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# Landslide Susceptibility Zonation Model On Jeneberang Watershed Using Geographical Information System and Analytical Hierarchy Process

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*Abstract— **The area of Jeneberang Watershed is prone to landslides due to geologic, geomorphologic and rainfall characteristics of the region. In 2004, a huge caldera wall of the watershed collapsed in the Eastern part resulting in infrastructure damage, human casualties and sequence disaster as debris flow. Potential landslides still occur in the future. It is necessary to conduct research to prepare a landslide susceptibility map of the region. The objectives of this study are as follows: firstly, to investigate the contributing parameters induced land sliding in the Jeneberang watershed and secondly, to construct landslide susceptibility zonation map. In this study, the analytical hierarchy process (AHP) based on Geographical Information System (GIS) methods were used to produce map of landslide susceptibility. Data layers such as elevation, slope aspect, slope steepness, proximity to road, proximity to river, litho logy, lineaments, soil texture, rainfall, land use or land cover and landslide inventory were extracted from various sources and used to calculate index of landslide susceptibility. The study area was classified into five hazard classification namely: very low, low moderate, high and very high. The percentage distribution of landslide degrees was calculated. It was found that about 28.40% of the study area is classified as very and high susceptibility. The result of this study is useful for preparing landslide mitigation efforts through a comprehensive planning scheme.***

*Key words:* **AHP, GIS, Jeneberang, landslide, watershed.**

## I. INTRODUCTION

In Indonesia, landslides are the third most extremely natural disasters after flood and strong wind [1]; it is increasing in frequency each year. In Jeneberang watershed, South Sulawesi Province, landslides have occurred every year. The watershed is intensively occupied by agricultural land, settlement and local tourist destination. The frequent landslides often occurred in this region due to heavy rain fall and litho logy condition leading to various type of landslide, imposing hazards to people and property. The most recent landslide occurred in 2004, 2006, 2007, 2008, 2009 2010 and 2012. Landslides in this region have threatened the Bili-Bili reservoir and agricultural land along Jeneberang river bank. Bili-Bili multipurpose dam was completed in 1997, the first large dam constructed in eastern part of Indonesia. The dam lies 31 km from Makassar City, and it constructed to overcome flood, which is frequently occur in Makassar City and its surrounding, another purpose is source of row water for municipality water tap and irrigation for 24,000 ha in downstream of Jeneberang River. On 26th March, 2004, huge collapse occurred in northern caldera wall of Mt. Bawakaraeng (Elev. 2,830m). The collapsed area is identified a ridge including Mt. Sarongan (Elev. 2,514 m). The volume of collapsed mass is estimated more than 200 million $m^3$ [2]. The caldera-wall collapse with a height of 700-800m [3]. The collapsed mass has been running down as debris flow, it is reached the Bili-Bili reservoir and threated live time of the dam. The main cause of the landslide in this area is still unidentified [4]. Causative factors are the basis of landslide susceptibility analysis (LSA); where as many as 40 factors have been used in the building of discriminant LSA models [5]. Up to now there is no universal guidelines for selecting the factors that influence landslides in susceptibility and hazard assessment. The selection of causative factors may vary depending on the scale of analysis; the characteristic of the study area; the landslide type; and failure mechanism as well as the availability of existing data and resources [6]. It was clarified that not only the heavy rainfall but also rugged topography and fragile geology with volcanoes activity along seismic zone of study area significantly control the occurrences of landslide. The objectives of this study are as follows: firstly, to investigate the contributing parameters induced land sliding in the Jeneberang watershed using spatial-multicriteria evaluation (MCE) technique, through pairwise comparation (Analytical Hierarchy Process-AHP), and secondly, to construct landslide susceptibility zonation map.

## II. MATERIAL AND METHODS

### *A. Location*

The study area encompasses the Lompobattang and its surrounding. It is located around 31 km east of Makassar City, South Sulawesi Province (Fig.1), and bounded by latitude of 5$^{o}$ 10’00”S up to 5$^{o}$26’00”S, and longitude 119$^{o}$56’10”E up to 119$^{o}$56’10”. Jeneberang River rises in Mt. Bawakaraeng, which has an elevation of 2.833 m above MSL and flows from the east to the west. After joining many tributaries and changing its course at Bili-Bili towards to the northwest, it joins Enemata River at distance of 29.4 km from the river mouth. Then, it passes through the southern part of Makassar City and empties into the Makassar Strait. The total length of the river is about 75 km and the catchment area is 727 $km^2$. The topographic gradients in the upper and the lower reaches of the Jenelata confluence are about 1/150 and 1/800, respectively. The study covers an area of 376.50 sq.km; it is part of Jeneberang Watershed.


