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LANDSLIDE SUSCEPTIBILITY ASSESSMENT USING THE INTEGRATION OF FREQUENCY RATIO AND WEIGHT OF EVIDENCE MODEL IN NORTH LUWU, SOUTH SULAWESI, INDONESIA

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Abstract: The masamba area of north luwu regency has been hit by a flash flood disaster on july 13, 2020. The flash flood claimed dozens of lives, hundreds of people were injured and thousands of houses were submerged. Based on the analysis of several information, the cause of the flash flood in masamba was due to high rainfall and landslides that occurred in the upstream area. Land movement vulnerability zoning is needed in this area to provide information in making disaster mitigation policies for post-disaster planning and development. Frequency ratio and weight of evidence methods were applied in this study by using parameters such as: slope, lithology, land cover, rainfall, slope direction, slope convexity, distance from river, distance from fault and soil type. The weight of evidence method provides more accurate results with an accuracy rate of 99.83%. Vulnerability zoning of landslides in the masamba area are grouped into 5 classes; the zone of vulnerability to soil movement is very high, around 6,822.27 ha or about 25.47% of the research area. The high ground movement vulnerability zone is about 4261.84 ha or about 15.91% of the research area.
Keywords: *Flash Flood; Landslide Susceptibility; Frequency Ratio;*

INTRODUCTION

A pile of rocks, dirt, or other material falls down a hill in an event or series of occurrences known as a landslide. The mechanics of landslides include the sliding, falling, or fowing of material down a slope as a result of gravity[1,2]. One of the most frequent natural disasters in North Luwu, South Sulawesi, Indonesia, is landslides. Several variables, including slope conditions and slope angle, lithology, soil type, and hydrologic or climatic conditions, might influence a landslide. Human activities like deforestation, changes brought on by building structures on slopes, undercutting the slope's toe for road construction, etc. are another potential influence. Less stable slopes can result from human modifications. Landslides have a detrimental influence on infrastructure (housing, buildings, roads, bridges, irrigation systems, and canals), cause geological and environmental damage (fractures, creeping, and slumping), and result in serious injuries and fatalities among people. South Sulawesi Province's Masamba region, the center of North Luwu Regency, was struck by flash floods and landslides on July 13, 2010. Tens of thousands of people fled, many of whom lost their possessions, at least hundreds of people were hurt, and even dozens of people died. According to the study of several field observations, heavy rains and landslides that happened in the upstream area were the main causes of the flash flood in Masamba. The geological condition of the studied area, which is predominately formed of granite lithology, supports the high landslide potential.

Due to the granite lithology's high susceptibility to weathering processes, numerous hazard mitigation measures must be taken to prevent the possibility of landslides following flash floods. Analyzing the distribution and frequency of previous landslides is necessary to pinpoint locations at increased risk of landslides. With the aid of remote sensing and Geographic Information System (GIS) capabilities, historical landslides can be easily mapped[3]. In order to identify a region's landslide susceptibility and provide the scientific data necessary for its mitigation and future landslide prevention, quantitative spatial analysis can be

[1] Iswar Chandra Das, "Spatial Statistical Modelling for Assessing Landslide Hazard and Vulnerability" (ITC, 2011).

[2] Manouchehr Motamedi, *Quantitative Landslide Hazard Assessment in Regional Scale Using Statistical Modeling Techniques* (The University of Akron, 2013).

[3] Sujit Mandal and Subrata Mondal, *Statistical Approaches for Landslide Susceptibility Assessment and Prediction*, vol. 27 (Springer, 2019).

used[4].

In order to better anticipate where, when, and how frequently landslides will occur in a given location, quantitative approaches are employed to evaluate the landslide events. By providing a relative estimation of the spatial events of landslides in a mapping unit based on the conditions of local terrain, Landslide Susceptibility (LS) is an assessment to quantify the volume or area and the spatial probability of a landslide event. It may also include information related to the temporal probability of the expected landslide event, the intensity and velocity rates of the existing or potential landslide events.

The aim of this study is to assess and evaluate the susceptibility for landslides within the North Luwu area in a GIS environment. Existing landslide data recorded on 2020 and the conditioning factors (lithology, soil type, land use, rainfall intensity, slope, slope aspect, slope convex, distance from fault and distance from river) were used to analyze landslide susceptibility across the region. The relationship between a landslide and the conditioning factors was determined using the integration of frequency ratio and weight of evidence analysis. Our hypothesis is that there will be a strong relationship between landslide occurrence and both natural and human-influenced conditioning factors in the study area.

RESEARCH METHODS

North Luwu is one of the administration areas in the South Sulawesi Province Indonesia, with total area approximately 7502,58 km^2. Astronomically, North Luwu is located between 01°53′19″−02°55′36″ South latitude, and between 119°47′46″−120°37′44″ East longitude. The geomorphology of the North Luwu region includes relatively low plains in the north to highlands in the south. The area ranges in altitude from 15 m above sea level to over 1000 m above sea level. The population density of North Luwu Regency in 2016 was 305.372 people/km^2, (Statistics of North Luwu Regency, 2017). Fig.1 represent the locations of historic landslides. The color-coded blue was used in the training dataset and red was used in the test set.

