JOURNAL OF DEGRADED AND MINING LANDS MANAGEMENT
Volume 10, Number 3 (April 2023):4537-4546, doi:10.15243/jdmlm.2023.103.4537
ISSN: 2339-076X (p); 2502-2458 (e), www.jdmlm.ub.ac.id

Research Article

Comparison of two landslide hazard zonation methods in the volcanic terrain of Temanggung Regency, Central Java, Indonesia

Wahyu Wilopo[1,3*], Doni Prakasa Eka Putra[1,3], Teuku Faisal Fathani[2,3], Avantio Pramaditya[2,3], Restu Tandirerung[4], Egy Erzagian[1,3]

[1] Geological Engineering Department, Gadjah Mada University, Jl. Grafika No.2 Bulaksumur, Yogyakarta, Indonesia
[2] Civil and Environmental Engineering, Gadjah Mada University, Jl. Grafika No.2 Bulaksumur, Yogyakarta, Indonesia
[3] Center for Disaster Mitigation and Technological Innovation (GAMA-InaTEK) Universitas Gadjah Mada, Yogyakarta, Indonesia
[4] Geological Engineering Department, Papua University, Jl. Poros Waisai - Warsambin, Kota. Raja Ampat, Indonesia

[*]corresponding author: wilopo_w@ugm.ac.id

Article history:
Received 30 November 2022
Accepted 22 January 2023
Published 1 April 2023

Keywords:
frequency ratio
landslide susceptibility map
Temanggung Regency
weight of evidence

Abstract

Landslides are a recurring phenomenon that disrupts the natural environment and causes yearly property damage, economic losses, and fatalities. The damage is expected to increase due to deforestation rates, population growth, agriculture, slope-building infrastructure expansion, and global climate change. This study assesses the susceptibility to landslides through Weight of Evidence (WoE) and Frequency Ratio (FR) methods in the Temanggung Regency, Central Java Province, Indonesia, that located on the slopes of two active volcanoes. Initially, a landslide record and the input parameters of the landslide controlling factors were prepared from field surveys, remote sensing data, and secondary data and processed by a geographic information system (GIS). Six landslide parameters in thematic layer maps were selected to develop landslide susceptibility: slope, lithology type, geological structure density, land cover, and rainfall. According to the WoE and FR models, a landslide susceptibility zoning map was classified into four landslide-prone zones from low to very high. Finally, the success and predictive rate curves method confirmed the landslide susceptibility maps to check the model accuracy. The results showed that the landslide susceptibility map using the WoE method had better accuracy than the FR method, with a success rate of 78.48% and a prediction rate of 81.1%. In comparison, the FR method was 74.53% for the success rate and 78.48% for the prediction rate. These landslide susceptibility maps can be used as a guideline to develop land-use planning and landslide disaster mitigation.

To cite this article: Wilopo, W., Putra, D.P.E., Fathani, T.F., Pramaditya, A., Tandirerung, R. and Erzagian, E. 2023. Comparison of two landslide hazard zonation methods in the volcanic terrain of Temanggung Regency, Central Java, Indonesia. Journal of Degraded and Mining Lands Management 10(3):4537-4546, doi:10.15243/jdmlm.2023.103.4537.

Introduction

Landslide is a recurring hazard, and the frequency increases yearly. Climate change that triggers extreme rains and the increasing number of people living in mountainous areas will increase the number of fatalities due to landslides (Haque et al., 2019). In Indonesia, at least 40.9 million people reside in landslide-prone areas (BNPB, 2020). The community exposed to landslides in developing countries is mainly located in rural areas with low accessibility, low education, and economically included in the middle to lower class (Fathani et al., 2014). Regional planning and development that put landslides into consideration could minimize the risk of land degradation. One way to put landslides in regional planning and development is by identifying and creating a good landslide zonation map (Rahman and Mapjabil, 2017).

Many disciplines have surveyed landslides, including geomorphologists, geologists, and engineering. All of them used different approaches but had to do with understanding the process and proposing ways to assess and avoid it (Morgan, 2005). The first phase is to create a reliable and accurate map to help predict the hazards and risks of ground movement in a particular area (Guerra et al., 2016).

There are three landslide susceptibility and hazard zonation methods: qualitative, semi-quantitative, and quantitative (Shano et al., 2020). Qualitative methods consist of inventory or distribution analysis, geomorphic analysis, and expert evaluation techniques (heuristics) based on the experience and knowledge of researchers (Corominas et al., 2014).

The qualitative method scores and correlates each factor toward landslide occurrence, heavily dependent on the researcher's experience and competence (Van Westen et al., 2006). The quantitative approach includes statistical, deterministic, and probabilistic (Raghuvanchi et al., 2014). The statistical method uses landslide data correlated to the landslide factor, in which the score is calculated using the statistic method, unlike the qualitative approach, which depends on the users (Gomez and Kavzoglu, 2005). The deterministic method uses physical properties such as cohesion and internal friction of slope materials. It proves that it is essential to predict an event of ground movement. It is usually conducted by creating a comprehensive model to look for its safety factor.

The quantitative method needs detailed data for a precise scale or small area. The qualitative methods are more subjective than quantitative methods (Gomez and Kavzoglu, 2005; Raghuvanchi et al., 2014; Girma et al., 2015); therefore, quantitative methods are more objective (Girma et al., 2015).

