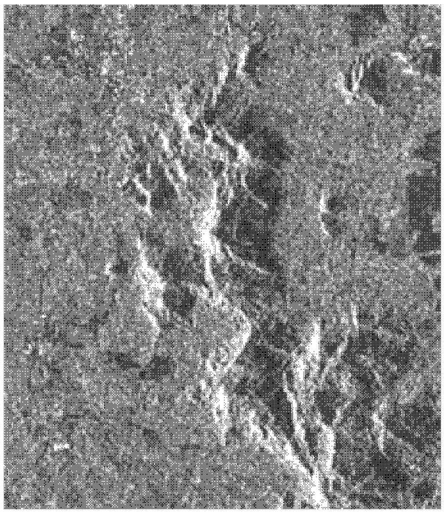
Where, DN_{value} represents gray values in RADARSAT images and K is threshold values. A flood extent extraction model was developed in ArcGIS 9.2 to extract the maximum extent of the historical floods from RADARSAT images. Water body extraction from RADARSAT images during flood includes the normal water extent, water filled paddy fields and the mountain shadow extent. To produce pure flood extent, the normal water extent, non flooded paddy field and shadow were removed; while the flooded paddy field were incorporated to the model to avoid underestimating of flood impact. Hence, the flood Extent modeling approach was involved three separate modeling processes: normal water extraction; flooded area extraction; and flooded paddy area extraction. Figure 2 shows the methodology adopted for flooded area extraction from RADARSAT images in Erdas Imagine 9.1 and ArcGIS 9.2. After performing the accuracy assessment, it was found that the overall accuracy is 91.18% with a Kappa coefficient of 0.8663.

3.2 DEM and Thematic Layer Preparation

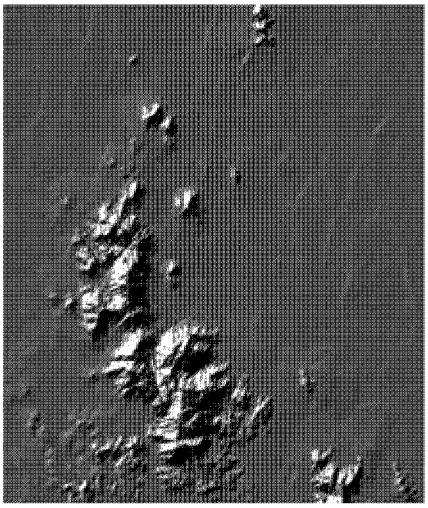
A digital elevation model (DEM) was created first using the digital topographic database provided by National Mapping Agency (JUPEM). Contour and survey base points that had elevation values from the 1:25,000-scale topographic maps were extracted, and a DEM was constructed with a resolution of 10 meter. A total of 3,192 spot height points/benchmark points and 65,535 contour lines were extracted from digital topographic map (Source: JUPEM, Malaysia) for the generation of DEM over the Kelantan river basin. Additionally, about 720 ground control points (GCPs) were collected from ground survey and field observation (Sonar survey, DGPS and GPS survey). These GCPs points were used to validate and edit the Triangulated Irregular Network (TIN) which was derived from digital contour information. The accuracy of DEM was accessed using 123 Benchmark check points and 400 Differential Global Positioning System (DGPS) points. The accuracy assessment results show that the average error, root mean square error (RMSE), standard mean and standard devation values -2.122052, 1.065381, 0.542730 and 1.329019 respectively. Using this DEM, the slope angle, slope aspect, and slope curvature were calculated. In the case of the curvature negative curvatures represent concave, zero curvature represent flat and positive curvatures represents convex respectively. The curvature map was produced using the ESRI routine in Arc View. In addition; the distance from drainage was calculated using the topographic database. The drainage buffer was calculated in 1m intervals. The soil map was obtained from a 1:63,360-scale soil map (Source: Department of Agriculture, Malaysia). Land cover data was classified using a SPOT 5 image employing an unsupervised classification method and topographic map.



