



# PROCEEDINGS

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**Faculty of Mathematic and Natural Sciences  
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## **LANDSLIDE SUSCEPTIBILITY ANALYSIS USING WEIGHTED LINEAR COMBINATION (WLC) COMBINED WITH THE ANALYTICAL HIERARCHY PROCESS (AHP)**

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### **ABSTRACT**

Bone Pantai area is prone to landslides because of topography and land cover changes. Due to heavy rainfall in this area there were landslides resulting damage and human casualties in the end of 2013. Proper analysis and suitable modeling of dangers may reduce the impact of disaster. In this research, a weighted linear combination (WLC) combined with the analytical hierarchy process (AHP) methods were used to analysis the susceptibility. Elevation, slope angle, slope aspect, rivers, roads, rock formations and the land-cover are considered as the landslide-conditioning parameters. These research reviews that, Bone Pantai have 1.12% very high and 36.82% low susceptibility areas. The result was verified by ground truth assessment of existing landslide susceptibility mapping of the location where the accuracy was 80% and overall Kappa statistics was 0.7337.

**Keywords:** Accuracy, Landslide, Mapping, Susceptibilit

### **INTRODUCTION**

Landslides play an important role in the evolution of landforms and one of the most widespread damaging natural hazard in hilly regions [1], [2]. Bone Pantai (0°21' - 0°28' S, 123°9'30" - 123°17'30" E) is a hilly area that susceptible to landslides. In 2013, landslides have occurred in this area resulting in damage and human casualties.

Landslide susceptibility mapping is considered to be an effective tool for reducing the damages to people and infrastructures. The effectiveness of decision making is clearly dependent on the quality of the data used to produce the landslide susceptibility map, as well as on the method used for decision making analysis. In the present study, Weighted Linear Combination (WLC) combined with The Analytic Hierarchy Process (AHP), were used to analyze and obtain more accurate and reliable landslide susceptibility map.

### **MATERIALS AND METHODS**

#### **Weighted linear combination (WLC) with The Analytic Hierarchy Process (AHP) Method**

WLC technique is a decision rule for deriving composite map using Geographic Information System (GIS) [3]. The weighted linear combination method is performed to derive the final susceptibility values (1).



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$$Y(i, j, t) = \sum_{k=1}^n w_k X_k(i, j, t), \text{ where } \sum_{k=1}^n w_k = 1 \quad (1)$$

$Y(i, j, t)$  is final susceptibility value for pixel  $(i, j)$  and  $w_k$  is the linear combination weight for  $k$ -th factor, where  $k$  = number of data.

The analytic hierarchy process (AHP) method [4]–[6] are used to determine the weight for each factor of landslide. The AHP consists of following five steps: (i) break down a decision problem into component factors; (ii) arrangement of these factors in a hierarchic order; (iii) assignment of numerical values to determine the relative importance of each factor according to their subjective relevance; (iv) set up of a comparison matrix; and (v) computation of the normalized principal eigenvector, which gives the weight of each factor. In this method, the pair-wise matrix is used and ranking of all parameters is made by a continuous scale ranging from 1/9 to 9. The results of the pair-wise comparison matrix and the factor weights are shown in Table 2. In AHP, an index of consistency, known as the CR (consistency Ratio), is used to indicate the probability that the matrix judgements were randomly generated. This ranges from 0 to 1, CR close to 0 indicates the probability that the matrix's rating was randomly generated. Saaty recommended the CR to be  $\leq 0.1$  to be valid. The CR in this study is 0.02 (Table 2).

$$CR = \frac{CI}{RI} \quad (2)$$

Where RI is the average of the resulting consistency index depending on the order of the matrix given by Saaty[4] (Tabel 1) and CI is the consistency index that is expressed in the following equation.

$$CI = \frac{\lambda_{\max} - n}{n - 1} \quad (3)$$

where  $\lambda_{\max}$  is the largest eigenvalue and  $n$  is the order of the comparison matrix.

Table 1. Random Consistency Indeks (RI)

N	1	2	3	4	5	6	7	8
RI	0	0	0,58	0,90	1,12	1,24	1,32	1,41

N	9	10	11	12	13	14	15
RI	1,45	1,49	1,51	1,53	1,56	1,57	1,59

## Parameters of landslide

Topography, land cover, rock formations, rivers and roads was a parameters of landslides in this research.