[4] Işık Yilmaz, "Landslide Susceptibility Mapping Using Frequency Ratio, Logistic Regression, Artificial Neural Networks and Their Comparison: A Case Study from Kat Landslides (Tokat—Turkey)," *Computers & Geosciences* 35, no. 6 (2009): 1125–1138.

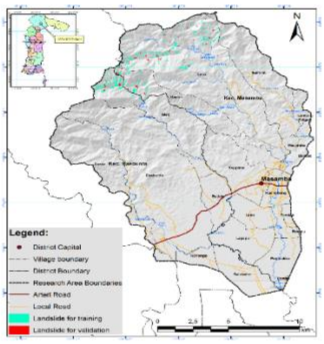

Fig. 1 Landslide map of the Disaster on July 13, 2002 in North Luwu, South Sulawesi Indonesia

The Frequency Ratio (FR) approach and the Weight of Evidence (WoE) method are used to analyze ground motion susceptibility. The outcome of the parameter map overlay will reveal each parameter map's weight value. Slope maps, geological maps, land cover maps, rainfall maps, road, river, fault, and soil type maps are some of the parameter maps that are employed. One technique for mapping the risk of ground motion is the Weight of Evidence approach. Data on past ground motion occurrences in the research area are used in this strategy. The ground motion's occurrence will give an outline of the elements affecting it.

Four main steps make up a land slide susceptibility analysis: (1) data gathering and building a spatial database from the pertinent factors, (2) determining the susceptibility using the relationships between the landslide and landslide influence factors, (3) validating the results, and (4) interpreting and comparing the results. Remondo and Van Westen evaluated various approaches that have been used to assess regional landslide susceptibility[5]. Fig.2 shows the flow chart of the research analysis on the landslide susceptibility.

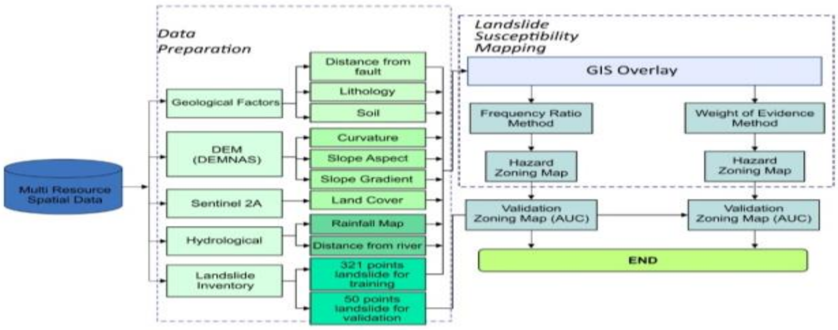

Fig. 2 Flow chart of the research analysis in the Landslide Susceptibility

[5] C J Van Westen, Th W J Van Asch, and Robert Soeters, "Landslide Hazard and Risk Zonation—Why Is It Still so Difficult?," *Bulletin of Engineering geology and the Environment* 65 (2006): 167–184.

This WoE method is a quantitative analysis method for actual landslide incidents. A map of weighted data, both continuous and categorical, based on prior and posterior probability is created using a variety of data combinations in this method[6].

$$W^{+} = \ln \left[\frac{\frac{\text{Npix landslide in class}}{\text{Npix total landslide area}}}{\frac{\text{Npix stable area in class}}{\text{Npix total stable area}}} \right] = \ln \left[\frac{\frac{\text{Area landslide in class}}{\text{Total landslide area}}}{\frac{\text{Area stable area in class}}{\text{Total stable area}}} \right] \quad \text{..............(1)}$$

$$W^{-} = \ln \left[\frac{\frac{\text{Npix landslide outside class}}{\text{Npix total landslide area}}}{\frac{\text{Npix stable area outside class}}{\text{Npix total stable area}}} \right] = \ln \left[\frac{\frac{\text{Area landslide outside class}}{\text{Total landslide area}}}{\frac{\text{Area stable area outside class}}{\text{Total stable area}}} \right] \quad \text{..............(2)}$$

Where:

W+ is the weight of the probability of ground motion in a parameter map class (positive weight).

W– is the weight of the improbability of ground motion in a class of parameters (negative weight).

The weights of W+ and W- are combined as a contrast value (C), with the following formula:

C = W+ - W- (3)

The contrast value in each special case or class serves as a gauge of its impact on landslide occurrences in the study area. The frequency ratio approach is based on the weight value of each parameter map class and the density of landslides. The area of landslides in one class unit divided by the area of the parameter map class corresponds to the density value of each class on each parameter map.

The parameter maps' weight values, which were derived from the density analysis of the aforementioned landslide events, will be combined and overlaid. To determine the total weight of the parameter map, the weight of each parameter map is added up. Following the summation of the weights, the results are divided into five (five) zones: the very low landslide danger zone; the low landslide hazard zone; the moderate landslide hazard zone; the high landslide hazard zone; and the very high landslide hazard zone.

