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LANDSLIDE SUSCEPTIBILITY MAPPING AT LEBIR AND GALAS RIVER BASINS AFTER EXTREME FLOOD EVENT USING WEIGHTS OF EVIDENCE

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Abstract: Landslides are natural disasters that cause a significant negative impact on the loss of life, property, infrastructure, organization, industry and the environment. Continuous and heavy precipitation triggered a large landslide at the Lebir and Galas River basins on end of the year 2014. The landslide debris rapidly turned into a high volume debris flow that was deposited into the river which may cause serious damage to the nearby infrastructures. The purpose of this study is to develop a landslide inventory map, to identify the critical and prone area and to produce a landslide susceptibility map for the Lebir and Galas River Basin after an extreme flood event on 2014. Landslides area was identified from aerial photograph interpretation, SPOT 5 Satellite Images and extensive field studies. Ten factors were used to generate landslide susceptibility map, including slope, aspect, geology (lithology), land use, precipitation, distance to drainage, distance to road, distance to fault, soil depth, and Normalized Difference Vegetation Index (NDVI). The landslides conditioning factors were mapped into ArcGIS, converted from vector to raster maps and analysed using Weights of Evidence (WOE) method. The importance of each factor was indicated by weight, Wi+ where positive Wi+ indicates the factor is favourable for the occurrence of landslides and vice versa. The result shows that distance to fault acquired the highest weight among other parameters (2.255814) followed by land use (1.031512) and geology (0.847892). The combination of 10 factors layer with a landslide inventory produced landslide susceptibility map.

KEYWORDS: landslide, debris flow, susceptibility, GIS, weight-of-evidence

Introduction

The flood brought more damage to people and the environment. Grieving the loss of lives and properties are undeniable, but we often take for granted the damage to the banks of the river due to erosion during heavy current flow. In December 2014, major floods have hit Kelantan and cause the most devastating damage to the state (Figure 1). Severe damage can be seen on the banks of the river due to erosion from flooding (Figure 2). Erosion occurs naturally, along with the riverbank when a powerful action of adjacent moving water. Based on Pimentel *et al.* (1995), when the flow of the river through the bank with steep slopes (30% or more), the loss of soil due to erosion is increasing. Even on a relatively flat land condition with only 2% slope, river banks are eroded primarily during heavy rain and flooding.

Landslides are one of the natural disasters that change the morphology and the shape of the earth's surface. It leads to property destructions, property damage and loss of life. Therefore, hilly steep and mountainous areas have been referred to landslides in order to mitigate in advance any possible damage caused by them. There are a few definitions about landslide hazards and one of them stated that it only considered as hazardous when they threaten mankind (Lee & Pradhan, 2006). Besides that, the probability of occurrence of a potentially damaging landslide phenomenon within a given period of time and a given area is a definition of the landslide hazards proposed by Mezughi *et al.* (2011). Preparation of landslide inventory and landslide susceptibility is very important in the management of landslide hazards; observation of landslide along the road including steep hills has been subjected to identify potential areas that have the possibility for a landslide to occur (Mezughi *et al.,* 2011).

A Landslide can be concluded as a rapid displacement of rock, residual soil or sediments adjoining a slope and contour gravity of moving the mass advance in a downward and outward direction (Terzahi, 1950). The movement of the mass of rock, debris or earth down a slope whose experienced gravity in various ways, including of flowing, sliding, toppling or falling (Guzzetti *et al.,* 2012). Many landslides occurred involving the combination of two or more types of movements. Most of the landslides occur was at cut slopes or embankments alongside roads and highways in mountainous areas. It is also occurring near high-rise apartments and in residential areas that may cause death to humans (Lee & Pradhan, 2007). Previous studies show that Southeast Asia experienced seasonal dry periods, excessive rainfall intensities, steep hill slopes and unstable soils which may cause landslides. Due to the nature of the topography, Shahabi and Hashim (2015) choose Cameron Highlands, Malaysia which has a rough area of geomorphology and moderate climatology category. They found that 66% of the slope gradients are more than 20° which has the possibility of erosion and landslide to occur.

Table 1.1 shows the previous landslide occurred in Malaysia from the year 1961 till the year 2015; as we can see that there is a repeating event for Cameron Highlands. The landslide had caused huge economic loss and large numbers of causalities especially in hilly and mountainous areas in Malaysia (Jamaludin & Hussein, 2006).

Table 1.1: Landslides historical data in Malaysia (1961 - 2015).