Methods

The research was conducted in Temanggung Regency Central Java, Indonesia, covering around 870 km^2, as shown in Figure 1 (BIG, 2021; BPS Temanggung, 2021; Google Earth, 2021). The topography of Temanggung Regency includes highlands with an altitude of more than 500 masl. The topographical pattern of the area generally resembles a giant basin or depression that opens in the southeast-south and west bounded by two active volcanoes, namely Mt. Sumbing (3,260 masl) and Mt. Sindoro (3,151 masl) (BPS Temanggung, 2021). It is bordered by a small mountain range stretching from the northeast to the southeast in the north. Temanggung Regency has a tropical climate. It has a dry season from April to September and a rainy season from October to March, with generally high annual rainfall, wherein 2020 reaches 2,464 mm (BPS Temanggung, 2021). The Temanggung Regency area is typically cold, with mountain air ranging from 20 ºC to 30 ºC. The population of Temanggung Regency in 2020 was 790,174 people. Most residents work as farmers and stay in rural areas (BPS Temanggung, 2021). The susceptibility map was developed by statistical methods of the weight of evidence (WoE) and frequency ratio (FR). The WoE is a data-driven method used for a combination set of data–landslide factors to predict the probabilities of future landslides (Carranza, 2004; Wang et al., 2016; Cao et al., 2021). This method considers before and after landslide occurrence in its calculation (Van Westen et al., 2003). The formula of WoE calculation is presented in equations 1 to 3 (Van Westen et al., 2003).

$$W^{+} = \ln\left(\frac{\frac{(x)}{(z)}}{\frac{(a)}{(c)}}\right) \quad (1)$$

$$W^{-} = \ln\left(\frac{\frac{(y)}{(z)}}{\frac{(b)}{(c)}}\right) \quad (2)$$

$$C = W^{+} - W^{-} \quad (3)$$

where:

C : Final score
(y) : landslide area outside class
(a) : stable area in the class
(c) : total stable area
(x) : landslide area in class
(z) : total landslide area
(b) : the stable area outside class

The FR method is similar to the WoE, which compares the landslide area/occurrence in each parameter class (Lee and Pradhan, 2007). The equation for frequency ratio is shown in equation 4 (Lee and Pradhan, 2007).

$$FR = \frac{D_i/A_i}{\sum_{i-1}^{N} D_i / \sum_{i=1}^{N} A_i} \quad (4)$$

where:

FR : Frequency ratio value
Di : Total of landslide area of a class in one parameter
Ai : Total area of a class in one parameter
∑Di : Total landslide area
∑Ai : Total research area

The difference between the two methods is that the WoE considers the stable area while the frequency ratio calculates the total area. The WoE and FR create a value for the following calculation using the landslide susceptibility index (LSI), as shown in equation 5 (Avinash and Ashmanjari, 2010).

LSI = FR(Factor 1)+FR(Factor 2)+...FR(Factor n).. (5)

The score of each factor was accumulated and then divided into classes using the equal distance method. The area with a high LSI is equivalent to a highly susceptible area (Avinash and Ashmanjari, 2010).

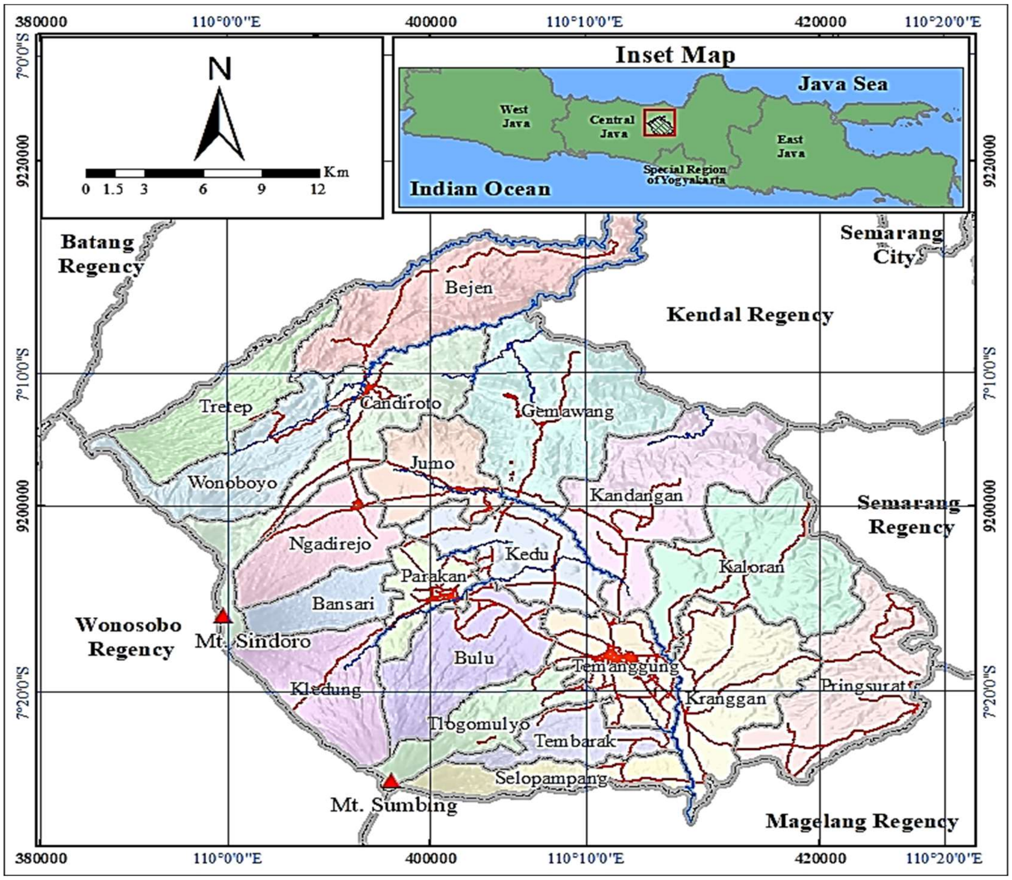

Figure 1. Research area.