RESEARCH RESULTS

The Area under Curve is then used to assess each of the chosen conditioning elements (AUC). AUC is one sort of accuracy in statistics used to evaluate or analyze

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[6] Netra R Regmi, John R Giardino, and John D Vitek, "Modeling Susceptibility to Landslides Using the Weight of Evidence Approach: Western Colorado, USA," *Geomorphology* 115, no. 1–2 (2010): 172–187.

natural disaster events using prediction models (probabilities).The landslide susceptibility mapping utilizing the FR approach would apply the conditioning factors defined by the AUC value.The statistic accuracy of the model, which describes the prediction threshold independently, is higher the higher the value of AUC (if threshold definition gets the maximum value of 1)[7,8,9],[10]. The minimum threshold of 0.6 for the AUC of conditioning components to be deemed processed in this study must be exceeded, indicating that performance is higher classified by chance.

A threshold independent approach on Receiver Operating Characteristic (ROC) is used to assess the impact of conditioning parameters on landslide activity by displaying the results of the accuracy values achieved against a predetermined threshold value. In order to evaluate a binary response model, such as a logistics model, receiver operating characteristic (ROC) curves and area under ROC curves (AUC) are typically used[11]. This curve shows how the ROC curve is produced and its area is estimated using validation and cross validation data sets. When using SPSS statistics, the ROC curve is tested using the matrix value of each parameter. The area under the curve (AUC) calculation formula, i.e., Pimentel 2010, is used to calculate the results, which are shown as the proportion of the study region classified as vulnerable (x-axis) versus the cumulative percent of landslide occurrence (y-axis). The data used in this study are as follows:

Occurence of Past Landslides

Landslides that have already occurred in a place can give information about other potential areas with the same criteria for upcoming landslides.

The study began with the compilation of a landslide inventory map based on previously recorded historic landslide events, documentation of field sites, and Sentinel-2A 2020 satellite imagery interpretation. A total of 371 observed historic landslide points were mapped in the area (Fig.2).

The landslides in the landslide inventory were randomly divided into a training

[7] Jill Lepore, "The Whites of Their Eyes," in *The Whites of Their Eyes* (Princeton University Press, 2011).

[8] Mandal and Mondal, *Statistical Approaches for Landslide Susceptibility Assessment and Prediction*, vol. 27, p. .

[9] Mukesh Meena et al., "Regulation of L-Proline Biosynthesis, Signal Transduction, Transport, Accumulation and Its Vital Role in Plants during Variable Environmental Conditions," *Heliyon* 5, no. 12 (2019): e02952.

[10] Majid Mohammady, Hamid Reza Pourghasemi, and Biswajeet Pradhan, "Landslide Susceptibility Mapping at Golestan Province, Iran: A Comparison between Frequency Ratio, Dempster–Shafer, and Weights-of-Evidence Models," *Journal of Asian Earth Sciences* 61 (2012): 221–236.

[11] Mauro Rossi and Paola Reichenbach, "LAND-SE: A Software for Statistically Based Landslide Susceptibility Zonation, Version 1.0," *Geoscientific Model Development* 9, no. 10 (2016): 3533–3543.

set area (70%) with 321 points, and a test set area with 50 points (30%) using the Subset Features Tools in ArcGIS. There is no specific limit in determining the distribution of training set and test set, but the greater the percentage of datasets for analysis, the higher the validation value (AUC) that will be obtained. In this study, the data set uses a ratio of 70%: 30% because the 70% data set is considered sufficient to represent analysis and 30% is considered sufficient to validate the model (Wang et al. 2016; Meena et al. 2019; Rossi and Reichenbach 2016).

Fig.2 Landslides events in North Luwu, South Sulawesi, Indonesia

Lithology

Landslide occurrences and geology were mapped in the field to establish a landslide inventory and a geological map. The geological data of North Luwu (Table 1) are providedin polygons at scales of 1:250,000 and were previously published by Geological Agency of Indonesia. The study area is covered by fourth lithological units such as alluvium formation unit,Lamasi volcanic formation unit, Bonebone formation unit, and Kambuno Granite formation unit (Fig.3).

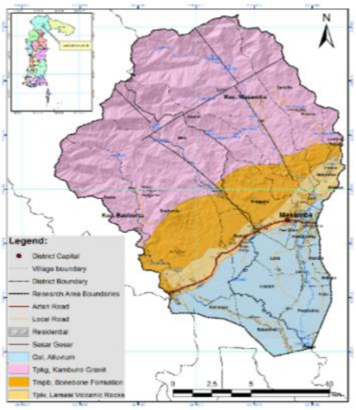

Fig.3 Geology map of North Luwu, South Sulawesi, Indonesia

3.3 Type of Soil

Particle size, shape, and pore distribution of the soil matrix influence slope stability and certain soil characteristics may be useful observations for assessing landslide frequency[12]. The soil properties influence infiltration of water, the velocity and the rate of interflow and baseflow of water movement, and the capacity of the soil to hold water. Soils with smaller (finer- textured) particles such as clay and silt have a larger surface area than the coarse-textured soils, and tend to holdlarge volumes of water, especially under unsaturated conditions (Lepore et al. 2011). In both the bedrock and the soil cover—cohesion, permeability, etc. are important. Increased pore pressures will weaken both rock and soil.