Year	Place/State	Year	Place/State
1961	Cameron Highlands, Pahang	2008	Cameron Highlands, Pahang
1993	Pantai Remis, Perak	2008	Kajang, Selangor
1993	Highland Tower, Ulu Klang	2008	Petaling Jaya, Selangor
1995	Genting Highlands, Pahang	2008	Terubong Jaya, Penang
1996	Gua Tempurung, Perak	2008	Kuala Kubu Baru, Selangor
1996	Pos Dipang, Perak	2008	Jalan Semantan, Kuala Lumpur
1999	Ulu Klang, Selangor	2008	Ulu Klang, Selangor
2002	Ulu Klang, Selangor	2011	Hulu Langat, Selangor
2003	Bukit Lanjan, Selangor	2011	Jalan Bukara, Sandakan Sabah
2006	Ulu Klang, Selangor	2012	Bukit Setiawangsa, Kuala Lumpur
2007	Kapit, Sarawak	2013	Jalan Penampang-Tambunan, Sabah
1995	Genting Highlands, Pahang	2013	Ukay Perdana, Kuala Lumpur
1996	Gua Tempurung, Perak	2014	W.P.Labuan
1996	Pos Dipang, Perak	2014	Bukit Beruntung, Selangor
1999	Ulu Klang, Selangor	2014	Cameron Highlands, Pahang
2002	Ulu Klang, Selangor	2015	Hulu Selangor, Selangor
2003	Bukit Lanjan, Selangor	2015	Taman Yew Lai
2006	Ulu Klang, Selangor	2015	Bentong, Pahang
2007	Kapit, Sarawak		

Figure 1: Landslide and slope failures at Hulu Sungai Galas (Left). Erosion and slope failures along Sungai Lebir Riverbank (Right).

There are many techniques and studies conducted to determine the relationship between landslide and parameters using GIS. Mohammady *et al.* (2012), Akgun and Bulut (2007), Bednarik *et al.* (2012), Pradhan *et al.* (2012), Wan and Lei (2009), Kayastha *et al.* (2013) are among the researchers, to name a few. Statistical model also being used in the landslide hazard analysis, such as the logistic regression model, analytical hierarchy process (AHP) and frequency ratio (Shahabi *et al.,* 2012). The objectives of this study are to develop a landslide inventory map, to identify the critical and prone area and to produce a landslide susceptibility map for the Lebir and Galas River Basins after the extreme flood event.

Study Area

Lebir and Galas River covers two districts, which is Kuala Krai and Gua Musang. Originated from Kelantan River then it splits into two routes in Kuala Krai and become Galas River and Lebir River (Figure 2). Lebir and Galas River basins were chosen as a study area for erosion because during floods the bank is submerged into water and stagnated water seeps as groundwater. Because of a very weak and porous soil profile in both banks, it weakens and dissects the bank deep-rooted.

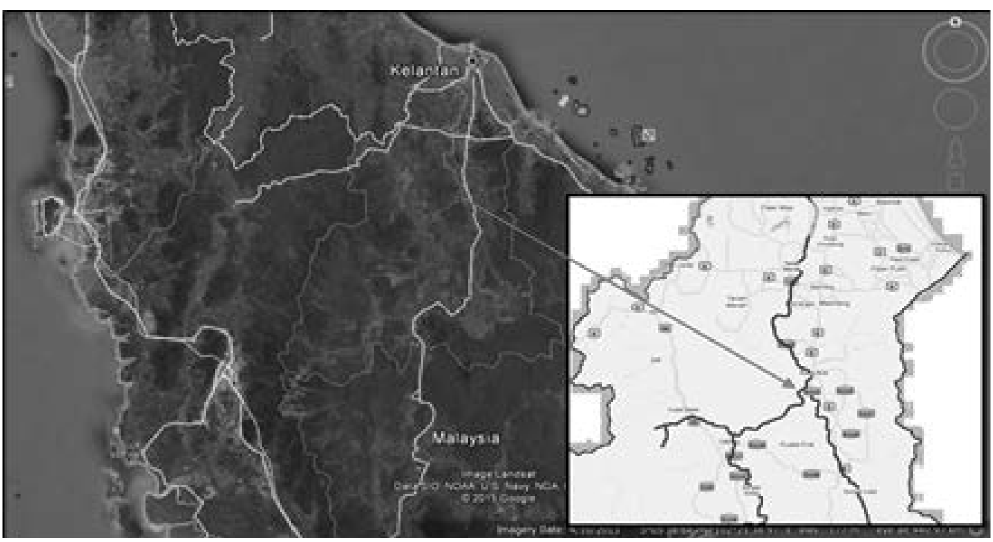


Figure 2: Lebir and Galas River Systems

Materials and Methods

The landslide susceptibility mapping was developed which involves four main steps; identifying the parameters for landslide mapping, data collection, database generation, and landslide susceptibility analysis with its validation. Figure 3 below shows the flowchart of methodology in the production of landslide susceptibility maps.