The landslide susceptibility map was confirmed by a success rate curve using 70% of the total landslide occurrence and the remaining data for the prediction rate curve (Nguyen et al., 2019; Nohani et al., 2019; Ul Moazzam et al., 2020). The success and prediction rate curves explain WoE and FR's accuracy for landslide events' selected causal factors. Success and prediction rate curves were estimated by the LSI values ranging from very low to highly vulnerable and combined with landslide event data through geostatistical tools in GIS. The area under (AUC) method confirmed the susceptibility maps' accuracy from WoE and FR models. The AUC graph was created by assigning a cumulative area of the LSI class as the X-axis and the percentage of a landslide occurrence of the LSI class as the Y-axis (Samodra et al., 2017). The high accuracy of the success and the prediction rate curves were indicated by sharp curves and their high percentage value. All the thematic maps were plotted in the topographic map, digital elevation model (DEMNAS), and Google Earth (BIG, 2018; BIG, 2021).

Results and Discussion

The parameters used in this research were slope, lithology type, geological structure (lineament) density, land cover, drainage density, and rainfall. The slope in Temanggung Regency is varied from 0^o to 47^o, classified into five classes of 0^o-8^o, >8^o-15^o, >15^o-25^o, >25^o-45^o, and >45^o (Samodra et al., 2017), as shown in Figure 2(a). The dominant slope class is 0^0-8^o and >8^o-15^o. Most landslides occurred in the slope around >8^o-15^0. Field data found seven lithology units: volcanic sediment, andesite breccia, Sindoro breccia, Sumbing breccia, andesite, tuffaceous sandstone, and marl (Saputra et al., 2017), as shown in Figure 2(b). Almost all the rocks in the field have been weathered. Andesite breccia is the dominant lithology in Temanggung Regency, while Marl is the minor lithological type. Most of the landslides occurred in the breccia. The geological structure (lineament) was delineated according to the regional geology and the digital elevation model (DEM) to determine its density (BIG, 2018). The density class was divided into 10 using the equal value method, as shown in Figure 2(c). The dividing method into ten categories referred to previous research (Avinash and Ashmanjari, 2010; Pradhan and Lee, 2010; Wang et al., 2016). This treatment is specified for raster data with an ordinal value obtained by secondary data processing. The area closer to the geological structure will be less compact and brittle, making it easier to move (Kirkpatrick et al., 2021).

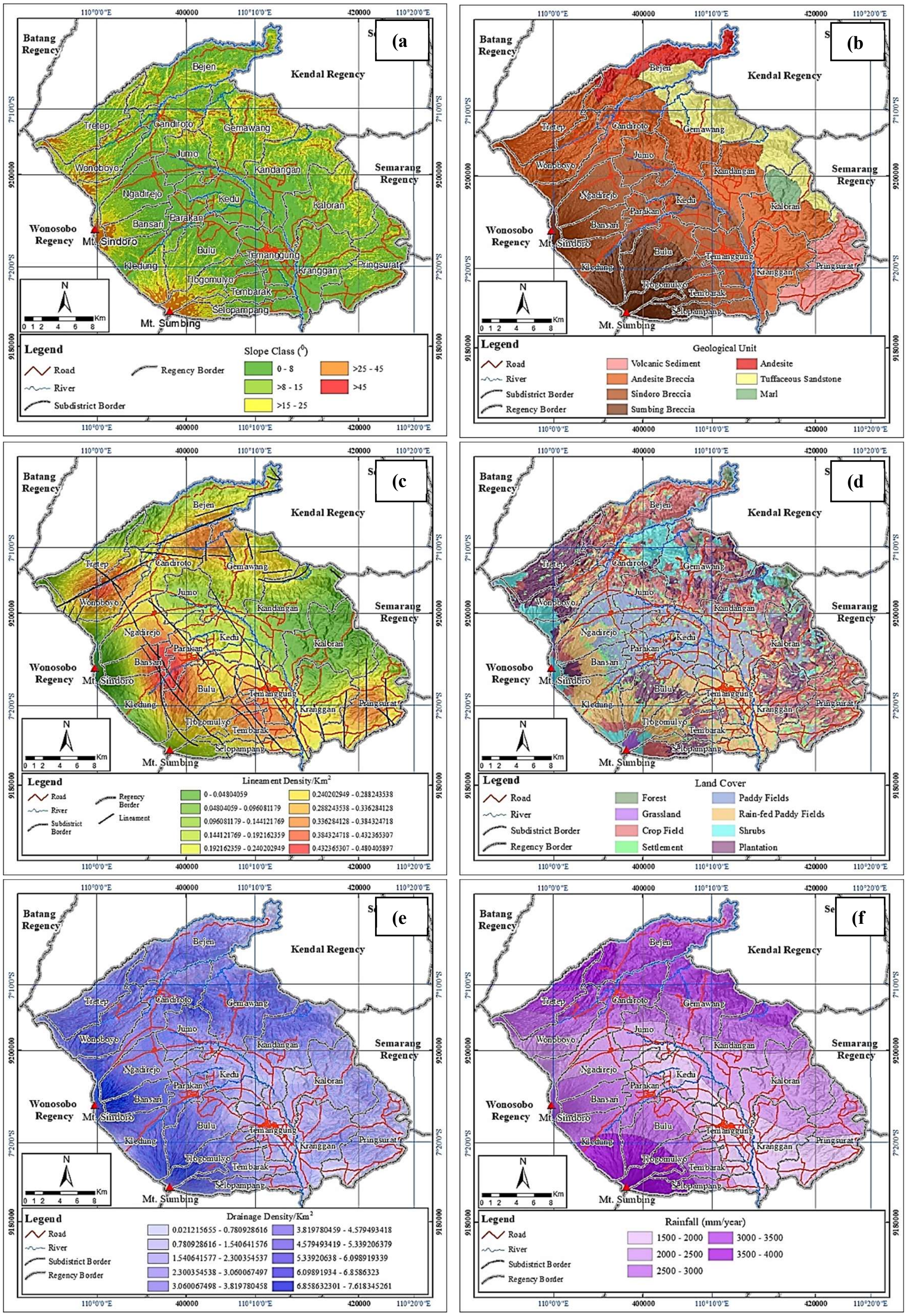

Figure 2. Parameters of landslide susceptibility map. (a) slope; (b) lithology; (c) lineament density; (d) land cover; (e) drainage density and (f) rainfall.