- Topography  
Topography thematic data layers such as elevation, slope angle, and slope aspect were prepared from Digital Elevation Model (DEM).

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- The distance above a datum level called elevation. Elevation indicates the potential energy for landslide. Elevation classified into five different classes (Figure 1a); (i) 0 – 500, (ii) 500 – 1000, (iii) 1000 – 1500, (iv) 1500 – 2000, (v) > 2000.
- Slope gradients ranges of 15% - 70% have a large impact on landslides. Slope angle map classified into five different classes (Figure 1b); (i)  $\leq 20^\circ$ , (ii)  $20^\circ-40^\circ$ , (iii)  $40^\circ-60^\circ$ , (iv)  $60^\circ-80^\circ$ , (v)  $80^\circ>$ .
- Slope aspect is the direction of maximum slope of the terrain surface. Slope aspect was divided into nine classes: (i) Flat, (ii) North (N), (iii) North-east (NE), (iv) East (E), (v) South-east (SE), (vi) South (S), (vii) South-west (SW), (viii) West (W), and (ix) North-west (NW) and reclassified based on susceptibility from processed the Sentinel 1b. (Figure 1c).

## • Land-Cover

Changes in land cover such as deforestation, cultivation on steep slopes, road construction, forest logging, and fire can have an important impact on landslide activity. Land-cover layer was generated from Landsat 8 (L8) using *Normal Differential Vegetation Indeks* (NDVI)[7]. NDVI is one of the most popular methods for vegetation monitoring[8]. The NDVI can be expressed as [9]–[12].

$$NDVI = \frac{\rho_{NIR} - \rho_R}{\rho_{NIR} + \rho_R} \quad (4)$$

where  $\rho_{NIR}$  is the reflectance radiated in the near-infrared waveband and  $\rho_R$  is the reflectance radiated in the visible red waveband of L8 (LC81130602015084LGN00). NDVI classified into five different classes (Figure 1e); (i) 0,75 – 1,00, (ii) 0,50 – 0,75, (iii) 0,25 – 0,50, (iv) 0 – 0,25, and (v) -1 – 0.

## • Rock Formation

The landslide mechanisms are mainly controlled by geological conditions[12]–[14]. Geological factors form rock formations used in this study, because each formation has a great tolerance towards the water and landslides. The study area has the following six rock formations.

- Molasa Celebes (QTs) ; conglomerates and breccias composed by various component materials form of pieces of andesite, basalt, granite, drandidorit, limestone, sandstone and quartz
- Alluvium and coastal sediment (Qal) : sand, clay, mud, gravel and gravel
- Limestone reef (Ql) : uplifted coral limestone and clastic limestone with coral main component
- Formation Sedimentary facies Tinombo (Tets): sandstone with inserts limestone and chert.
- Diorite Bone (Tmb) : quartz diorite, diorite, granodiorite, granite.
- Volcanic rocks Bilungala (Tmbv) : Breccia, tuff and lava composed of andesite, dacite and rhyolite.

The Sixth of rock formation was reclassified based on susceptibility from processed the Sentinel 1b (Figure 1).

## • Rivers

Landslides often occur in areas of the river[15], [16]. Rivers was divided into five distance to river classes (Figure 1d): (i) 150m, (ii) 120m, (iii) 90m, (iv) 60m, (v) 30m.



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## • Roads

A road constructed beside the slopes causes a increase in the load on the heel of the slope, it cause landslides may occur on the road and on the side of the slopes affected [17], [18]. Such as rivers, roads was divided into five distance to road classes (Figure 1f): (i) 150m, (ii) 120m, (iii) 90m, (iv) 60m, (v) 30m.