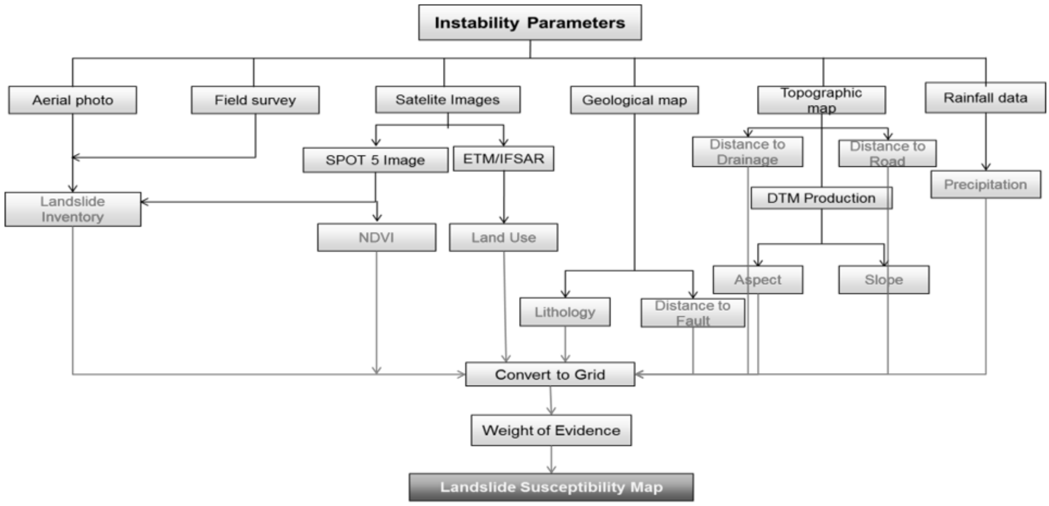


Figure 3: Flowchart of methodology in production of landslide susceptibility map.

Data Collection

Rainfalls, topography of the target area, field data collection are needed to understand the physical information. The geological topographical characteristics of the sources and along the river channel were surveyed and analysed. The land use status is also needed before and after the flood events based on image data and site observation. Data needed for developing landslide susceptibility map are precipitation, DTM, SPOT 5 Satellite Image, geology (Lithology map), Soil map, and land use.

Landslide Inventory Theorem Environments

One of the major steps in landslide susceptibility mapping is landslide inventory. The landslide inventory map is needed in order to study the relationship between landslide and conditioning factors (Mohammady *et al.,* 2012). Landslide susceptibility mapping is based on landslide inventory including geology (lithology), geomorphology (slope and aspect), land cover, distance to road, distance to drainage and precipitation. Landslide inventory map of the study area was identified using large-scale aerial photography. The landslide event identified were carried out and used to train the visual interpretation of SPOT imagery. The interpretation was conducted for the entire 2.5m SPOT scene. SPOT 5 satellite image. Landslide inventory was used to record the previous location in literature and where known the date of occurrence and also the types of mass movements that have left discernable traces in an area. According to (Kaab *et al.,* 2008), a landslide can be detected based on their characteristic of both the landslide; size and contrast with the surrounding terrain and the sensor used such as spatial and spectral resolution. Figure 5 shows a total of 340 landslides identified from field survey. Landslides properties also were recorded on a landslide inventory data sheet. Dots in the landslide inventory map represent the entire landslide that occurred in the study area.