A land cover is divided into eight classes: forest, grassland, crop field, settlement, paddy fields, fain-fed paddy fields, shrubs, and plantation, as shown in Figure 2(d). The landslide dominated the settlement and cultivated plantations, paddy fields, and shrubs. Only a very few are located in the forest area. Drainage data was obtained and identified from the Geospatial Information Agency of Indonesia (BIG, 2018). The drainage has the same treatment as a geological structure, which was processed to obtain its density and classified into ten classes, as shown in Figure 2(e). Rainfall data were collected from the meteorological, geophysical, and climatological agency (BMKG) of Central Java, as shown in Figure 2(f).

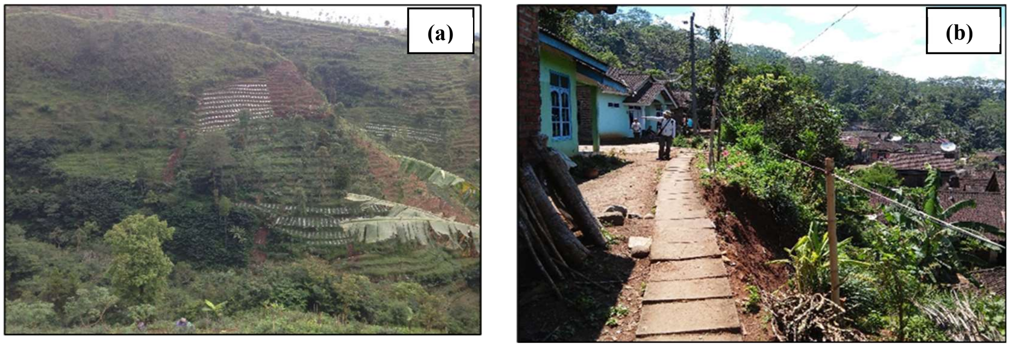

Figure 3. (a) Landslide in the agricultural area; (b) Landslide in the settlement area.

Landslide susceptibility map

A total of 182 landslide data was collected in this research five years ago. Many landslides occur in the agricultural and settlement areas, as shown in Figure 3. In addition, the distribution of landslides is mainly located on the research area's west side, consisting of volcanic material from Mt. Sumbing and Mt. Sindoro. The landslide data are divided into two categories, model and validation data. The calculation of each landslide parameter and landslide data for the model of landslide susceptibility using WoE and FR methods, as shown in Table 1. One hundred twenty-seven landslide data (70% of the total landslides) for developing the susceptibility model and 55 for validation were picked randomly, as shown in Figure 4.

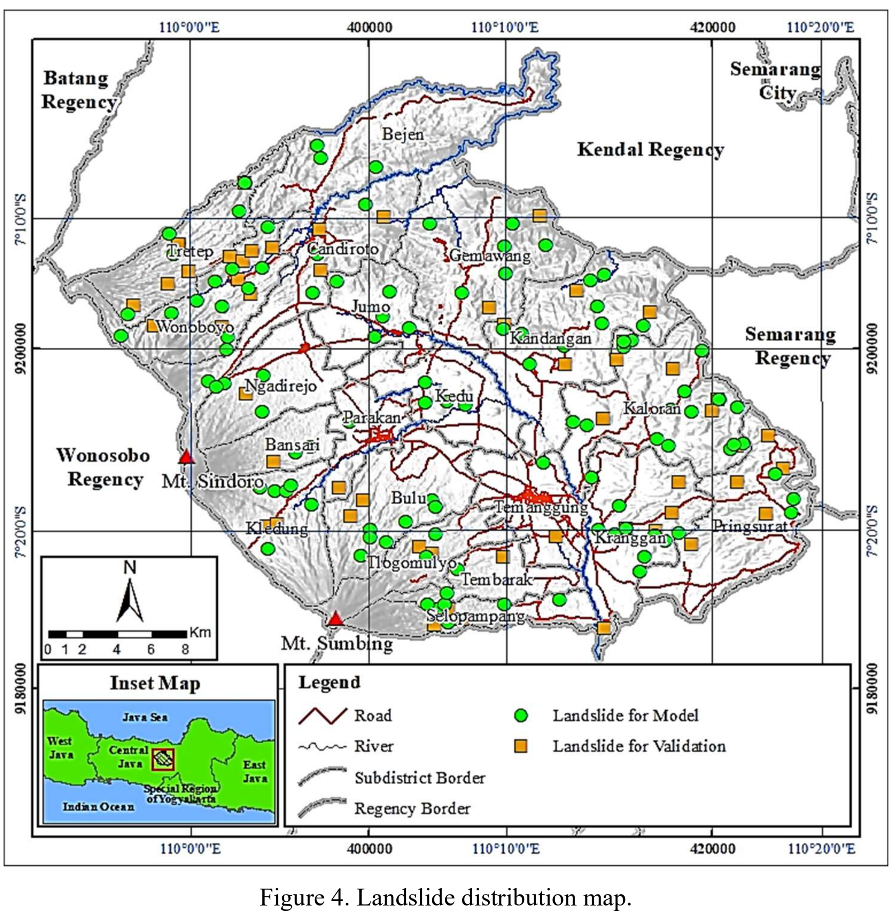

Figure 4. Landslide distribution map.

