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Susceptibility of Soil Movement in Tawangmangu District, Karanganyar Regency with Bivariate Statistic Method – Weight of Evidence

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ABSTRACT. Tawangmangu district, located in Karanganyar Regency, Central Java is a crowded area susceptible to disaster. Therefore, susceptibility zoning analysis is needed to support the planning and development of the area. The method used is bivariate statistics – the weight of evidence which has never been implemented in its location. There are two types of data, data of potential and soil movement case (divided into train data as 61 points and test data as 40 points); and parameter data of soil movement causes. Parameter data of soil movement is processed to be a WoE (Weight of Evidence) parameter map using train data to know the weight. Later, it will be validated based on the AUC value. If it is >0.60, then the process will proceed. The parameter with an AUC value >0.60 is type of lithology, slope, hill, elevation, slope direction, distance from the fault, and vegetation density index. All those parameters are attached and are being final validated by test data. Further, the zonation consists of four; zone of very low soil movement susceptibility, low, medium, and high. The area of the very low soil movement susceptibility zone is 19.68%. The zone of low susceptibility is mostly 24.57%. The zone of medium susceptibility is 25.88%. Meanwhile, the zone of high susceptibility is 29.86%. The final validation result shows that AUC value from the zoning model belongs to a good category, which is 0.757.

Keywords: Bivariate Statistics · Weight of Evidence · Soil Movement Susceptibility Zoning.

1 INTRODUCTION

One of the disasters that commonly happens in Indonesia is soil movement or landslides. (Badan Standardisasi Nasional, 2016). Varnes (1978) states that soil movement refers to a process of earth material being carried away (bedrock, unconsolidated sediment, and soil that flows down the slope because of gravitation). One of the areas where soil movement disaster happens is in the Tawangmangu district. Tawangmangu is one of the districts in Karanganyar regency, Central Java. This district has become one of the nature tourism destinations. Further, it became the icon of the Karanganyar regency. It makes this district crowded with many visitors. Moreover, this district also connects Karanganyar and Magetan districts, becoming the link between Central Java and East Java. These things make this district a functional area as it becomes the center of civilization and crowd. Nevertheless, as stated in the beginning, the Tawangmangu district is an area with soil movement susceptibility. BPBD data of Karanganyar district and BNPB state that there is soil movement disaster in the Tawangmangu district almost every year. As a functional area, it deserves research about zoning soil movement susceptibility analysis to support the planning and development of the area. One of the analysis methods on the zoning of soil movement susceptibility, which has a high value of objectivity and accuracy, is bivari-

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ate statistics – the weight of evidence. Although this method has never been used in the Tawangmangu district, it has a high accuracy value.

Bivariate statistics method – the weight of evidence has been used in the analysis of soil movement susceptibility by previous researchers. Ram *et al.* (2020) researched movement susceptibility in Uttarakhand, Himalaya using bivariate statistics. The result shows that the accuracy value was 0.75. Further, Saragih (2020) did the same research with the weight of evidence method in Kokap district, Kulon Progo regency. The result of accuracy was 0.73 (good accuracy).

Meanwhile, Siswanto (2021) researched movement susceptibility with the weight of evidence method in Jurangrejo Village, Tancep, Ngawen district, Gunung Kidul regency, and the result was 0.75. Tawangmangu distinct has been used as movement susceptibility research yet using different methods and areas. One can be seen in Adi's research (2014), which mapped soil movement susceptibility in Tengklik village and the surrounding Tawangmangu district with the AHP method. The result was susceptibility zoning, starting from the lowest zone, low, medium, and highest in some Tengklik villages (Adi, 2014). Based on the previous research, bivariate statistics – the weight of evidence is capable of gaining quite a good accuracy value to analyze the soil movement susceptibility so that it can be implemented in the Tawangmangu district. Furthermore, this research serves zoning maps of soil movement susceptibility with the weight of the evidence method.

2 WORKING AREA

The working area is in Tawangmangu district, Karanganyar regency, Central Java (Figure 1). This location is 70.03 km^2 with an average height of 1,000 m above sea level. Based on the accessibility, this district can be reached in one hour by motorcycle from Surakarta city. Tawangmangu district is located in the East part of Karanganyar, bordering Magetan, East Java, in the east of this district. Tawangmangu district consists of 10 villages. They are Bandar Dawung, Karanglo, Nebula, Plumbon, Sepanjang, Tawangmangu, Kaliboro, Tengklik, Blumbang, and Gondosuli.