Each form of soil has unique physical characteristics, and because these characteristics will influence the degree of soil stability, this type of soil's parameters are significant in this study. The 1:50,000 scale Semi Detailed Soil Map created in 2014 by the Indonesian Agricultural Research and Development Agency, Indonesian Ministry of Agriculture, served as the basis for the soil type map. The greatest number of landslides, with a total of 93.86% events, occurred in Dystrudepts- Hapludults-Lithic Dystrudepts type.

Other soil types with failure occurence rates include the Association of Fluvaquents-Endoaquepts-Fluvaquentic Endoaquepts type (6.1%) and Dystrudepts, Hapludults, and Aquic Dystrudepts type (0.04%). There were no landslides discovered despite the presence of Fluventic Eutrudepts-Aquic Eutrudepts-Epiaquepts, Endoaquepts-Fluventic Endoaquepts-Aquic Eutrudepts, and Eutrudepts-Hapludalfs type (Fig.5).

Fig.5 Soil map of North Luwu, Indonesia

Land Cover/Landuse

The primary cause of landslides is thought to be land usage or cover. The

[12] Ibid.

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effects of weather, erosion, and slope instability rarely affect vegetated terrain[13]. Sentinel-2A 2020 satellite imagery was interpreted to produce the land cover map. About 99.77% of landslides in tropical forests and 0.23% in freshwater rivers occur there. There are no landslides in swamp water, ponds, inland sand dunes, pioneer airports, rice fields, vegetation, open space, or fields (Fig.6).

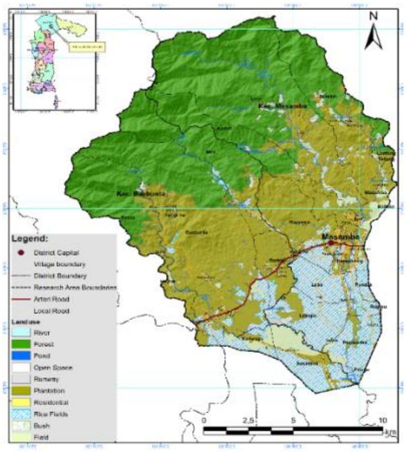

Fig.6 Landuse map of North Luwu, Indonesia

Rainfall

High rainfall in a region is one of the factors contributing to high landslides. Transportation Research Board, 1996; Timilsina et al., 2014. This research site is in the tropics, an area with heavy rainfall. High rainfall has an impact on the slopes' or soil's level of stability, which could cause landslides. Data on rainfall is derived from the Makassar Regional IV Meteorology and Geophysics Agency's yearly average rainfall. The area of the landslide increases by 47.76% at rainfall rates of (2500-3000 mm/year), 32.64% at (2000-2500 mm/year), 17.27% at (1500-2000 mm/year), and 2.34% at (1000-1500 mm/year (Fig.7).

[13] Tarun Kumar Raghuvanshi, Jemal Ibrahim, and Dereje Ayalew, "Slope Stability Susceptibility Evaluation Parameter (SSEP) Rating Scheme–an Approach for Landslide Hazard Zonation," *Journal of African Earth Sciences* 99 (2014): 595–612.

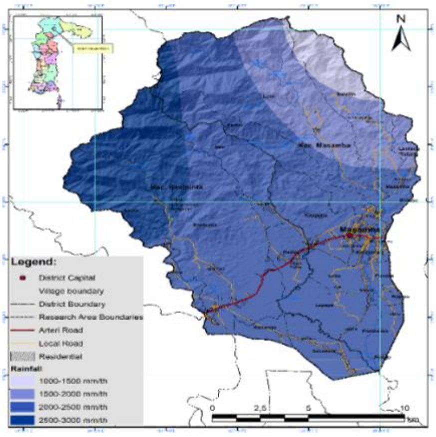

Fig.7 Rainfall map of North Luwu, Indonesia

Slope

In landslide analysis, the slope angle parameter is crucial[14]. The likelihood of landslides happening increases with slope angle. Generalized slope maps from DEMNAS data are categorized in this work into 5 classes: (0-8%), (8-15%), (15-30%), (30-40%), and (> 40%). With a percentage value of 78.28%, the landslide occurrence at the research site is the highest on the slope (>40%). There were no landslide incidents identified on slopes (0-8%), (30-40%), (15-30%), (5-15%), or (0.98%). The slopes with the highest percentages of landslides were (30-40%) and (15-30%) (Fig.8).