Table 1. Table of WoE and FR calculation

Parameter	Class	Class Area (m^2)	Research Area (m^2)	Landslide Area (m^2)	Total Landslide Area (m^2)	W+	W-	C	FR
Slope	0º-8º	432,054,742.67	86,882.23	949	5,082	-0.9795	0.4810	-1.4605	0.38
	>8º-15º	256,526,193.11		3264		0.7772	-0.6780	1.4552	2.18
	>15º-25º	139,267,746.60		739		-0.0974	0.0176	-0.1150	0.91
	>25º-45º	40,924,033.04		130		-0.6105	0.0223	-0.6328	0.54
	>45º	49,633.00		0		0.0000	0.0001	0.0000	0.00
Geological Unit	Andesite	37,554,258.83	86,882.23	15	5,082	-2.6841	0.0412	-2.7253	0.07
	Tuffaceous Sandstone	99,443,119.89		327		-0.5759	0.0550	-0.6310	0.56
	Andesite Breccia	297,732,964.61		1521		-0.1354	0.0639	-0.1993	0.87
	Sindoro Breccia	265,613,132.34		488		-1.1581	0.2639	-1.4220	0.31
	Sumbing Breccia	99,415,548.33		2460		1.4423	-0.5403	1.9826	4.23
	Volcanic Sediment	55,912,347.06		175		-0.6253	0.0315	-0.6568	0.54
	Marl	13,150,977.36		96		0.2215	-0.0038	0.2254	1.25
Lineament Density	0-0.0480	86,341,849.48	86,882.23	312	5,082	-0.4816	0.0413	-0.5229	0.62
	>0.0480-0.0961	65,446,193.65		250		-0.4261	0.0279	-0.4540	0.65
	>0.0961-0.1441	94,675,902.41		261		-0.7523	0.0627	-0.8149	0.47
	>0.1441-0.1922	126,511,723.51		414		-0.5808	0.0724	-0.6532	0.56
	>0.1922-0.2402	134,080,476.29		165		-1.5588	0.1346	-1.6934	0.21
	>0.2402-0.2882	143,953,921.51		734		-0.1373	0.0252	-0.1625	0.87
	>0.2882-0.3363	106,211,050.32		1960		1.1490	-0.3568	1.5058	3.15
	>0.3363-0.3843	78,791,953.79		710		0.4321	-0.0554	0.4876	1.54
	>0.3843-0.4324	20,223,299.27		156		0.2767	-0.0076	0.2843	1.32
	>0.4324-0.4804	12,585,978.19		120		0.4886	-0.0093	0.4979	1.63
Land Cover	Forest	10,773,655.03	86,882.23	10	5082	-1.8408	0.0105	-1.8514	0.16
	Grassland	5,208,034.10		0		0.0000	0.0060	0.0000	0.00
	Crop Field	243,350,377.73		913		-0.4441	0.1306	-0.5747	0.64
	Settlement	94,696,843.47		649		0.1584	-0.0212	0.1797	1.17
	Paddy Field	133,127,782.94		252		-1.1282	0.1155	-1.2437	0.32
	Rain-fed Paddy Field	153,155,678.27		1255		0.3371	-0.0897	0.4268	1.40
	Shrubs	81,664,623.88		860		0.5880	-0.0867	0.6747	1.80
	River	3,867,173.06		0		0	0.0045	0	0.00
	Plantation	142,978,179.95		1143		0.3124	-0.0750	0.3874	1.37

Parameter	Class	Class Area (m²)	Research Area (m²)	Landslide Area (m²)	Total Landslide Area (m²)	W+	W-	C	FR
Drainage Density	0-0.0480	11,103,481.73	86,882.23	0	5,082	1.0000	0.0129	-0.0129	0.00
	>0.0480-0.0961	72,287,948.69		116.00		0.9772	0.0638	-1.3572	0.27
	>0.0961-0.1441	200,742,802.68		528.00		0.8961	0.1530	-0.9523	0.45
	>0.1441-0.1922	142,955,521.07		437.00		0.9140	0.0899	-0.7388	0.52
	>0.1922-0.2402	188,069,052.36		838.00		0.8351	0.0637	-0.3359	0.76
	>0.2402-0.2882	153,315,628.50		1,113.00		0.7810	-0.0530	0.2690	1.24
	>0.2882-0.3363	63,535,465.31		1,300.00		0.7442	-0.2195	1.4717	3.50
	>0.3363-0.3843	22,634,204.80		750.00		0.8524	-0.1333	1.8676	5.66
	>0.3843-0.4324	8,526,532.16		-		1.0000	0.0099	-0.0099	0.00
	>0.4324-0.4804	5,651,711.12		-		1.0000	0.0065	-0.0065	0.00
Rainfall (mm/year)	1,500-2,000	143,054,571.73	86,882.23	331.00	5,082	-0.9274	0.1126	-1.0400	0.40
	>2,000-2,500	257,016,036.39		833.00		-0.5904	0.1717	-0.7621	0.55
	>2,500-3,000	230,905,537.92		932.00		-0.3710	0.1063	-0.4773	0.69
	>3,000-3,500	149,889,815.53		591.00		-0.3944	0.0657	-0.4601	0.67
	>3,500-4,000	87,956,386.86		2395		1.5380	-0.5305	2.0685	4.66

The LSI treatment is divided into ten categories to calculate the susceptibility map's success rate and prediction rate by the area under curve (AUC) method. The WoE method's value ranges from -8.4801 to 7.4859, as shown in Figure 5(a), and the FR method is from 0.92 to 17.02, as shown in Figure 5(b). Even though the value of each method is different, both have the same treatment divided into ten classes using equal distance. The landslide model data estimates the success rate for validation, whereas the prediction rate uses the remaining data for validation. Landslide susceptibility map by the WoE method has a success rate of 78.48%, while FR is 74.53%, as shown in Figure 6(a).