3 GEOLOGY REGIONAL

Tawangmangu district is in the zone of a quarter volcano, with Lawu mountain as the morphology shaper of this district. Lawu mountain is in the solo zone of Sensu Stricto (Van Bemmelen, 1949 in Pambudi *et al.*, 2014). This zone shapes areas such as high and steep sloping slopes. This thing becomes the weak point of soil movement existence. In general, the geology structure in the research area is dominated by faults and straight lines of the West-East, and Northwest-Southeast, which is caused by the tectonic force of regional Java Island (Pambudi *et al.*, 2014). Based on the map of the regional geology of Lembar Ponorogo by Sampurno and Samodra (1997), the working area was constructed by the oldest rock unit: Andesite Instruction, Wonosari Formation, Jobolarangan Breccia, Sidoramping Lava, Jobolarangan Lava, Lawu volcano rocks, Condrodimuko Lava and Lawu Lava. If it has been seen through geology data, the formation and rock units potentially causing the soil movement are Wonosari Formation, Jobolarangan Breccia, and Lawu Lava. Wonosari formation is constructed of limestone, which has low durability, making it easy to cause material movement. Furthermore, this formation also has old age, which is more susceptible to weathering. Meanwhile, both Jobolarangan breccia and Lawu lava are constructed with rocks with consolidation, which is not strong, allowing rainwater to fill the gaps and causing intense corrosion. When the duration is long, then it triggers the soil movement disaster.

4 RESEARCH METHODOLOGY

Results and discussion must include the study's findings and the scientific discussion. In addition, the results herein are shown in the form of tables or figures. The study's findings should be well explained in scientific thinking, including the reason that supported the results. Furthermore, it should be compared with other relevant findings. The method used in this research is bivariate statistics - the weight of evidence. This method uses two types of variables. Soil movement susceptibility is the tied variable, and the soil movement cause parameter is the free variable. The objective of this method

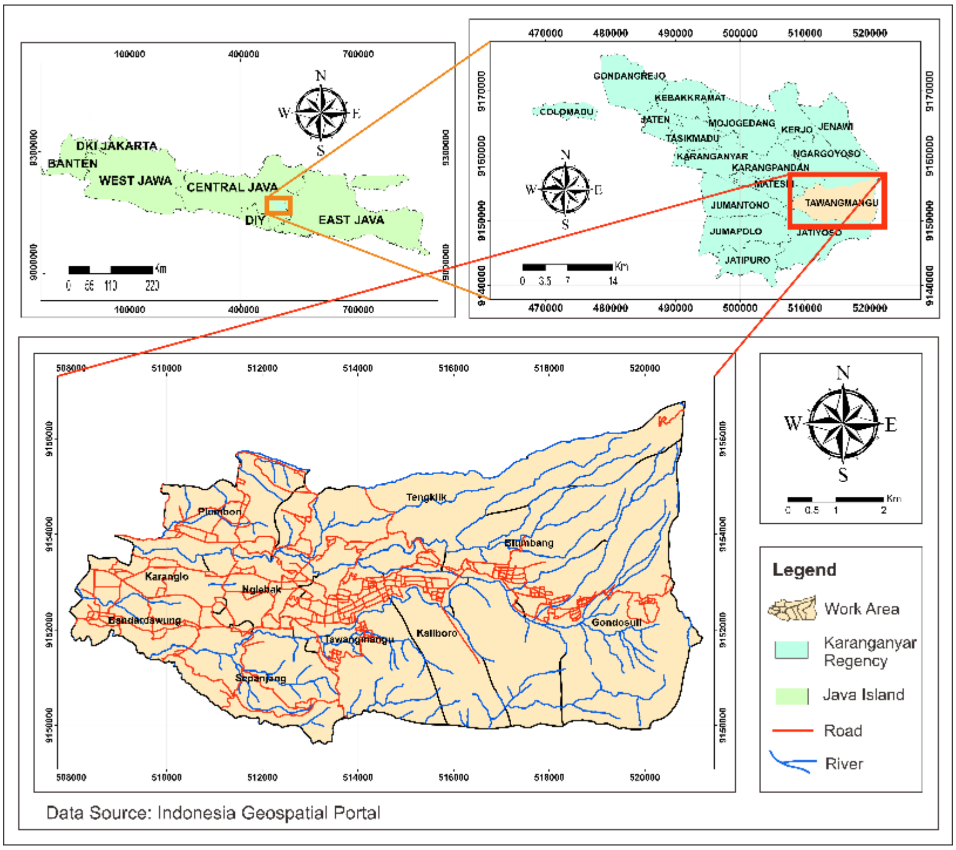

FIGURE 1. Index map of research location.

is to find the correlation between two types of variables with the assumption that each parameter cause of soil movement is unrelated. Many researchers have proven the accuracy of the bivariate statistics method, which is higher than the other method, especially in mapping landslide susceptibility (Ramesh and Anbazhagan, 2015; Vakhshoori and Zare, 2016; Huang *et al.*, 2018; Saranaarhan *et al.*, 2020). Weight of evidence (WoE) is a sub-method of bivariate statistics whose purpose is to get the weighting by using data such as evidence from the working area, and they are the potential and soil movement case. Charter (1994 in Pamela *et al.*, 2018) shows the WoE formulation as two similarities to counting the W^{+} value (probability weight) and W^{-} value (weight of improbability). After that, those are calculated for the WoE (final weight).