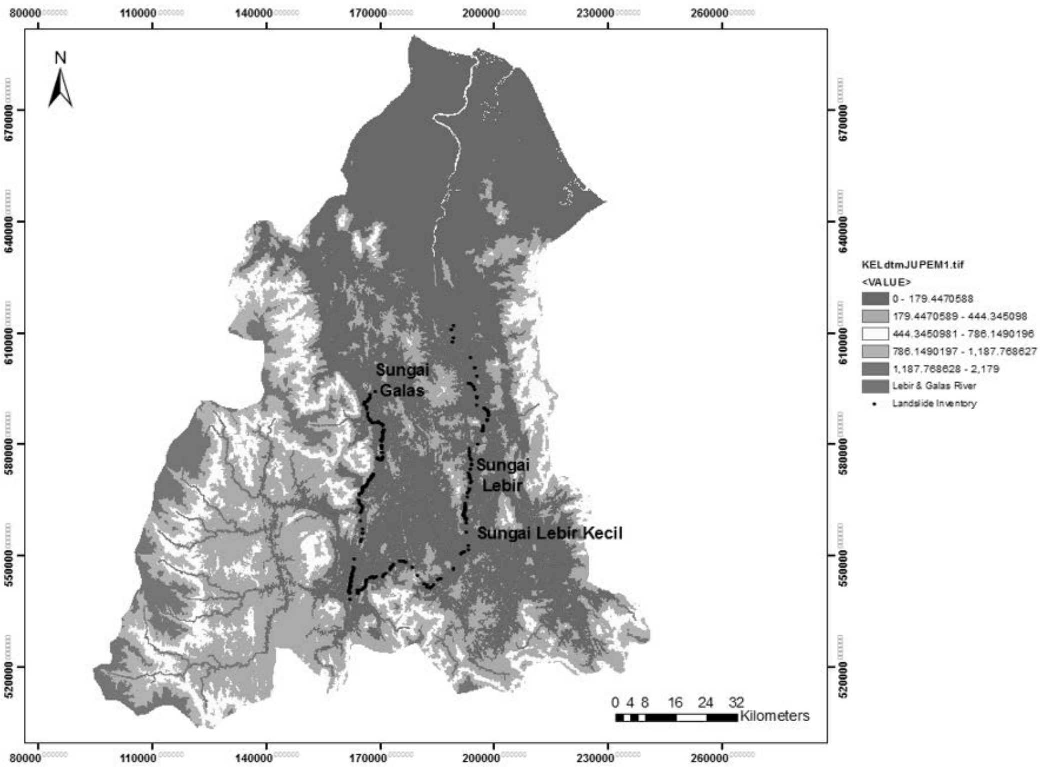


Figure 5: Landslide inventory map.

Spatial Database Construction

Some information regarding past events of landslides will need to be accountable and used as a reference in determining the parameter of probability for a landslide to occur in the future before producing a landslide susceptibility map. The first step in our study is to establish a spatial database that considers landslide-related factors from topographical maps, geological maps, satellite data, hydrological data, soil data and field data for a spatially explicit analysis of the degree of susceptibility. For preparation phase, all necessary geometric thematic editing was done on the original datasets and topology was created. Some of data collection needs to digitize from its original maps such as geology (lithology), soil map, and land use. Then, all vector layers were converted into a raster format, compiled into spatial datasets and were processed using Arc GIS. The study area covers 32.29 km^2. Ten factors were used for landslide susceptibility mapping including slope, aspect, geology (lithology), land use, precipitation, distance to drainage, distance to road, distance to fault, soil depth, and Normalized Difference Vegetation Index (NDVI), which considered as controlling factors in the occurrence of landslides in the study area.

The slope can be considered as the major controlling factor in landslide formation and frequently used in the calculation of the landslide susceptibility map. It consists of 10 degrees classes and was generated from the Digital Terrain Model (DTM) from Interferometric Synthetic Aperture Radar (IFSAR) data. Arc GIS software was applied to classify and calculate the relationship of landslide susceptibility. Slope aspect was also generated from IFSAR data. It is one of the main roles in a landslide event that has controlled the amount of water in the slopes and hillsides. Geology factor is considered as an independent variable in the landslide formation in that lithology and its varied structures tend to lead to a variation in stone stability and strength and also to varied soil texture. Geology map was retrieved from Mineral & Geoscience Department Malaysia (JMG) in a scale of 1: 67, 000 and digitized using Arc GIS software. As for the soil map, it was retrieved from the Department of Agriculture (DOA) and been re-classify according to soil terrain information. Precipitation data were collected from the Department of Irrigation and Drainage (DID) and was analysed using the Arc GIS software before converting into a raster map. Distance from roads was made by applying a buffer to the road network, and with a scale to 1000 meters by range. This factor map was generated to test the hypothesis that landslides may be more frequent along roads, due to inappropriate cut- slopes and drainage from the road. Distance from drainage was also generated using a buffer but in this case, is around the stream network and the same two distance classes were used for the roads. The hypothesis that was checked was the possible higher landslide frequency along streams, due to undercutting meanwhile for distance to fault, it has been same just like the distance from the drainage but in this case, it is focussed around the landslide area. Red band and Near Infrared band from SPOT 5 image were used to extract vegetation index value (NDVI).

Statistical Analysis

The preparation of landslide susceptibility map for Lebir and Galas River Basin was analyzed with a concept of indirect landslide susceptibility mapping using Weight of evidence (WOE) method (Bonham-Carter 1994) applied in Arc GIS software.

Indirect Landslide Susceptibility Mapping

Indirect landslide susceptibility mapping has a concept of controlling factors of future landslides that are the same as the previous observation of past events. This method was used by Westen *et al.* (2003) to evaluate the importance of geomorphological information in the generation of landslide susceptibility maps by using GIS to support indirect bivariate statistical analysis and comparison with landslide inventory and terrain factors. Indirect landslide susceptibility mapping is presented by predicting the degree of landslide susceptibility based on the events of landslide factors such as lithological units, slope classes or land use types. All landslides conditioning factors that can be mapped were entered into a GIS and converted from vector to raster maps and analysed using statistical approaches. Frequency statistics were calculated from the combination of each layer of landslide conditioning factors with a landslide inventory map. The preparation of the indirect landslide susceptibility map was analysed using the weight of the evidence method (Bonham-Carter, 1991; Westen *et al.,* 2001). A recent study from Pradhan *et al.,* (2010) and Mohammady *et al.,* (2012) also applied weights-of-evidence (WOE) method for their landslide susceptibility assessment. This method calculates the weight for each landslide predictive factors which only contain two classes, based on the presence or absence of the landslide.