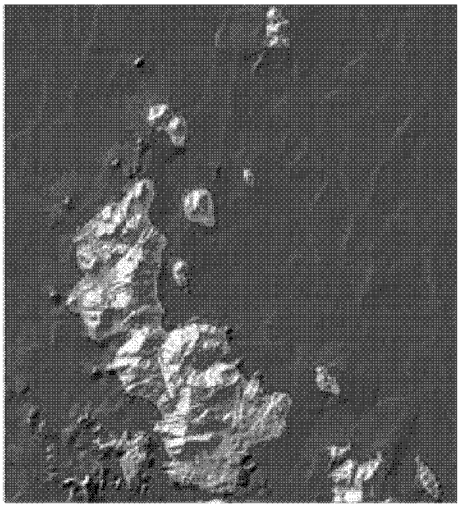
a) Before flood RADARSAT scene



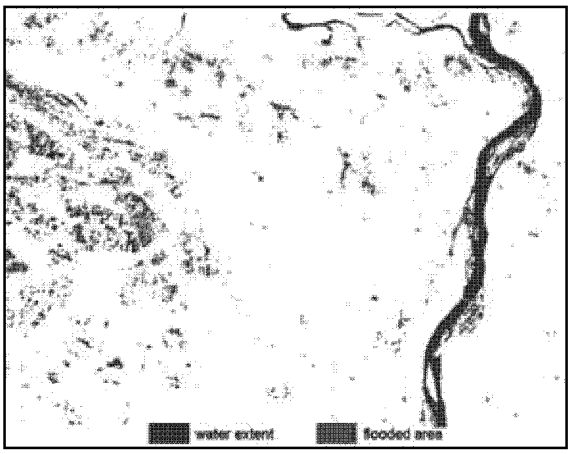
(b) After flood RADARSAT scene



(c) Mountain area in shaded relief



(d) Digitized mountain area



(e) Classification result shows the water extent and flooded areas

Figure 3: (a), (b) A zoom-in for the study area, blue as the shadow extracted while red is the remaining water body/shadow; (c), (d): Delineation of mountain overlaid with the shaded relief image; and (e) Classification results showing water extent and flooded areas

Table 3: Coefficients of logistic regression to flooded areas

Factor	Class	Coefficients of logistic regression
Slope	0° ~5° 6°~ 11° 12° ~17° 18° ~ 22° 23° ~ 28° 29° ~34° 35° ~ 39° 40° ~ 45° 46° ~ 51°	-0.00179
DEM	0.053 ~ 95.603m 95.603 ~ 191.153m 191.153 ~ 286.702m 286.702 ~ 860m	-0.00080
Curvature	Concave Flat Convex	-0.00562
Flow direction	North Northeast East Southeast South Southwest West Northwest	-0.0440 -0.0482 -0.1293 0.0036 0.0164 -0.0209 -0.0270 0.0000
Flow accumulation	0 ~370611 370612 ~741223 741224 ~ 1111835 1111836 ~ 1482447 1482448 ~ 1853058 1853059 ~ 2223670 2223670 ~ 2594282 2594283 ~ 2964894 2964895 ~ 3335506	0.00001
Distance from drainage	0-90m 91 ~195m 196 ~ 315m 316 ~ 447m 448 ~ 597m 598 ~ 774m 775 ~ 992m 993 ~ 1294m 1295 ~ 1851m 1852 ~8441m	-0.00002
Soil	BATANG MERBAU BATU HITAM BUNGOR CHERANG DURIAN HOLYROOD LUBOK MELAKA MINED LAND PEAT RENGAM-BUKIT RENGAM-JERANGA RUDUA-RUSILA SERDANG STEEPLAND TELEMONG TOKYONG URBAN LAND	-0.298 -0.610 -0.532 -0.091 -0.249 -0.184 -0.090 -0.115 -0.194 -1.301 -0.634 -0.812 -0.948 -15.374 -0.711 0.000 0.000
Land cover	Coconut Forest Lake Mangrove Mixed Horticulture Oil palm Paddy River Rubber Urban	1.43369 1.11290 0.0000 2.53387 1.19862 -17.73256 2.17407 0.13271 -0.48275 -3.20529
Precipitation	138- 163cm 164 ~188cm 189 ~ 214cm 215 ~ 239cm 240 ~ 264cm 265 ~ 290cm 291 ~ 315cm 316 ~ 340cm 341 ~ 366cm	0.00537

The land cover map has been classified into nine classes, such as Forest, Lake, Mangrove, Mixed Horticulture, Oil palm, Paddy, River, Rubber and urban areas were extracted for land cover mapping. Finally, precipitation data was interpolated using the meteorological station data for entire study area over last 20 years. Then the correlation between the historical flood extent and precipitation data was computed. The factors were converted to a raster grid with 10 m × 10 m cells for application of the logistic regression model. Figure 4 shows the list of input GIS data layers.