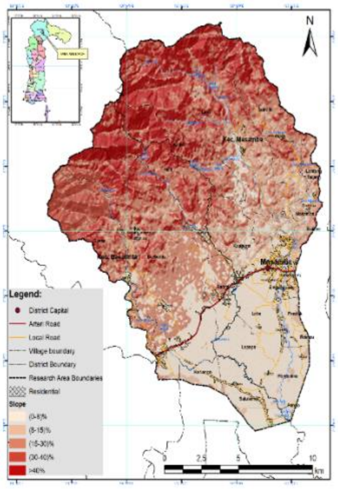

Fig 8. Slope map of North Luwu, Indonesia

Slope Aspect

Both the soil's wetness and the surrounding plants may be impacted by the

[14] Lulseged Ayalew, Hiromitsu Yamagishi, and Norimitsu Ugawa, "Landslide Susceptibility Mapping Using GIS-Based Weighted Linear Combination, the Case in Tsugawa Area of Agano River, Niigata Prefecture, Japan," *Landslides* 1 (2004): 73–81.

slope's aspect.

Slope humidity has a significant impact on the stability of the soil, which might result in landslides. From DEMNAS data, the slope aspect parameter is generalized with the following classifications: East, North, North, Northeast, Northwest, South, Southeast, Southwest, and West. With a score of 39.80%, the Southeast's slope aspect has the highest percentage of landslide occurrences. The South has the second-highest proportion of landslide events at 24.35%, followed by the East at 12.58%. The slope aspect is southwest, with a 10.30% incidence rate for landslides, a 6.84% incidence rate for landslides in the northeast, and a 3.09% incidence rate for landslides in the north.

The slope aspect in the north has a percentage value of 1.35%, the west has a percentage value of 1.09%, and the northwest has a percentage value of 0.60% for the occurrence of landslides (Fig. 9).

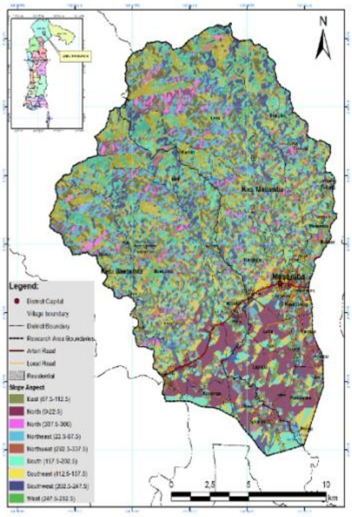

Fig.9 Slope aspect map of North Luwu, Indonesia

Slope Convex

A concave slope may be able to hold more water after rain and maintain it for a longer period of time than a convex slope. On the other hand, convex slopes mark outcrops of solid bedrock between looser rocks in several locations. As a result, the concave area's slope profile has a larger likelihood of experiencing a landslide than the convex area[15].

With a value of 52% of the total landslide occurrence, the percentage of

[15] I Ladas, I Fountoulis, and I Mariolakos, "Large Scale Landslide Susceptibility Mapping Using GIS-Based Weighted Linear Combination and Multicriteria Decision Analysis—A Case Study in Northern Messinia (SW Peloponnesus, Greece)," in *Proceedings of the 8th Panhellenic Congress of the Geographical Society of Greece*, vol. 1, 2007, 99–108.

landslide area on the convexity parameter likewise has the highest percentage value on the concave. The percentage value in the concave region is 48%. The likelihood of landslides increasing with an area's concavity (fig.10).

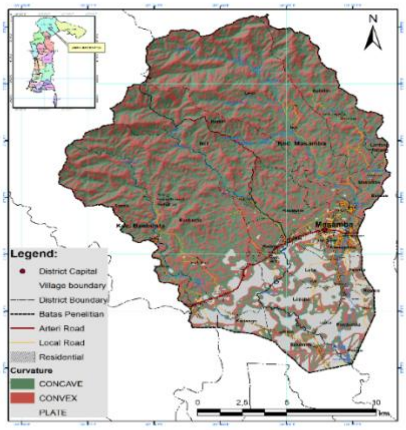

Fig.10 Curvature Map of North Luwu, Indonesia

Distance from Fault

Fault areas generally form joints so that they form cracks in the rock. The zone traversed by the fault becomes an unstable area, especially on steep slopes. The largest percentage of landslide events is also in the class (1000-1500m) with a value of 27.16%. In class (0-500m) with a percentage value of 25.58%, then in class (500-1000m) with a percentage of 20.82. In class (1500-2000) the percentage value is 10.85%. In class (2500-3000m) with a percentage of 6.57%. In the (2000-2500m) class with a percentage of 6.40% and the lowest in the (>3000m) class with a percentage value of 2.61%. (Fig.11).