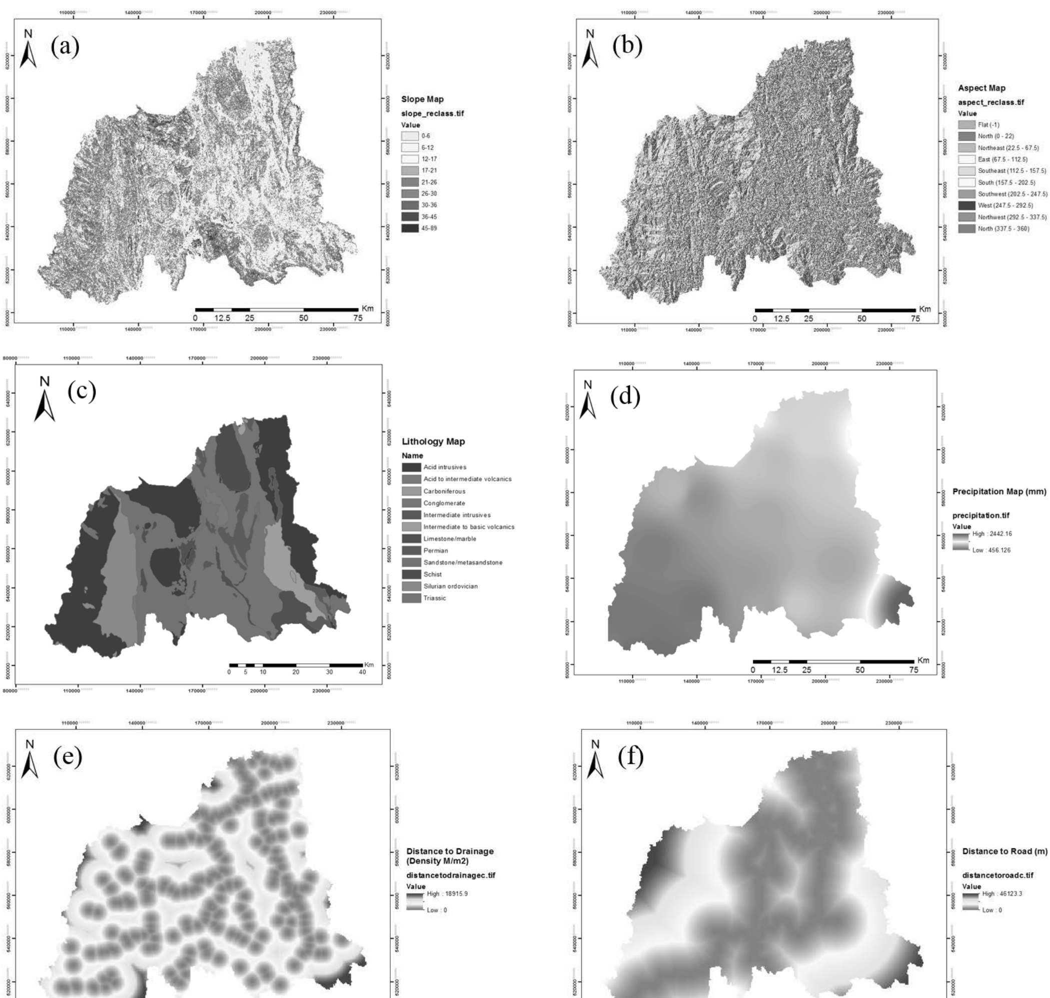
Table 1: Matrix of statistical factors.

Bi: Potential landslide conditioning factor			
S: Landslides	Present	*Npix*1	*Npix*2
	Absent	*Npix*3	*Npix*4

Wi^+ is used for those pixels of factor represented as a class in a multi-class map to indicate the importance of the presence of the factor for the occurrence of landslides and if Wi^+ is positive, the presence of the factor is favourable for the occurrence of landslides and vice versa. Weights with extreme values are the factor that is useful to the susceptibility mapping meanwhile factors who have weight around zero have no relation to the occurrence of landslides. Wi^+ can be written in the number of pixels as follows:

$$W_I^{+} = \frac{\text{Npix1}/\,(\text{Npix1} + \text{Npix2})}{\text{Npix3}/\,(\text{Npix3} + \text{Npix4})}$$

For preparation phase, ten thematic maps editing for causative factors considered in the analysis, including slope, aspect, geology (lithology), land use, precipitation, distance to drainage, distance to road, distance to fault, soil depth, and Normalized Difference Vegetation Index (NDVI) was done on the original datasets and topology was created. Then, all vector layers were converted into a raster format, compiled into spatial datasets and were processed using Arc GIS. All maps were stored in raster format (Figure 6). The factor maps were all combined with the landslide inventory map for the calculation of positive and negative weights. Since all of the maps are multi-class maps which contain several factors (classes), the presence of one factor implies the absence of the other factors of the same map. The positive weight of the factor itself was added to the native weight of the other factors in the same map in order to obtain the total weight of each other.