**Fig. 1a. Location Map Of South Sulawesi[3]**

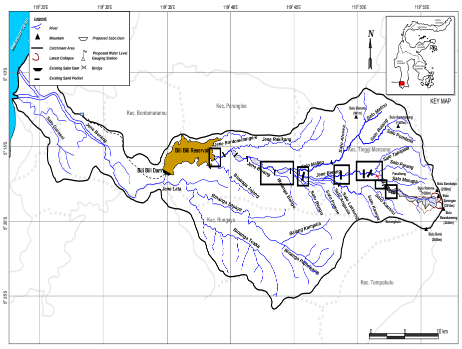

**Fig. 1b. Map Of Jeneberang Watershed [7]**

The lithology of the study area consists of Camba Formation in Miocene, Baturape-Cindako Volcanic in Pliocene, Lompobatang volcanic rocks in Pleistocene and Quaternary overburden from lower stratigraphy. The Camba Formation is widely distributed in the west side of the Study Area, and fresh rock is hard. Baturape-Cindako Volcanic is an extrusive rock from old volcanoes which were active in Pliocene, and is mainly composed of basaltic volcanic rocks and basalt lava, and is partly distributed in north east side and south west side of the Study Area and its fresh part is hard, but generally weathered. Lompobatang volcanic rocks is an extrusive rock from new volcanoes which were active in Pleistocene, and is composed of volcanic rocks, eruptive center rocks, pyroclastic rocks, parasitic eruptive products etc., and is distributed in overall area of Mt. Bawakaraeng and its caldera. Lava part is hard, but pyroclastic rock is rather weak in concreteness [7]. Based on research work conducted by [8], land use in the study area mainly occupied by dry land agriculture or mixed garden, paddy field, forested land grassland, settlement, and bare land. Dance forest throughout on the Caldera cone but in the inner site of caldera covered by bare land in dry season or bush land in the rainy season. Paddy field covered mostly area in the lowland and the river flood plain. The climate of the study area is tropical humid. Precipitation various due to elevation, average of annually precipitation between 2700 -5007 mm.

***B. Data sources***

In this study, ten landslide causative factors were used, namely: elevation, slope aspect, slope steepnes, proximity to stream network, proximity to roads, lithology, distance of terrain to lineament, soil texture mean annual rainfall and landcover or landuse. Each category was subdivided into different classes by its value or feature

Topography causative factors, such as slope steepness, slope aspect and lineaments have been exstracted from a Digital Elevation Model (DEM). The resolution and accurancy have a direct influence on the quality of these factors [9]). The 30 x 30 m DEM used in this study was developed from Suttle Radar Topographical Mission (SRTM). The Geological data, which generated lithological and lineament maps were derived from the 250000 scale regional geology map produced by Directorat General Geology. Proximity to roads and natural drianage line network maps developed from the 50000 scale regional produced by [10]. Other factor such as mean annual rainfall data, collected from rainfall gauge stations were available around study area. Data preparation is the first fundamental and essential step for landslide hazard analysis. In this study GIS database was mainly composed of two parts: landslide location map and landslide predisposing factor maps. Landslide inventory of the area, were detected by sattelite image interpretation and verified by fieldwork. In order to evaluate susceptibility of landslide, the factors leading to landslide must be identified and analyzed. The causative factors of the landslides were chosen after a careful bibliographical review of those most frequently referenced by the authors [11], [12], [13] and field investigations. These factors are as follows: elevation, slope aspect, slope steepness, proximity to river , proximity to road, lithology, lineament, soil texture, rainfall and landcover or land use. All causative factors can be obtained or created in the form of maps, each representing large quantities of spatial data. The preparation of a hazard zonation map involves, manipulating, analyzing and presenting these data in GIS In this study, digital geology map of the area were prepared based digital of South Sulawesi geological sheet maps at 1:250000 scale. Slope aspect, slope gradient and elevation thematic maps were constructed from Shuttle Radar Topographical Mission (SRTM) of the area with spatial resolution (30 m). Soil texture map was provided based on Land system map at 250000 scale, road and drainage maps were extracted from topography map of the area in scale 1: 50000 produced by National Coordinating Survey and Mapping Board (BAKOSURTANAL). Land use thematic map of the study area was created using unsupervised classification of Landsat TM satellite image (2009) with 30x30m resolution.