4. Flood Susceptibility Analysis using Logistic Regression Model

Logistic regression allows one to form a multivariate regression relation between a dependent variable and several independent variables. Logistic regression, which is one of the multivariate analysis models, is useful for predicting the presence or absence of a characteristic or outcome based on values of a set of predictor variables. The advantage of logistic regression is that, through the addition of an appropriate link function to the usual linear regression model, the variables may be either continuous or discrete, or any combination of both types and they do not necessarily have normal distributions. In the case of multi-regression analysis, the factors must be numerical, and in the case of a similar statistical model, discriminant analysis, the variables must have a normal distribution. In the present situation, the dependent variable is a binary variable representing presence or absence of flood. Where the dependent variable is binary, the logistic link function is applicable (Atkinson and Massari, 1998). For this study, the dependent variable must be input as either 0 or 1, so the model applies well to flood susceptibility analysis. Logistic regression coefficients can be used to estimate ratios for each of the independent variables in the model. Quantitatively, the relationship between the occurrence and its dependency on several variables can be expressed as:

$$p = {}^{1}\!/_{(1+e^{-z})}$$

Equation 3

Where, p is the probability of an event occurring. In the present situation, the value p is the estimated probability of flooded areas. The probability varies from 0 to 1 on an S-shaped curve and z is the linear combination. It follows that logistic regression involves fitting an equation of the following form to the data:

$$z = b_0 + b_1x_1 + b_2x_2 + \ldots\ldots + b_nx_n$$

Equation 4

Where b_0 is the intercept of the model, the b_i $(i = 0, 1, 2, \cdots\cdots, n)$ are the slope coefficients of the logistic regression model, and the x_i $(i = 0, 1, 2, \cdots\cdots, n)$ are the independent variables. The linear model formed is then a logistic regression of presence or absence of flooded areas (present conditions) on the independent variables (pre-failure conditions). Using the logistic regression model, the spatial relationship between flood-occurrence and factors influencing flooded areas were assessed. The spatial databases of each factor were converted to ASCII format files for use in the statistical package, and the correlations between flooded areas and each parameter were calculated. There are two cases. In the first case, only one factor was used. In this case, logistic regression mathematical equations were formulated for each case. The coefficient is shown in Table 3. Finally, the probability that predicts the possibility of flooded-areas was calculated using the spatial database, data from Table 3, equations (3) and (4). In the second case, all factors were used. In this case, logistic regression mathematical equations were formulated as shown in equations (4) and (5) for each case. The coefficient is shown in Table 2.

$$z_n = (-0.00179 * SLOPE * 10000) + (-0.00562 * CURVATURE * 10000) + (0.00537 * PRECIPITATION * 10000) + (-0.00002 * DRAINAGE * 10000) + (-0.00080 * DEM * 10000) + (0.00001 * FLOW\ ACCUMULATION * 10000) + FLOW\ DIRECTIONc + LANDCOVERc + SOILc\ 3.98050$$