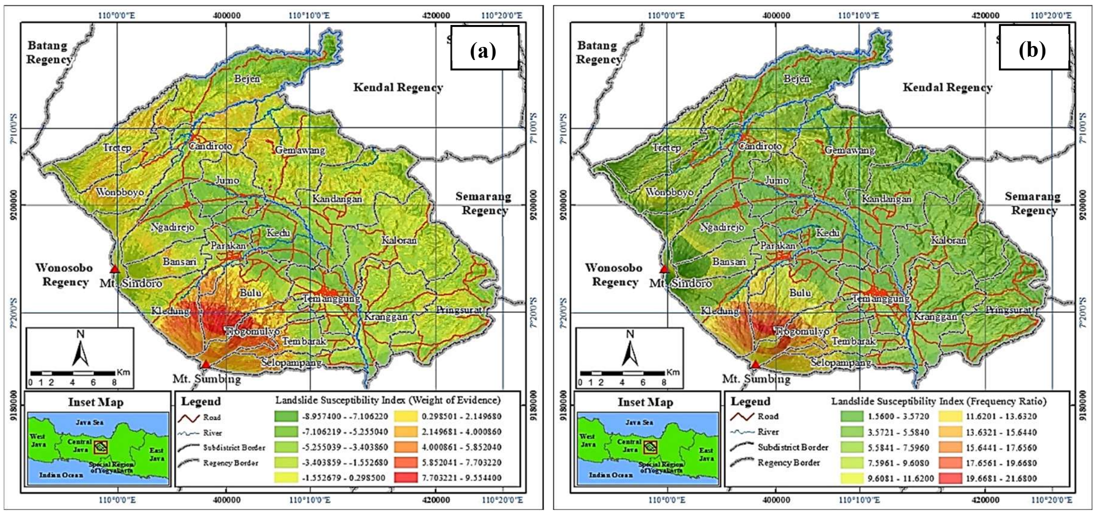

Figure 5. Landslide susceptibility index map of research area, (a) WoE method and (b) FR method.

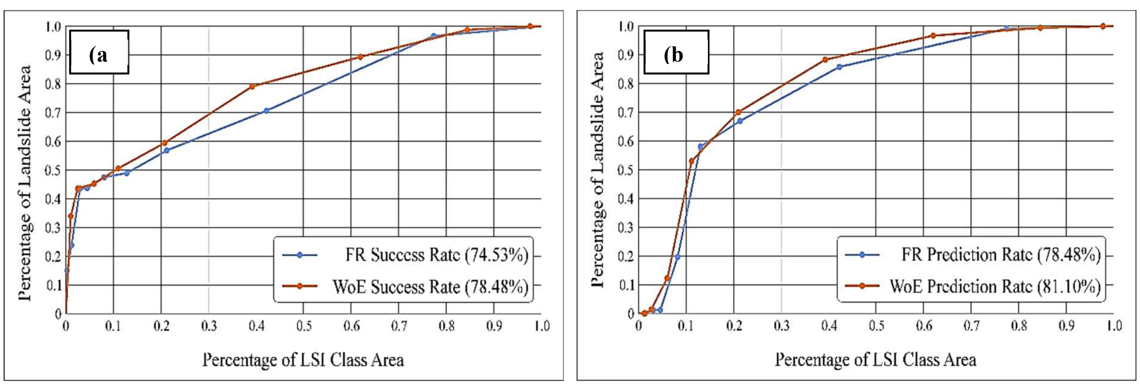

Figure 6. The accuracy of the landslide susceptibility maps (a) Success Rate Curve; (b) Prediction Rate Curve.

Instead, the landslide susceptibility map using the WoE method has a prediction rate of 81.10%, while the FR method is 78.56%, as shown in Figure 6(b). Whether using a success or prediction rate, the WoE method produces a better map within the same parameters and landslide data for the Temanggung Regency area. It must be known that the landslide data being used was picked randomly. The result is purely obtained by using statistics without prior knowledge to interfere.

To make the map applicable, it is divided into four susceptibility classes: low, medium, high, and very high (BSN, 2016), using the Natural Breaks Jenks classification. This classification is commonly used for its high reliability (North, 2009). It is shown that the WoE method has more medium and high susceptibility areas than the FR method. It might be one reason the WoE method has higher accuracy than the FR method. The WoE and FR methods created different susceptibility distribution areas, as shown in Figure 7. Both methods' extent and susceptibility distribution in each class also have different values, as shown in Table 2. The WoE susceptibility class consists of very low 22,334 ha, low 28,030 ha, medium 26,238 ha, and high 10,278.43 ha. Instead, the FR susceptibility class is very low at 12,636 ha, low at 39,488 ha, medium at 27,367 ha, and high at 7,389 ha. The distribution of landslide area in the WoE method following the susceptibility class with the very high susceptibility has the most area distribution of landslide area is more suitable in the WoE method than the FR method.