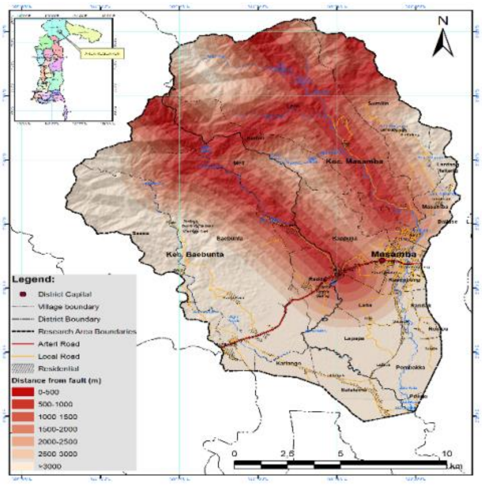

Fig.11 Distance from fault map of North Luwu, Indonesia

Distance from River

River distance is one of the parameters in this study. The flow of the river affects the walls or slopes of the river which can result in erosion of the walls or slopes of the river. River distance 0-50 m is the largest percentage of landslide events with a value of 64.26%, at a distance of 50-100 m the percentage of landslide occurrence area is 28.93%, at a distance of 100-150 m the percentage value of landslide occurrence area is 11.28%, at a distance of 150-200 m, the percentage value of the area of landslide occurrence is 4.07%. The smallest percentage of landslide occurrence is at a distance of 200-250 m with a value of 1.41%. At distances greater than 250 m, no landslides occurred (Fig. 12).

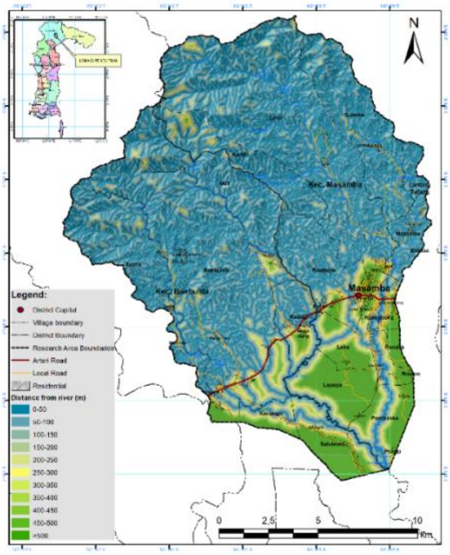

Fig.12 Distance from river map

The landslide map was evaluated with a parameter map to get the density and weight values. Calculation of the weight of each parameter as in Table 1

Zoning

The landslide vulnerability zone is grouped into 5 classes, namely very high vulnerability zone, high vulnerability zone, medium vulnerability zone, low vulnerability zone and very low vulnerability zone. In this paper, there are 9 parameters used in the analysis of ground motion zoning, namely, lithology, slope, slope aspect, distance from fault, distance from river, land cover, rainfall, soil type, and slope convexity.

The results of the zoning analysis of the vulnerability of ground movement using the Frequency Ratio method show that 9.82% of the research area is in the very high hazard zone (VHH), 18.62% high hazard zone (VH), 14.69% medium hazard zone (MH). 26.48% are in the low hazard zone (LH) and 30.39% are in the very low hazard zone (VLH), (Fig.13). The zoning of landslide susceptibility using the Weight of Evidence method shows that 25.47% of the research area is in the very high hazard zone (VHH), 15.91% of the high hazard zone (VH), 14.10% of the medium hazard zone (MH), 25.45% are in the low hazard zone (LH) and 19.06% are in the very low hazard zone (VLH) (Fig.14, table 2.).

Table 1 Parameter Map Weighting Result

Parameter	Unit Area (ha)	Landslide Area (ha)	Weight FR	W+	W-	(C) WOE
Land cover						
Swamp Water	17.39	0	0.00000	-230.259	0.09590	-239.849
River Fresh Water	208.01	0.248129	0.29126	-0.94055	0.10036	-104.091
Jungle	11159.71	10.944.633	239.465	0.91967	-226.469	318.437
Pool	11.52	0	0.00000	-230.259	0.09570	-239.829
Sand / Sand Dune	2.00	0	0.00000	-230.259	0.09538	-239.796
Pioneer Airport	53.49	0	0.00000	-230.259	0.09714	-239.972
Plantation / Garden	9377.77	0	0.00000	-230.259	0.49602	-279.860
Settlement	793.26	0	0.00000	-230.259	0.12279	-242.538
Ricefield	3597.64	0	0.00000	-230.259	0.22785	-253.044
Shrubs / Reeds	557.59	0	0.00000	-230.259	0.11453	-241.712
Wasteland	29.37	0	0.00000	-230.259	0.09631	-239.890
Field	976.45	0	0.00000	-230.259	0.12927	-243.185
Grand Total	26784.22	10.969.446	100.000			
Slope Direction						
East (67.5-112.5)	3648.27	13.794.223	0.92322	0.02267	0.10630	-0.08363
North (0-22.5)	3550.19	3.393.653	0.23341	-110.060	0.19694	-129.754
North (337.5-360)	621.46	1.481.341	0.58202	-0.38416	0.10433	-0.48849
Northeast (22.5-67.5)	2696.50	7.502.286	0.67934	-0.25046	0.12756	-0.37801
Northwest (292.5-337.5)	1160.70	0.657543	0.13832	-143.618	0.13033	-156.650
South (157.5-202.5)	5058.00	26.710.289	128.942	0.32999	0.03185	0.29814
Southeast (112.5-157.5)	5111.72	43.663.505	208.567	0.78619	-0.17061	0.95680
Southwest (202.5-247.5)	3071.77	11.298.893	0.89814	-0.00224	0.10728	-0.10953
West (247.5-292.5)	1865.62	1.192.727	0.15610	-136.428	0.15140	-151.568
Grand Total	26784.22	10.969.446				
Slope						
(0-8)%	7858.13	0	0.00000	-230.259	0.41714	-271.973
(15-30)%	7043.35	10.644.654	0.36902	-0.75915	0.28237	-104.152
(30-40)%	3892.39	12.157.449	0.76264	-0.14862	0.13149	-0.28011