***C. METHODOLOGY***

To produce landslide susceptibility map for the Jeneberang Watershed, the AHP technique was used. In this method, the landslide susceptibility index (LSI) value for each considered pixel was computed by summation of each factor's weight multiplied by class weight (or rating) of each referred factor

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$$LSI = \sum_{i=0}^{n} (W \ x \ R) \cdots\cdots\cdots\cdots\cdots\cdots \ (1)$$

Where LSI is the required landslide susceptibility index of the given pixel, Ri and Wi are class weight (or rating value) and the factor weight for factor i derived using AHP technique.

## III. RESULTS AND DISCUSSION

In this study, both the comparison of the parameters relative to each other and the determination of the decision alternatives, namely the effect values of the sub-criteria of the parameters (weight), were based on the comparison of landslide inventory maps constructed using satellite imagery with landslide susceptibility map. Consequently the weight values were determined accurately for the real land data (Table 1). In this study, spatial databases were used, obtained as a result of the field, and desk studies carried out to create landslide susceptibility map. The analysis of data layers converted to a raster data model was completed by determining their weights in terms of both data layers and sub-criteria, in consequence of the calculation carried out according to the AHP. As a result of these analyses, the Landslide susceptibility map was produced for the area of Jeneberang Watershed as shown as in Figure 1. For the model, where AHP was used, the CR (Consistency Ratio) was calculated. The model with a CR greater than 0.1 were automatically rejected. With the AHP method, the values of weights factors were spatially defined [14]. Using a weighted linear sum procedure, the acquired weights were used to calculate the landslide susceptibility models as demonstrated by [15]. Similar application has also been implemented for analysing soil and water protection in the Jeneberang watershed [16]. One important point that should be mentioned in this application that the values og weighting factors may be simulated to find the best representing weights specifically for the Jeneberang watershed. Comparison was also needed between the actual situation in the ground and the results of the model developed in this study.