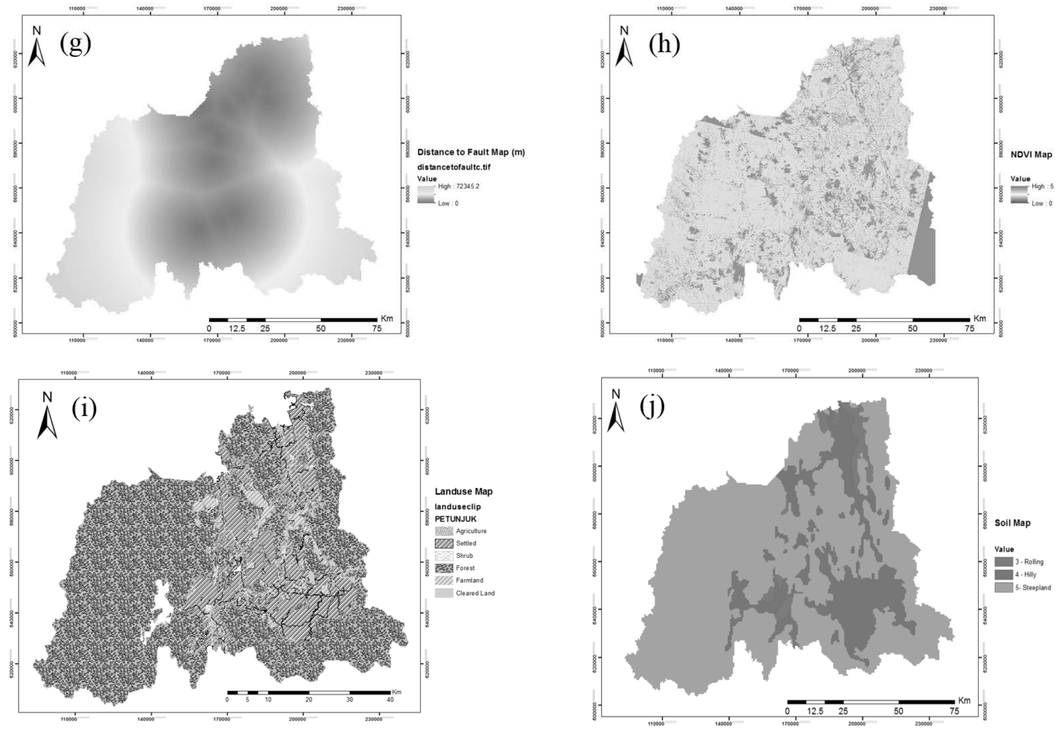
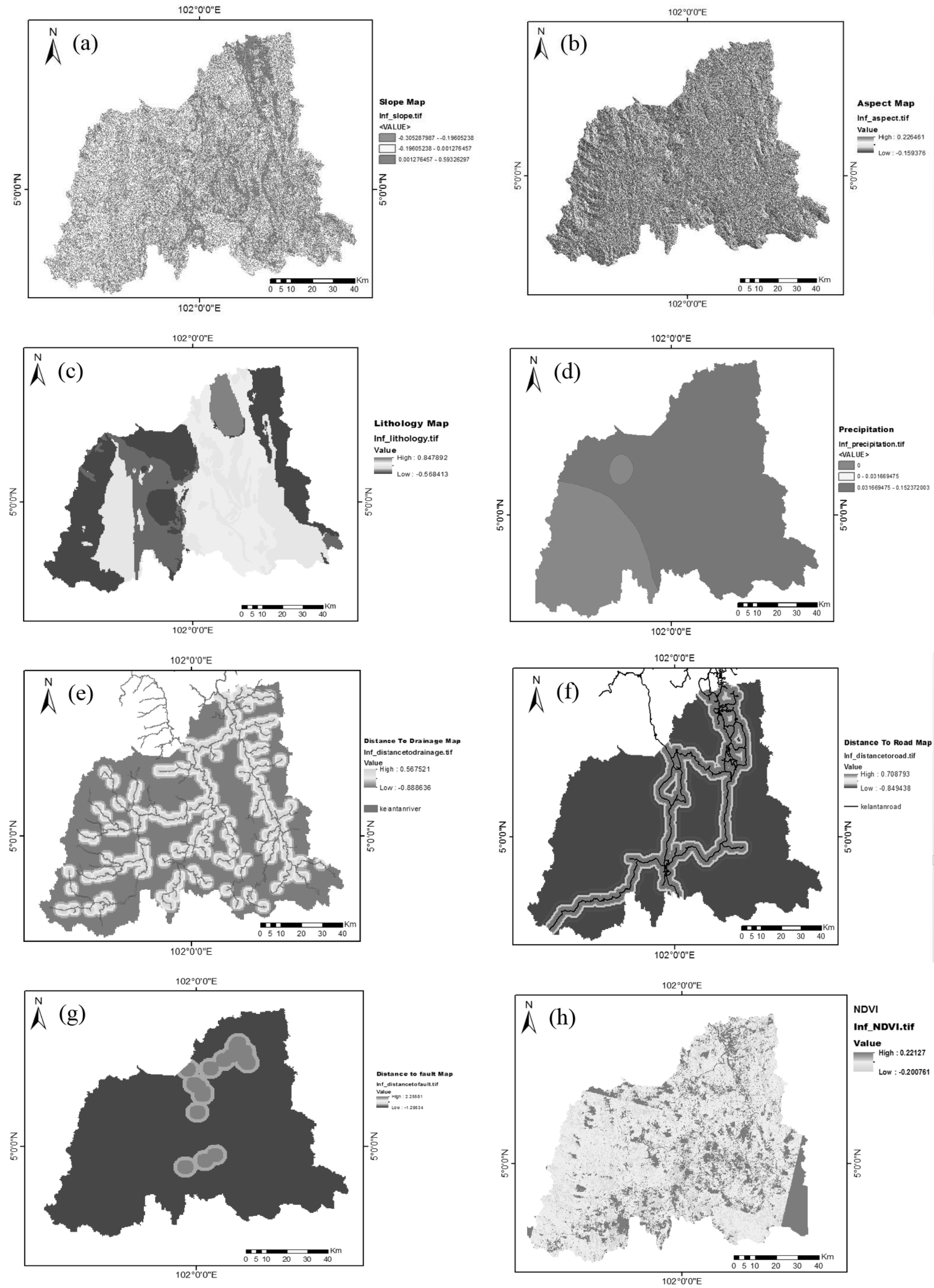