Parameter	Unit Area (ha)	Landslide Area (ha)	Weight FR	W+	W-	(C) WOE
(8-15)%	3289.86	1.027.743	0.07628	-173.733	0.20697	-194.430
>40%	4700.49	85.864.614	446.031	153.141	-101.423	254.564
Grand Total	26784.22	10.969.446				
Distance From fault						
0-500	3634.72	28.057.227	188.481	0.68899	-0.04021	0.72920
500-1000	3498.10	22.839.627	159.423	0.52953	0.01035	0.51919
1000-1500	3265.32	29.793.739	222.789	0.84981	-0.07371	0.92352
1500-2000	3021.71	11.903.415	0.96186	0.05988	0.09973	-0.03985
2000-2500	2442.63	7.023.542	0.70209	-0.22161	0.12224	-0.34384
2500-3000	1883.94	7.212.074	0.93473	0.03390	0.09981	-0.06591
>3000	9037.79	2.864.836	0.07740	-173.101	0.45280	-218.380
Grand Total	26784.22	10.969.446				
Soil Type						
Fluventic Eutrudepts, Aquic Eutrudepts, Typic Epiaquepts	2503.22	0	0.00000	-230.259	0.18529	-248.787
Typic Dystrudepts, Typic Hapludults, Aquic Dystrudepts	5856.02	0.044453	0.00185	-228.429	0.32264	-260.693
Typic Dystrudepts, Typic Hapludults, Lithic Dystrudepts	7946.46	10.295.523	316.351	119.147	-167.651	286.798
Typic Endoaquepts, Fluventic Endoaquepts, Aquic Eutrudepts	2647.07	0	0.00000	-230.259	0.19076	-249.334
Typic Eutrudepts, Typic Hapludalfs,	2535.32	0	0.00000	-230.259	0.18650	-248.909
Typic Fluvaquents, Typic Endoaquepts, Fluvaquentic Endoaquepts	5296.13	6.694.775	0.30865	-0.89703	0.23997	-113.700
Grand Total	26784.22	10.969.446				
Litology						
Alluvium	5665.41	0	0.00000	-230.259	0.31457	-261.715
Lamasi Volcanic Rock	1769.33	0	0.00000	-230.259	0.15789	-246.048
Bonebone Formation	4203.00	0	0.00000	-230.259	0.25234	-255.493
Kambuno Granit	15146.47	10.969.446	176.835	0.62805	-230.259	293.063
Grand Total	26784.22	10.969.446				
Convexity of the Slope						

Parameter	Unit Area (ha)	Landslide Area (ha)	Weight FR	W+	W-	(C) WOE
CONCAVE	12958.40	57.042.539	107.483	0.16141	0.02916	0.13225
CONVEX	10572.00	52.651.921	121.605	0.27546	-0.04226	0.31772
PLATE	3253.82	0	0.00000	-230.259	0.21425	-251.683
Grand Total	26784.22	10.969.446				
Rainfall						
1000-1500 mm/th	990.82	2.561.744	0.63130	-0.31424	0.10816	-0.42240
1500-2000 mm/th	3987.23	18.945.243	116.017	0.23186	0.06941	0.16245
2000-2500 mm/th	17451.22	35.801.781	0.50093	-0.51099	0.71326	-122.426
2500-3000 mm/th	4354.94	52.385.692	293.714	111.865	-0.32446	144.312
Grand Total	26784.22	10.969.446				
Distance from River						
0-50	12438.35	59.525.374	116.851	0.23848	-0.04774	0.28623
50-100	6880.90	3.173.085	112.598	0.20422	0.05475	0.14947
100-150	2135.44	12.372.882	141.475	0.41684	0.06197	0.35488
150-200	872.40	4.466.793	125.019	0.30120	0.08759	0.21361
200-250	571.41	1.549.852	0.66228	-0.27265	0.10201	-0.37466
250-300	443.88	0.048709	0.02679	-206.604	0.11017	-217.621
300-350	375.91	0	0.00000	-230.259	0.10822	-241.081
350-400	326.03	0	0.00000	-230.259	0.10650	-240.908
400-450	289.45	0	0.00000	-230.259	0.10523	-240.782
450-500	247.31	0	0.00000	-230.259	0.10378	-240.637
>500	2203.14		0.00000	-230.259	0.17398	-247.656
Grand Total	26784.22	10.969.446				