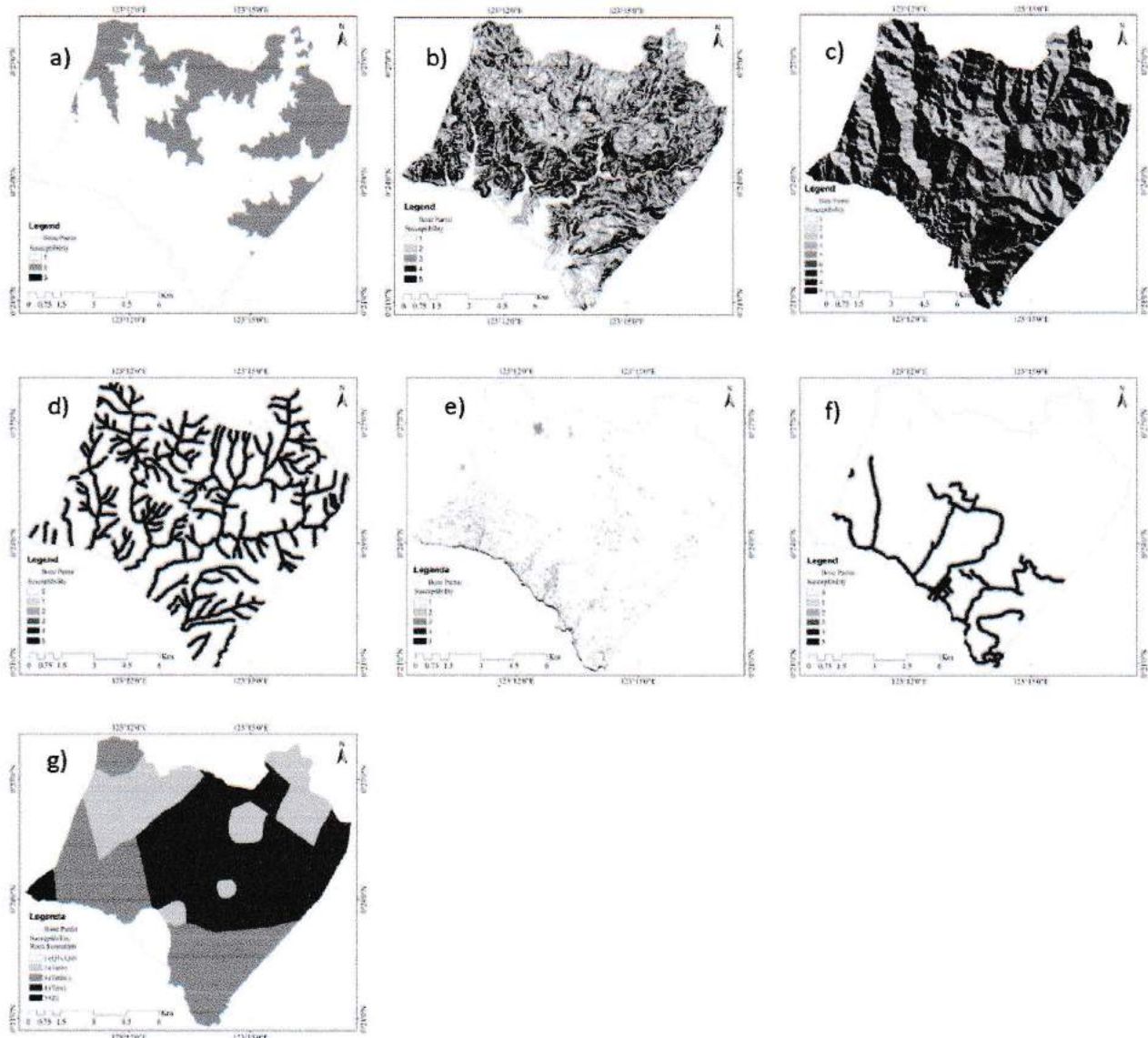


Figure 1. Parameters of landslide; a) Elevation, b) Slope gradient, c) Slope aspect, d) Rivers, e) Land-cover, f) Roads, g) Rock Formations

## Model Assessment

In this research, the kappa index value are used to show the similarity between the susceptibility maps with ground truth assessment. Equation (5) is The kappa coefficient[19].

$$\hat{k} = \frac{p_0 - p_c}{1 - p_c} \quad (5)$$

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where  $p_o$  is percentage number of inter-rater consistency measurement and  $p_c$  percentage number of inter-rater measurement changes. The kappa ranges from 0.0 to 1.0. A Kappa value of 1 indicates a perfect similarity between the model and ground truth assessment of existing landslide location.

## RESULTS AND DISCUSSION

The pair-wise matrix is used and ranking of all parameters of landslide using the AHP method resulted rock formations is the most heavily weighted parameter followed by land-cover and slope angle (Table 2).