**Table 1. The Pair-Wise Comparison Matrix, Factor Weight, Class Weight (Rating) and Consistency Ratio**

| FACTORS | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | Weights |
|---|---|---|---|---|---|---|---|---|---|---|
| Elevation (m) | | | | | | | | | | 0.026 |
| (1) <500 | 1 | ¼ | ¼ | 1/6 | 1/7 | 1/8 | | | | 0.023 |
| (2) 500 – 1000 | | 1 | 1/5 | 1/6 | 1/6 | 1/8 | | | | 0.036 |
| (3) 1000 – 1500 | | | 1 | 1/6 | 1/6 | 1/8 | | | | 0.063 |
| (4) 1500 – 2000 | | | | 1 | ¼ | 1/6 | | | | 0.137 |
| (5) 2000 – 2500 | | | | | 1 | 1/7 | | | | 0.217 |
| (6) >2500 | | | | | | 1 | | | | 0.524 |
| Slope aspect | | | | | | | | | | 0.034 |
| (1) Flat | 1 | 1/7 | 1/3 | ½ | 1/6 | 1/7 | 1/7 | 1/5 | 1/8 | 0.019 |
| (2) North | | 1 | 1 | 3 | 1 | ½ | 1/2 | 1 | ½ | 0.091 |
| (3) Northeast | | | 1 | 2 | ½ | 1/6 | 1/2 | 1 | 2 | 0.064 |
| (4) East | | | | 1 | 1/5 | 1/8 | 1/4 | 1/3 | ¼ | 0.030 |
| (5) Southeast | | | | | 1 | 1/6 | 3 | 1 | 1/3 | 0.112 |
| (6) South | | | | | | 1 | 1/7 | 1 | 1 | 0.291 |
| (7) Southwest | | | | | | | 1 | 1 | 1/3 | 0.093 |
| (8) West | | | | | | | | 1 | 1/3 | 0.116 |
| (9)Northwest | | | | | | | | | 1 | 0.182 |
| | | | | | | | | | | 0.222 |
| Slope degree ($^{O}$) | | | | | | | | | | |
| (1) 0 – 5 | 1 | ¼ | ¼ | 1/6 | 1/6 | 1/8 | 1/9 | | | 0.018 |
| (2) 5 – 10 | | 1 | ½ | ¼ | 1/5 | 1/6 | 1/8 | | | 0.031 |
| (3) 10 – 15 | | | 1 | ¼ | 1/5 | 1/6 | 1 | | | 0.079 |
| (4) 15 – 20 | | | | 1 | 1/3 | 1/5 | 1/7 | | | 0.088 |
| (5) 20 – 25 | | | | | 1 | 1/5 | 1/7 | | | 0.129 |
| (6) 25 – 30 | | | | | | 1 | 1/5 | | | 0.247 |
| (7) >30 | | | | | | | 1 | | | 0.408 |
| River proximity (m) | | | | | | | | | | 0.039 |
| (1) 0 – 50 | 1 | 5 | 6 | 6 | 8 | 9 | | | | 0.495 |
| (2) 50 – 100 | | 1 | 5 | 5 | 6 | 8 | | | | 0.250 |
| (3) 100 – 150 | | | 1 | 4 | 4 | 5 | | | | 0.118 |
| (4) 150 – 200 | | | | 1 | 4 | 4 | | | | 0.071 |
| (5) 200 – 250 | | | | | 1 | 4 | | | | 0.041 |
| (6) >250 | | | | | | 1 | | | | 0.023 |
| Road proximity (m) | | | | | | | | | | 0.017 |
| (1) 0 – 50 | 1 | 4 | 5 | 6 | 7 | 8 | | | | 0.475 |
| (2) 50 – 100 | | 1 | 4 | 5 | 6 | 7 | | | | 0.259 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| (3) 100 – 150 | | | 1 | 4 | 4 | 4 | | 0.129 |
| (4) 150 – 200 | | | | 1 | 2 | 3 | | 0.062 |
| (5) 200 – 250 | | | | | 1 | 2 | | 0.043 |
| (6) >250 | | | | | | 1 | | 0.031 |
| | | | | | | | | |
| Lithology | | | | | | | | 0.237 |
| (1) (Qlv) | 1 | 5 | 4 | | | | | 0.695 |
| (2) (Tpbv) | | 1 | 1 | | | | | 0.149 |
| (3) (Tmc) | | | 1 | | | | | 0.160 |
| | | | | | | | | |
| Road lineaments (m) | | | | | | | | 0.052 |
| (4) 0 – 50 | 1 | 4 | 6 | 7 | 8 | 8 | | 0.497 |
| (5) 50 – 100 | | 1 | 4 | 5 | 6 | 7 | | 0.250 |
| (6) 100 – 150 | | | 1 | 4 | 4 | 4 | | 0.122 |
| (7) 150 – 200 | | | | 1 | 2 | 3 | | 0.058 |
| (8) 200 – 250 | | | | | 1 | 2 | | 0.041 |
| Soil texture | | | | | | | | 0.113 |
| (1) Silty clay | 1 | ¼ | 1/6 | 1/7 | 1/8 | 1/9 | | 0.069 |
| (2) Silty clay loam | | 1 | 4 | 1/7 | 1/6 | 1/7 | | 0.079 |
| (3) Clay loam | | | 1 | 1/5 | 5 | 1/6 | | 0.131 |
| (4) Loam | | | | 1 | 5 | 1/5 | | 0.263 |
| (5) Silty loam | | | | | 1 | 3 | | 0.187 |
| (6) Sandy loam | | | | | | 1 | | 0.324 |
| | | | | | | | | |
| Rain fall (mm) | | | | | | | | 0.169 |
| (1) <2000 | 1 | ¼ | 1/5 | 1/6 | 1/8 | 1/9 | | 0.036 |
| (2) 2000 – 2500 | | 1 | ¼ | 1/5 | 1/6 | 1/8 | | 0.042 |
| (3) 2500 – 3000 | | | 1 | ¼ | 1/5 | 1/6 | | 0.077 |
| (4) 3000 – 3500 | | | | 1 | ¼ | ¼ | | 0.144 |
| (5) 3500 – 4000 | | | | | 1 | ¼ | | 0.261 |
| (6) > 4000 | | | | | | 1 | | 0.451 |
| | | | | | | | | |
| Landover | | | | | | | | 0.092 |
| (1) Bare land | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 0.171 |
| (2) Paddy field | | 1 | 1 | 2 | 1 | 1 | 1 | 0.140 |
| (3) Mix garden | | | 1 | 3 | 1 | ¼ | 2 | 0.131 |
| (4) Horticulture | | | | 1 | 1 | ¼ | 1 | 0.072 |
| (5) Bush | | | | | 1 | 1/3 | 4 | 0.131 |
| (6) Forest | | | | | | 1 | 7 | 0.298 |
| (7) Grass cover | | | | | | | 1 | 0.059 |