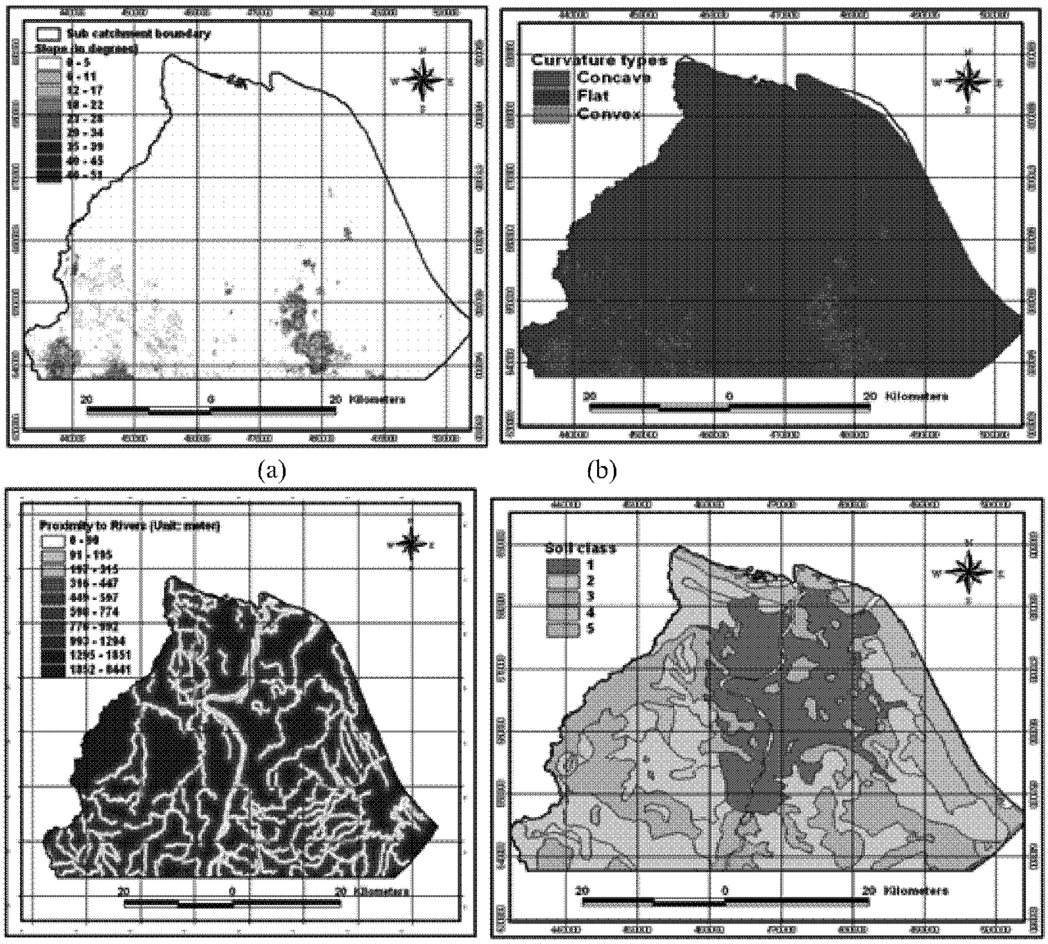
Equation 5

(Where *SLOPE* is slope value; *CURVATURE* is curvature value; *PRECIPITATION* is PRECIPITATION value; *DRAINAGE* is distance from drainage value; *DEM* is elevation value; *FLOW ACCUMULATION* is flow accumulation value and $FLOW\ DIRECTION_c$, $LANDCOVER_c$ and $SOIL_c$ are logistic regression coefficient value listed in Table 3 and z_n is a parameter).Using formula (3) and (4), the possibility of flooded areas was calculated.