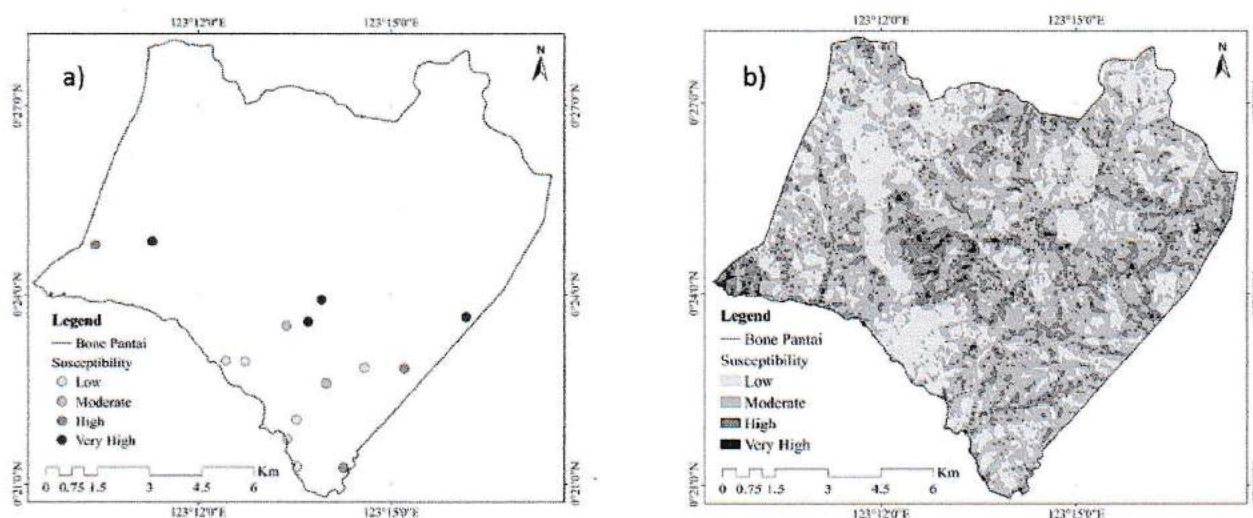


Figure 2. Landslide Susceptibility Map of Bone Pantai: a) ground truth, b) The Wlc-Ahp Method.

Table 2. The Pair-Wise Comparison Matrix, Parameter Weights And Consistency Ratio Value.

Parameters	X <sub>1</sub>	X <sub>2</sub>	X <sub>3</sub>	X <sub>4</sub>	X <sub>5</sub>	X <sub>6</sub>	X <sub>7</sub>	W
X <sub>1</sub>	1.00							0.089
X <sub>2</sub>	2.44	1.00						0.176
X <sub>3</sub>	1.17	0.79	1.00					0.104
X <sub>4</sub>	1.19	0.87	1.43	1.00				0.114
X <sub>5</sub>	2.03	0.87	2.69	2.47	1.00			0.210
X <sub>6</sub>	1.15	0.56	0.65	0.73	0.48	1.00		0.084
X <sub>7</sub>	1.94	1.10	2.10	2.50	0.97	3.65	1.00	0.224

Consistency ratio (CR): 0.02 < 0.1 (acceptable)

Based on the weighted (w) parameters and WLC method, mathematical equation of landslides (6) and landslide susceptibility map was produced (Figure 2b). The map shows that, Bone Pantai have 36.82% low, 45.10% moderate, 16.97% high and 1.12% very high susceptibility areas. The result was verified by ground truth assessment of existing landslide location (Figure 2a) where the overall accuracy was 80% and kappa statistic 0.7337.



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$$Y = (0.089X_1) + (0.176X_2) + (0.104X_3) + (0.144X_4) + (0.210X_5) + (0.084X_6) + (0.224X_7) \quad (6)$$

where Y is final susceptibility,  $X_1$  is elevation,  $X_2$  is slope angle,  $X_3$  is slope aspect,  $X_4$  is rivers,  $X_5$  is land-cover,  $X_6$  is roads, and  $X_7$  is rock formations.

## CONCLUSION

A reliable and accurate susceptibility map depends on the role of reviews these parameters and methods. Seven landslide-controlling parameters items, namely elevation, slope angle, slope aspect, land-cover, rock formations, rivers and roads were analyzed used the WLC-AHP method that can sufficiently represents the landslide susceptibility map in this research. Bone Pantai is still safe from landslide based on this research. Landslide studies with other methods are needed to improve the accuracy of the landslide susceptibility map in the Bone Pantai subdistrict.

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