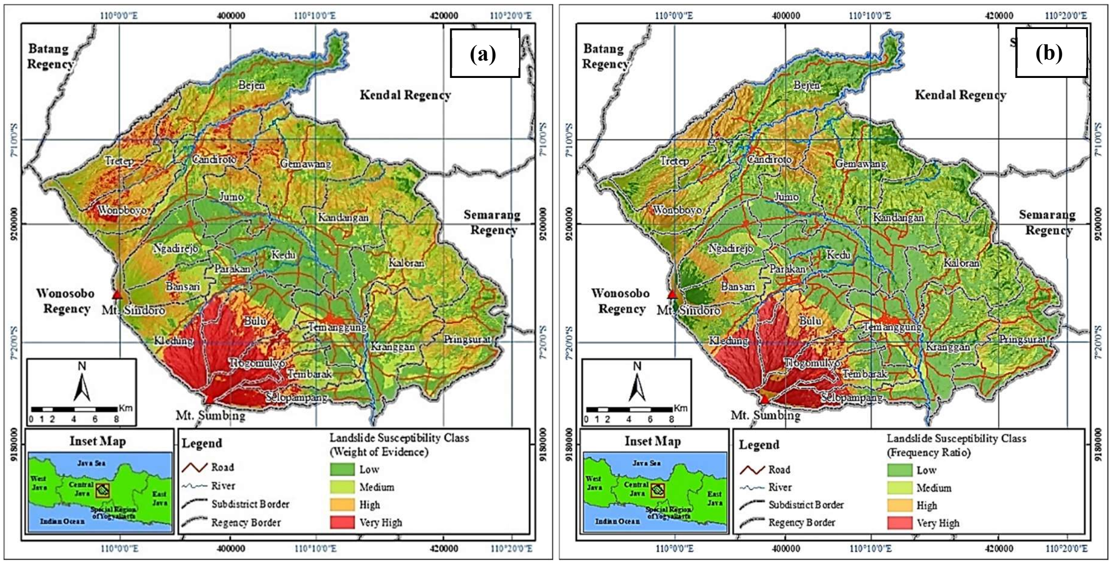

Figure 7. The landslide susceptibility map of Temanggung Regency, (a) WoE method and (b) FR method.

Table 2. Comparison of the class area of WoE and FR.

Class	Weight of Evidence				Frequency Ratio			
	Area (ha)	Landslides occurrences	Landslides (m^2)	% of the landslide area	Area (ha)	Landslides occurrences	Landslides (m^2)	% of the landslide area
Low	22,334.40	21	316	0.00013	12,636.56	42	778	0.00062
Medium	28,030.48	40	972	0.00035	39,488.77	76	2,229	0.00058
High	26,238.93	72	2,101	0.00080	27,367.50	30	1,035	0.00038
Very High	10,278.43	30	3,963	0.00386	7,389.40	15	3,310	0.00447
Total	86,882.23	163	7,352		86,882.23	163	7,352	

Conclusion

In the current study, the weights of the evidence and the frequency ratio methods were applied to develop a landslide susceptibility map in Temanggung Regency, Central Java Province, Indonesia. Landslide susceptibility parameters comprised a slope, lithology type, geological structure density, drainage density, land cover, rainfall, and landslide data. The WoE model shows better results compared to the FR model in this study of the landslide susceptibility map, with a success rate of 78.48% and a prediction rate of 81.10%. The result of this study can be used by local disaster management authorities to arrange a mitigation technique for landslides, especially in the high susceptibility areas, to avoid casualties and infrastructure damages due to landslides in the future. The study also shows that landslide hazards are more common in volcanic material on the slope of an active volcano than in tertiary sedimentary rocks. Quaternary volcanic deposits that have not been well consolidated will be easier to move than sedimentary rocks. Therefore, appropriate land use planning and strict forest conservation on the volcano's slopes are necessary to reduce environmental damage.

Acknowledgements

The authors would like to thank the local disaster management authority (BPBD) of Temanggung Regency for providing secondary data and support during fieldwork. In addition, the authors would also thank the Ministry of Research and Technology of the Republic of Indonesia for the support under contract number 2323/UN1/DITLIT/Dit-Lit/PT.01.03/2022.

References

Avinash, K.G. and Ashmanjari, K.G. 2010. A GIS and Frequency Ratio Based Landslide Susceptibility Mapping: Aghnashini River Catchment, Uttara Kannada, India. *International Journal of Geomatics and Geoscience* 1(3):343-353.

Cao, Y., Wei, X., Fan, W., Nan, Y., Xiong, W. and Zhang, S. 2021. Landslide susceptibility assessment using the Weight of Evidence method: A case study in Xunyang area, China. *PLoS ONE* 16(1):e0245668, doi:10.1371/journal. Pone.0245668

Carranza, E.J.M. 2004. Weights of evidence modeling of mineral potential: a case study using small number of prospects, Abra, Philippines. *Natural Resources Research* 13(3):173-187, doi:10.1023 /B:NARR.0000046919.87758.f5.

Corominas, J., van Westen, C.J., Frattini, P., Cascini, L., Malet, J.P, Fotopoulou, S, Catani, F, van den Eeckhaut, M., Mavrouli, O.C, Agliardi F., Pitilakis, K., Winter, M.G, Pastor, M., Ferlisi, S., Tofani, V., Hervás, J. and Smith, J.T. 2014. Recommendations for the quantitative analysis of landslide risk. *Bulletin of Engineering Geology and the Environment* 73(2):209-263, doi:10.1007/s10064-013-0538-8.

Fathani, T.F., Karnawati, D. and Wilopo, W. 2014. An adaptive and sustained landslide monitoring and early warning system. In: Sassa, K., Canuti, P. and Yin. Y.(eds). *Landslide Science for a Safer Geoenvironment* Vol.2. Springer International Publishing. P.563-567, doi:10.1007/978-3-319-05050-8_87.

Geospatial Information Agency (BIG). 2018. DEMNAS, accessed at https://tanahair.indonesia.go.id/demnas/#/demnas on April 2021.

Geospatial Information Agency (BIG). 2021. Indonesian Digital Topographic Map. Accessed at https://portal.ina-sdi.or.id/downloadaoi/ on August 2021.

Girma, F., Raghuvanshi, T.K., Ayenew, T. and Hailemariam, T. 2015. Landslide hazard zonation in Ada Berga District, Central Ethiopia - a GIS based statistical approach. *Journal of Geometry* 9(1):25-38.