$$\text{Flood prone areas (Susceptibility index)} = \exp(z) / (1 + \exp(z))$$

Equation 6

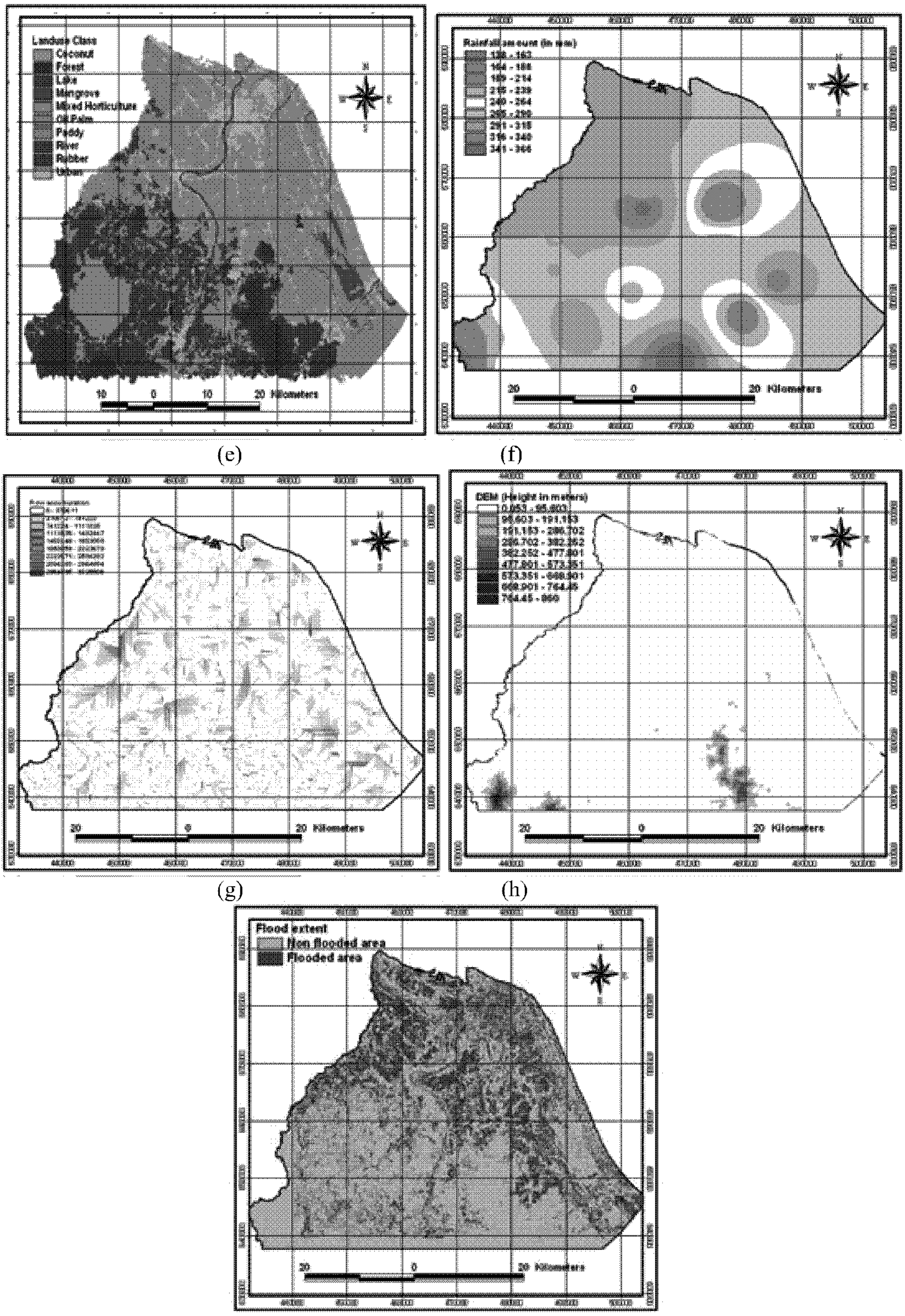
Figure 5 shows the flood susceptibility map produced by using the Equation (6).



(a) (b)

(c) (d)

Figure 4: Input data layers (next page)



(e) (f)

(g) (h)

(i)

Figure 4: Input data layers (a) Slope; (b) Curvature; (c) Distance from drainage; (d) Soil; (e) Land cover; (f) Precipitation amount; (g) Flow accumulation amount; (h) DEM and (i) Historical flood extent derived from RADARSAT images