Over all concistency: 0,05

**Table 2. Index of Landslide Susceptibility Class**

| Susceptibility classes | Susceptibility index value | Number of fixel | Area (ha) | % of area |
|---|---|---|---|---|
| Very low susceptibility (VLS) | 0.0383 – 0.0903 | 115199 | 10367.91 | 27.54 |
| Low susceptibility (LS) | 0.0903 – 0.1422 | 124801 | 11232.09 | 29.83 |
| Moderate susceptibility (MS) | 0.1422 – 0.1942 | 59536 | 5358.24 | 14.23 |
| High susceptibility (HS) | 0.1942 – 0.2462 | 107926 | 9713.34 | 25.80 |
| Very high susceptibility | 0.2462 – 0.2892 | 10880 | 979.20 | 2.60 |
| Sum | | 418342 | 37650.78 | 100.00 |

The LSI values were separated into five classes using natural breaks algorithm to represent five categories of the landslide susceptibility zone (LSZ) of the area; namely, 1. Very high (VHS), 2. High (HS), 3. Moderate (MS), 4. Low (LS) and 5. Very low (VLS) susceptibility zones (Table 2). The landslide susceptibility map was verified using existing landslide inventory through the area of Jeneberang Watershed. The Figure no. 2 shows the relation between class of landslide zone and percentage of existing landslide. In this study, the analytical hierarchy process (AHP) was applied to develop landslide susceptibility map for Jeneberang Watershed. To achieve this objective, ten landslide inducing factors as mentioned in methodology were calculated. Based on data in Table 1, lithology parameter has highest weight value 0.237 followed by slope degree and rain fall parameters with value of 0.222 and 0.169 respectively. Landslides occurred mostly in The Lompobatang volcanic formation (Qlv) consist of mostly pyroclatic on the the steep slope especially around wall of Mt. Bawakaraeng caldera. Rainfall often generates the potential for initiating Instabilities of slope. It is known that the role of rainfall as triggering mechanisms of landslides is strongly influenced by the

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lithology and morphometry. The ten causative factors were evaluated, and then factor weight and class weight were assigned to each of the associated factors. Figure 2 shows; landslide susceptibility index (LSI) had a minimum value of 0.0389 and a maximum 0.2983, with mean value 0.1488 and a standard deviation 0.051. The LSI represents the relative susceptibility of landslide occurrence. Therefore, the higher index, the more of susceptibility the area is to landslide. These LSI value were divided into five classes based on percent break range, which represent five different zones in the landslide susceptibility map. These are very low (VLS), low (LS), moderate (MS), high (HS) and very high susceptibility (VHS) zones (Table 2). The obtained susceptibility map indicate that the very high (VHS) susceptible zones cover only 2.60% (979.20 hectare) of the total area, mean while about 25.80 % 9713.34 hectare) were classified as being the high (HS) susceptible and 14.23 % of the case study area (5358.24 hectare) are classified as moderate (MS) susceptible. The remaining, 57.37 % (216100 hectare) are classified as low (LS) and very low (VL) susceptibility zones. The map was also verified using landslides inventory for the area of Jeneberang watershed. Figure 3 show that more than 50% existing landslide occurred in VHS susceptible class, around 20% occurred in HS susceptible class and only less than 5% occurred in LS and VLS classes. The very highly susceptible index class covers most of the known landslides that occurred in the unstable slopes over the last several years and which were predominantly induced by fragile of lithology and high precipitation. It is known that the role of precipitation as triggering mechanisms of landslides is strongly influenced by the landscape dynamic and geology. Results of this research could be useful for explaining the known existing landslide, making emergency decisions and supporting the efforts of reduction and mitigation of future landslide hazards.