Figure 6: Landslide susceptibility pre-disposing factors/parameters: (a) Slope; (b) Aspect; (c) Geology (Lithology); (d) Precipitation Digitize; (e) Distance to drainage; (f) Distance to road; (g) Distance to fault; (h) NDVI; (i) Land use; (j) Soil type.

Results of total weights were shown in Table 2 and in Figure 7, directly indicate the importance of each factor. If the total weight is positive, the factor is favourable for the occurrence of landslides meanwhile if it has negative of total weights, it is not favourable for the occurrence of landslides. Based on Table 2, most of the factors show hardly any relation or no relation with the occurrence of landslides, as evidenced by weights close to 0. As for land use, the analysis proved that settled land use has the highest positive total weight (1.031512) compared to other factors, followed by farmland (1.011425) and agriculture (0.554189). Most of the slope classes show values with a weight around zero without any extreme positive and negative values. The highest positive total weight for slope is in 0-6 degrees and >45 degrees classes which have 0.593263 meanwhile the highest negative total weight was at 6-12 degrees (-0.305288). As for the aspect, possibilities for a landslide to occur is 0.226461 at the east (E) which not really high values for total weight. The highest values for soil, precipitation, distance to road, distance to drainage, and NDVI are 0.440761 (hilly), 0.152372 (>900 mm), 0.708793 (0-1000 m), 0.567521 (0-1000 m), and 0.22127 (-0.991-0.254). Among the parameters, distance to a fault has the highest value of weight 2.255814 (0-1000 m), which means it has the highest possibilities for a landslide to occur in the future.

Table 2: Weights for non-geomorphological factors, calculated with the weights of evidence modelling (Value).

No	Factor Map	Factor Class		Total Weight
1	Landuse	Agriculture		0.554189
		Settled		1.031512
		Farmland		1.011425
2	Geology	Acid intrusives		-0.568413
		Triassic		0.405217
		Sandstone/metasandstone		-0.424112
		Schist		0.847892
		Carboniferous		-0.568413
3	Slope	0-6 degrees		0.593263
		6-12 degrees		-0.305288
		17-21 degrees		0.001453
		21-26 degrees		-0.195352
		26-30 degrees		-0.048938
		36-45 degrees		0.397837
		>45 degrees		0.593263
4	Aspect	Flat	(-1)	N/A
		N	(0-22.5)	0.174217
		NE	(22.5 – 67.5)	-0.159376
		E	(67.5-112.5)	0.226461
		SE	(112.5-157.5)	0.157427
		S	(157.5-202.5)	-0.119996
		SW	(202.5-247.5)	0.050079
		W	(247.5-292.5)	N/A
		NW	(292.5-337.5)	-0.114855
		N	(337.5-360)	0.176529
5	Soil	Class 3 - Rolling		N/A
		Class 4 - Hilly		0.440761
		Class 5 - Steepland		-0.529945
6	Precipitation	456 mm		N/A
		800-900 mm		0.032186
		>900 mm		0.152372
7	Distance to road	0-1000 m		0.708793
		1000-2000 m		0.028814
		2000-3000 m		0.522048
		3000 - 4000 m		-0.077072
		4000-5000 m		-0.056878
		>5000 m		-0.849438
8	Distance to drainage	0-1000 m		0.567521
		1000-2000 m		0.40564
		2000-3000 m		0.123231
		3000 - 4000 m		-0.21718
		4000-5000 m		-0.473174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-0.19605238 - 0.001276457
0.001276457 - 0.59326297
(b)
Aspect Map
Inf_aspect.tif
Value
High : 0.226461
Low : -0.159376
(c)
Lithology Map
Inf_lithology.tif
Value
High : 0.847892
Low : -0.568413
(d)
Precipitation
Inf_precipitation.tif
<VALUE>
0
0 - 0.031669475
0.031669475 - 0.152372003
(e)
Distance To Drainage Map
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Value
High : 0.567521
Low : -0.888636
kelantanriver
(f)
Distance To Road Map
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Value
High : 0.708793
Low : -0.849438
kelantanroad
(g)
Distance to fault Map
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Value
High : 2.25581
Low : -1.29534
(h)
NDVI
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High : 0.22127
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102°0'0"E
5°0'0"N
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0 5 10 20 30 40