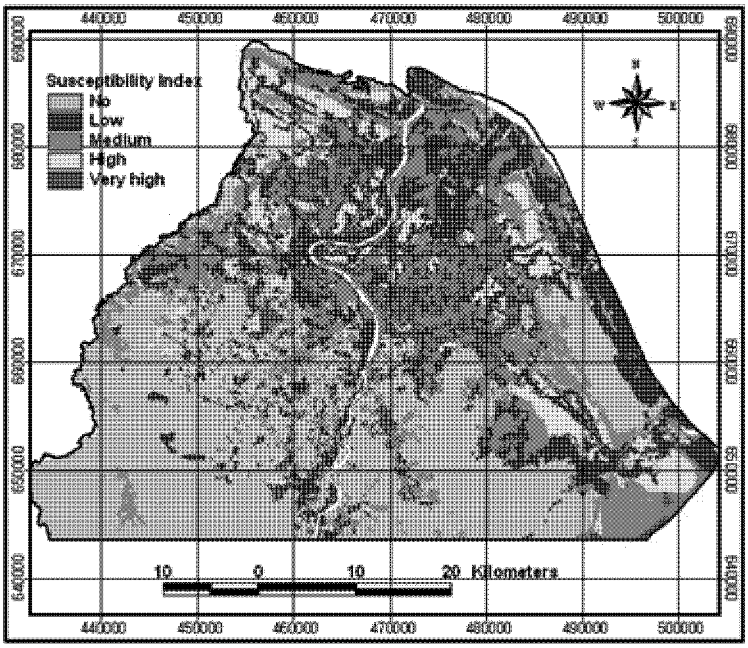


Figure 5: Flood susceptibility map based on logistic regression model

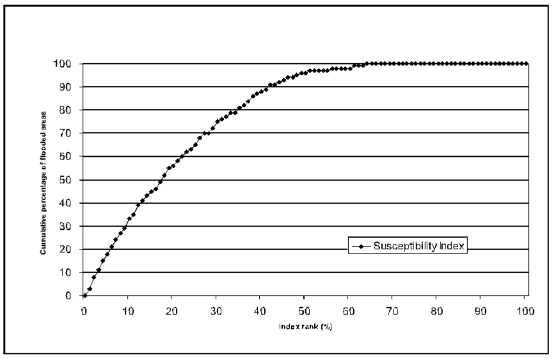


Figure 6: Cumulative frequency diagram showing flood susceptibility index rank occurring in cumulative percent of flooded areas

5. Verification of the Model

For validation of flood susceptibility models, two basic assumptions are needed. One is that flooded areas are related to spatial information such as topography, soil, flow direction, flow accumulation and land cover, 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 susceptibility analysis result was validated using known extent of flooded areas from 2007. Validation was performed by comparing the known flood extent data with the flood susceptibility map. Each factor used and logistic regression values was compared. The rate curves were created and its areas of the under curve were calculated for all cases. The rate explains how well the model and factor predict the flooded areas. So, the area under curve can assess the prediction accuracy qualitatively. To obtain the relative ranks for each prediction pattern, the calculated index values of all cells in the study area were sorted in descending order. Then the ordered cell values were divided into 100 classes, with accumulated 1% intervals. The rate verification results appear as a line in Figure 6. For example, in the case of logistic regression model used, 90 to 100% (10%) class of the study area where the flood susceptibility index had a higher rank could explain 61% of all the flooded areas. In addition, the 80 to 100% (20%) class of the study area where the flood susceptibility index had a higher rank could explain 82% of the flooded areas. To compare the result quantitative, the areas under the curve were re-calculated as the total area is 1 which means perfect prediction accuracy. So, the area under a curve can be used to assess the prediction accuracy qualitatively. In the case of logistic regression model used, the area ratio was 0.8476 and we could say the prediction accuracy is 84.76%.

6. Discussions and Conclusion

In the present study, logistic regression model were applied for the flood susceptibility mapping for part of Kelantan river basin. In this research, a statistical approach to estimating the susceptible flow-flood area using remote sensing technique and the GIS was performed. For the flood susceptibility analysis, the detected historical flooded areas and the flood related database were constructed for Kelantan river basin. Using the constructed database, flood susceptibility analysis was performed using logistic regression model. It is remarked that the probability method is somewhat simplistic, and the process of input, calculation and output could be understood easily. Moreover, there is only a simple conversion of database from GIS to ASCII is required, as the large amount of data can be processed in the GIS environment quickly and easily. The logistic regression model is simple; the process of input, calculation and output can be readily understood. The large amount of data can be processed in the GIS environment quickly and easily. The logistic regression model requires conversion of the data to ASCII or other formats for use in the statistical package, and later re-conversion to incorporate it into the GIS database. Moreover, it is hard to process the large amount of data in the statistical package. In the case of a similar statistical model (discriminant analysis), the factors must have a normal distribution, and in the case of multi-regression analysis, the factors must be numerical. However, for logistical regression, the dependent variable must be input as 0 or 1, therefore the model applies well to flood susceptibility analysis. Using the parameters used this research; probability method was applied to analyze the flood susceptibility analysis. The analyzed results were used to reconstruct the classified grid database, then to flood susceptibility map. The flood susceptibility map might be of great help to planners and engineers for choosing suitable locations to implement developments in Kelantan river basin. Besides, the flood susceptibility map shows five classes of susceptibility index as very high, high, medium, low, and no susceptibility index was also illustrated in Figure 5. It was noted that the city of Kota Bharu is falling under a medium- high susceptibility index. In general, the middle part of Kelantan river basin and its adjacent banks had very high to high flood susceptibility whereas the lower downstream part of the stream had very low flood susceptibility. Whereas the western and northern steep-cliff areas had a high to medium flood susceptibility whereas the main other parts else of the sub-basin have in general very low flood susceptibility. Recently, flood susceptibility mapping has shown a great deal of importance for suitable urban developments. The results shown in this paper can help the developers, planners and engineers for slope management and land-use planning. However, one must be careful while using the models for specific site development. This is because of the scale of the analysis where other causative factors need to be considered. Therefore, the models used in the study are valid of generalized planning and assessment purposes.

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