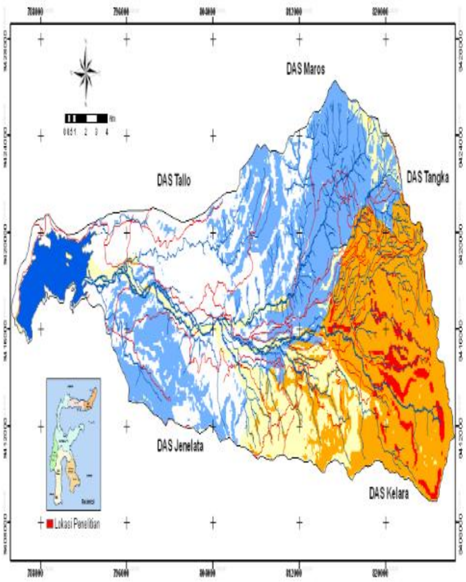


**Fig 2. Map Landslide Susceptibility Zone**

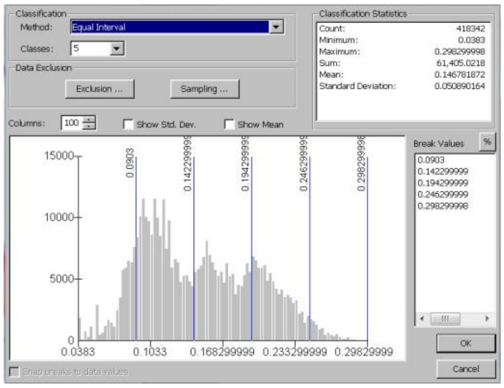


**Fig 3 Graph Reclassified Landslide Susceptibility Index**

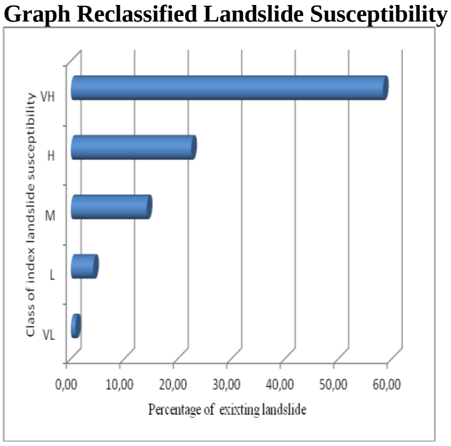


**Fig 4 Graph Percentage of Existing Landslide For Each Class of LSI**

## IV. CONCLUSION

In this study landslide susceptibility maps have been constructed using the relationship between landslide locations and causative factors. The AHP model was applied, to study the influence of different causative factors on landslide occurrence and prediction map of the area constructed based on that. This model has some advantages such as simplicity; inputs, outputs, and calculation process are really understandable. Even a large amount of data can be processed in the GIS environment quickly and easily. Moreover the influences of factors on the landslide susceptibility map were evaluated qualitatively to selection of positive factors and improve the prediction accuracy of the landslide susceptibility map. This means that the selection of factors is important to landslide susceptibility mapping. The most important causative factors in the study area are lithology and slope steepness, since other factors such as soil texture, river and road network in relation to the lithology, have secondary importance. All other factors also have some positive influences on landslide susceptibility analysis. Based on this study the most sensitive classes to landslide in the Jeneberang Watershed are as the Quaternary Lompobattang volcanic deposits and the areas have more than 30° slope steepness. Less than 50m proximity to road network, and area close to the river channel also are among the most susceptible areas for landslide occurrence. Prepared landslide prediction map could be the basis for decisions making. The information provided by this map could help citizens, planners and engineers to reduce losses caused by existing and future landslides by means of prevention, mitigation and avoidance.

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Muchtar Salam Solle was born in Makassar-Indonesia 1957. He received B.Sc and Ir. degree in soil science, Hasanuddin University of Indonesia in 1980 and 1983., Post Graduate Diploma at ITC-Netherland in watershed management 1988, and Master degree in Environmental Risk Assessment, Chiang Mai University in 1984. Now, He is Ph.D student in Graduate school at Hasanuddin Unversity Indonesia. His current research interest is landslide.