Gomez, H. and Kavzoglu, T. 2005. Assessment of shallow landslide susceptibility using artificial neural networks in Jabonosa River Basin, Venezuela. *Engineering Geology* 78, doi:10.1016/j.enggeo.2004.10.004.

Guerra, A.J.T., Fullen, M.A., Jorge, M.C.O. and Bezerra, J.F.R. 2016. Slope processes, mass movements, and soil erosion: a review. *Pedosphere* 27(1):27-41, doi:10.1016/S1002-0160(17)60294-7.

Haque, U., da Silva, P.F., Devoli, G., Pilz, J., Zhao, B., Khaloua, A., Wilopo, W., Andersen, P., Lu, P., Lee, J., Yamamoto, T., Keellings, D., Wu, J.H. and Glass, G.E. 2019. The human cost of global warming: Deadly landslides and their triggers (1995-2014). *Science of The Total Environment* 682:673-684, doi:10.1016/j.scitotenv.2019.03.415

Indonesia National Board for Disaster Management (BNPB). 2020. Indonesian Disaster Risk Index (IRBI), BNPB, Jakarta, 218p.

Kirkpatrick, H.M., Moon, S., Yin, A. and Harrison, T.M. 2020. Impact of fault damage on eastern Tibet topography. *Geology* 49(1):30-34, doi:10.1130/G48179.1.

Lee, S. and Pradhan, B. 2007. Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. *Landslides* 4(1):33-41, doi:10.1007/s10346-006-0047-y.

Morgan, R.P.C. 2005. *Soil Erosion and Conservation*: Oxford, Blackwell, 304pp. doi:10.1002/9781118786352.wbieg0381.

National Standardization Agency (BSN). 2016. SNI 8281:2016 Development and determination of landslide vulnerability zones, National Standardization Agency, Jakarta, 28p.

Nguyen, H., Mehrabi, M., Kalantar, B., Moayedi, H. and Abdullahi, M.M. 2019. Potential of hybrid evolutionary approaches for assessment of geo-hazard landslide susceptibility mapping. *Geomatics, Natural Hazards and Risk* 10(1):1667-1993, doi:10.1080/19475705.2019.1607782.

Nohani, E., Moharrami, M., Sharafi, S., Khosravi, K., Pradhan, B., Pham, B.T., Lee, S. and Melesse, A.M. 2019. Landslide susceptibility mapping using different GIS-based bivariate models. *Water* 11(7):1402, doi:10.3390/w11071402.

North, M.A. 2009. A Method for Implementing a Statistically Significant Number of Data Classes in the Jenks Algorithm. *6th International Conference on Fuzzy Systems and Knowledge Discovery,* doi:10.1109/FSKD.2009.319

Pradhan, B. and Lee, S. 2010. Delineation of landslide hazard areas on Penang Island, Malaysia, by using frequency ratio, logistic regression, and artificial neural network models. *Environmental Earth Sciences* 60(5):1037-1054, doi:10.1007/s12665-009-0245-8.

Raghuvanshi, T.K., Ibrahim, J. and Ayalew, D. 2014. Slope stability susceptibility evaluation parameter (SSEP) rating scheme-an approach for landslide hazard zonation. *Journal of African Earth Sciences* 99:595-612, doi:10.1016/j.jafrearsci.2014.05.004.

Rahman, H.A. and Mapjabil, J. 2017. Landslides disaster in Malaysia: an overview. *Health and Environment Journal* 2017, 8(1):58-71.

Samodra, G., Chen, G., Sartohadi, J. and Kasama, K. 2017. Comparing data-driven landslide susceptibility models based on participatory landslide inventory mapping in Purwosari area, Yogyakarta, Java. *Environmental Earth Sciences* 76, Article number:184 (2017), doi:10.1007/s12665-017-6475-2.

Saputra, S.E.G. , Putra, D.P.E., Atmaja, R.R.S. and Wilopo, W. 2017. Groundwater flow model of groundwater basin among volcanoes; a case study of Magelang-Temanggung groundwater basin, Central Java, Indonesia. *Proceeding The 1st Annual Scientific Meeting Association of Indonesian Groundwater Experts*. 16-17 November 2016, Institut Teknologi Bandung, Indonesia. p 1-10.

Shano, L., Raghuvanshi, T.K. and Meten, M. 2020. Landslide susceptibility evaluation and hazard zonation techniques - a review. *Geoenvironmental Disasters* 7:18:1-19, doi:10.1186/s40677-020-00152-0.

Statistic of Temanggung Regency (BPS Temanggung). 2021. Temanggung Regency in Figures, Statistic of Temanggung Regency, 283p.

Ul Moazzam, M.F., Vansarochana, A., Boonyanuphap, J., Choosumrong, S., Rahman, G. and Djueyep, G.P. 2020. Spatio-statistical comparative approaches for landslide susceptibility modeling: a case of Mae Phun, Uttradit Province, Thailand. *SN Applied Sciences* 2, Article number: 384 (2020), doi:10.1007/s42452-020-2106-8.

Van Westen, C.J., Rengers, N. and Soeters, R. 2003. Use of geomorphological information in indirect landslide susceptibility assessment. *Natural Hazards* 30(3):399-419, doi:10.1023/B:NHAZ.0000007097.42735.9e

Van Westen, C.J., van Asch, T.W.J. and Soeters, R. 2006. Landslide hazard and risk zonation-why is it still so difficult?. *Bulletin of Engineering Geology and the Environment* 65:167-184, doi:10.1007/s10064-005-0023-0.

Wang, L.J., Guo, M., Sawada, K., Lin, J. and Zhang, J. 2016. A comparative study of landslide susceptibility maps using logistic regression, frequency ratio, decision tree, weights of evidence and artificial neural network. *Geosciences Journal* 20(1):117-136, doi:10.1007/s12303-015-0026-1.