Table 2 Landslide Movement Susceptibility Zoning Validation

Zonation	FR					WOE				
	Area Zonation (ha)	Zonation %	Area Lanslide (ha)	Lanslide %	Tot	Area Zonation (ha)	Zonation %	Area Lanslide (ha)	Lanslide %	Tot
Very High Hazard (VHH)	2630.46	9.82	11.84	59.69	94.47	6822.27	25.47	18.03	90.88	99.83
High Hazard (HH)	4987.94	18.62	6.9	34.79		4261.84	15.91	1.78	8.95	
Medium Hazar	3933.43	14.69	0.87	4.4	4.4	3776.95	14.1	0.03	0.17	0.17

d (MH)										
Low Hazard (LH)	7093.21	26.48	0.22	1.13	1.13	6816.99	25.45		0	0
Very Low Hazard (VLH)	8139.19	30.39		0		5106.16	19.06		0	
Grand Total	**26784.2**	100	**19.84**	100		**26784.2**	100	**19.84**	100	

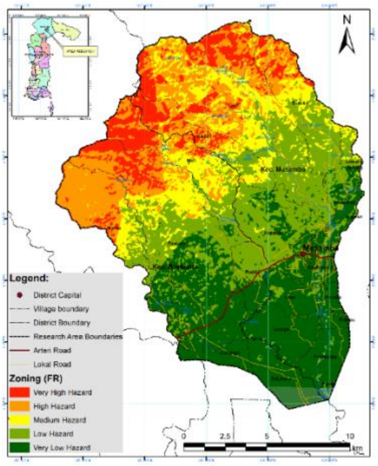

Fig.13 Zoning (FR Method)

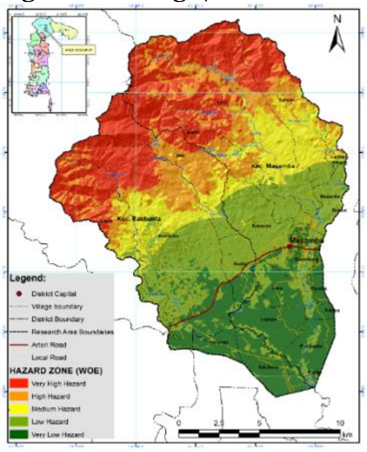

Fig.14 Zoning (WoE Method)

Zoning Validation

The validation of the zoning map was carried out by overlaying the zoning results with the old ground motion map which was not used in the analysis. The results of the analysis using the Frequency Ratio method, obtained an accuracy value of 94.47%, where the area of past landslides in the VHH zone was 59.69% and those in the VH zone were 34.79%. The area of past landslides in the MH zone was 4.40%, in the LH hazard zone was 1.13% and those in the VLH zone were 0.0%. (Table 2, Fig.13).

The results of the analysis using the Weihgt of Evidence method, obtained an accuracy value of 99.83%, where the area of past landslides in the VHH zone was 90.88% and those in the VH zone were 8.95%. The area of past landslides in the MH zone was 0.17%, in the LH hazard zone 0.0% and in the VLH zone it was 0.0%. (Table 2, Fig.14).

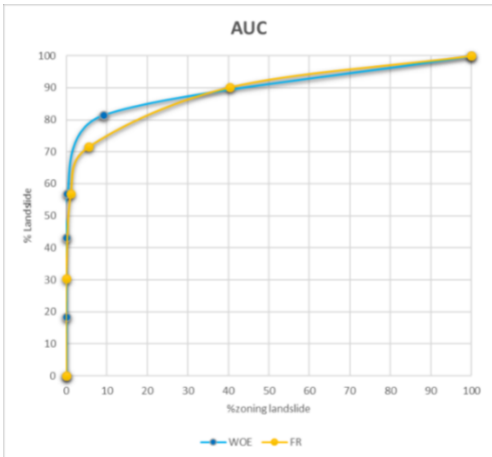

Fig.15 ROC Method accuracy test

Test the accuracy of the landslide susceptibility zoning map using the Receiver Operating Characteristic (ROC) method. This analytical method gives results in the form of ROC and AUC (Area Under Curve) curves as shown in Figure 15. The accuracy of the ground motion zoning map can be seen from the AUC on the curve which shows an accuracy of 88.75% for the WoE method and or 88.20% for the Frequency Ratio method.

The zoning accuracy of ground motion susceptibility is affected by the parameter map used in the overlay. Parameter maps that need to be added in further research are linear maps and weathering level maps. With the addition of these parameter maps, it is hoped that the accuracy of ground motion zoning can increase

CONCLUSION

One of the objectives of this research is to obtain the zoning of the susceptibility of the soil movement by using a comparison of two methods. The stages of activities in this research are literature review, secondary data collection, field survey, analysis, and report preparation. This study uses nine causal factors, namely; lithology, distance from fault, distance from river, land cover, rainfall, soil type, slope convexity, slope and slope aspect. The analytical method used is the Frequency Ratio method and the Weight of Evidence method. The parameter map overlay gets the total weight divided into five zones. Based on the validation results of the two landslide susceptibility zoning maps, it can be concluded that zoning using the Weight of Evidence method is more accurate than the Frequency Ratio method.

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