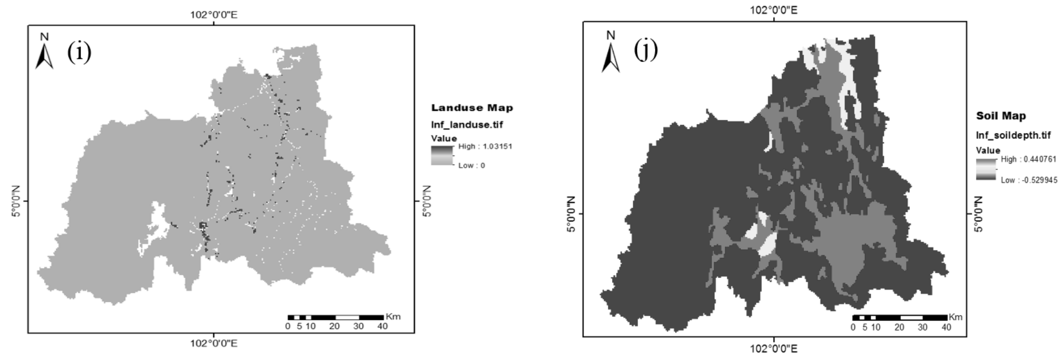

Figure 7: Weights for non-geomorphological factors, calculated by the weights of evidence modelling (Mapping). (a) Slope; (b) Aspect; (c) Geology (Lithology); (d) Precipitation Digitize; (e) Distance to drainage; (f) Distance to road; (g) Distance to fault; (h) NDVI; (i) Land use; (j) Soil type.

Results and Discussion

Landslide Susceptibility Map

Non-geomorphology weight factors shown previously in Table 2, were calculated by the weight of evidence modelling applied in ArcGIS software. However, it can be seen that there is some part of the factor class does not have the value of total weight due to the landslide inventory map was not overlaid with a landslide conditioning factors map. All total weight of factor map was combined to produce a landslide susceptibility map.

Based on the result obtained from susceptibility map in Figure 8, 22.76% (7.34 km^2) of the total area shows a very low landslide susceptibility whereas 19.95% (6.44 km^2) shows a low landslide susceptibility map. Moderate, high and very high susceptibility zones make up 27.16% (8.76 km^2), 23.87% (7.70 km^2) and 6.27% (2.02 km^2) of the total area, respectively.

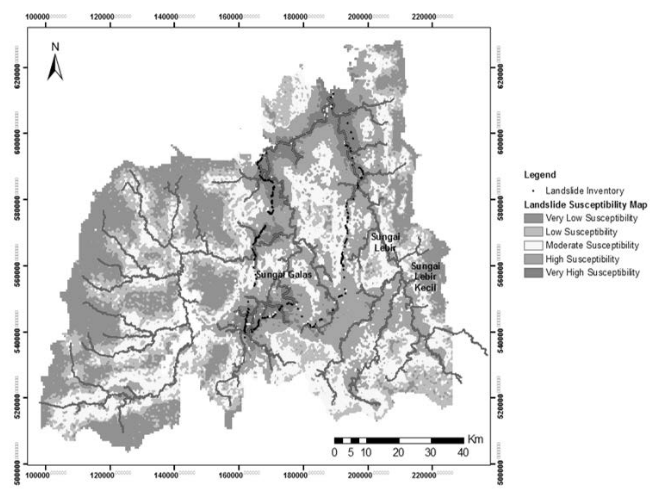

Figure 8: Landslide susceptibily map for Kuala Krai and Gua Musang Districts.

Conclusions

In this study, the landslide susceptibility mapping for Lebir and Galas River Basins were produced using GIS. The landslide susceptibility map shows that most of the area near the river is susceptible and prone to landslide. The landslides and erosions transformed into a debris flow, which deposited in the river during the flood. These tributaries produce debris flows which are typically more than 80% sediment by weight with individual particles ranging from fine clays to boulders. The information provided by this landslide susceptibility map could be used as the basis for prevention and mitigation of landslides and erosions in the future.

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