$$\text{WoE} = W^{+} - W^{-} \tag{1}$$

The data used in this research consists of two types, potential data & data of soil movement case and parameter data of soil movement cause. Figure 2 shows the data in the form of coordinates points of location with 101 points. This data is divided into train data at 60 % (61 points of location) and test data at 40 % (40 points of location). Those data were collected from BDBD Karanganyar district, BNPB, and the result of independent mapping in the area. Parameter data that causes soil movements consists of lithology, slope, hill, elevation, slope direction, distance from the fault, and vegetation density index. The weighting is done by generating train data so that it produces a map of WoE parameters. The result of parameter data weighting is then tested with the potential data and soil movement case in the train data using the concept of the area under the curve (AUC). The parameter of soil movement susceptibility is valid if the value is > 0.60. The higher the AUC value, the bigger that parameter influences the soil movement case.

$$W^{+} = \ln\left[\frac{P\{N_J|S\}}{P\{N_j|\bar{S}\}}\right] = \ln\left(\frac{\frac{P(N_J \cap S)}{P(S)}}{\frac{P(N_J \cap \bar{S})}{P(\bar{S})}}\right) \tag{2}$$

$$W^{+} = \ln \left(\frac{\frac{Npix\ landslide\ in\ class}{Npix\ total\ landslide\ are}}{\frac{Npix\ stable\ area\ in\ class}{Npix\ total\ stable\ area}} \right)$$

$$W^{-} = \ln \left[\frac{P\{\bar{N}_J|S\}}{P\{\bar{N}_j|\bar{S}\}} \right] = \ln \left(\frac{\frac{P(\bar{N}_J \cap S)}{P(S)}}{\frac{P(\bar{N}_J \cap \bar{S})}{P(\bar{S})}} \right) \quad (3)$$

$$W^{-} = \ln \left(\frac{\frac{Npix\ landslide\ outside\ class}{Npix\ total\ landslide\ are}}{\frac{Npix\ stable\ area\ outside\ class}{Npix\ total\ stable\ area}} \right)$$

All maps of WoE parameters with value >0.60 will be processed to be a zoning map of soil movement susceptibility. If the map of WoE parameters with AUC value <0.60, then it has considered not to influence causing soil movement significantly, so the parameter is not included in the following process. Figure 3 is footage of soil movement in the field. The map WoE parameter overlay result, which causes soil movement, will be validated based on the AUC value by using test data before proceeding to a zoning map of soil movement susceptibility. The higher the AUC value, the better model and map of soil movement susceptibility zoning.

5 Results and Discussion

5.1 Elevation

The elevation parameter is classified by referring to the research by Chen *et al.* (2020), shown in Figure 4. Table 1 shows the highest WoE value in the Elevation class >3000m and <900m. Elevation class >3000 m has quite a steep slope and is in the form of empty land, so it has low slope stability. Meanwhile, a class of $\leq$900m has lithology that is easily obsolete to move. The lowest value of WoE is in the elevation class >2400 – 2700m and >2700 – 3000m. Although having a steep slope, the vegetation cover is tight to secure the field from obsolete and infiltration processes.

5.2 Index of vegetation density

The index parameter of vegetation density is classified by referring to Peraturan Kementrian Kehutanan Republik Indonesia (2021). The highest WoE value is in the low verdure class, represented by a field with vegetation cover so that the obsolete process happens intensely. The lowest WoE is in the class without vegetation, usually in the form of a built field or settlement. The index of vegetation density is shown in Figure 5.

5.3 Distance from the river

The parameter of distance from the river is shown in Figure 6. The classification from this parameter refers to research by Mersha and Meten (2020). Table 1 shows no linear correlation between soil movement susceptibility and distance from the river. Even so, there is a trend that the farther distance from the river, the smaller the susceptibility class is. This suits the theory that a river can grind the wall rock that causes soil movement.

5.4 Slope direction

The slope direction is classified based on the wind direction. According to research by He and friends (2019), the parameter map is shown in Figure 7. The highest WoE value is in the east and northeast classes. Both are the direction of the sun's movement, so the obsolete is more inventive and equal. It is what triggers the soil movement. The lowest WoE value is in the flat class because the slope had excellent stability.

5.5 Distance from the fault

The distance parameter from the fault is collected using mapping results and secondary data. The classification is based on research by He *et al.* (2019), shown in Figure 8. Table 1 shows that the farther from the fault, the lower the WoE value. This happens because the fault is weak, so it is easy to undergo movements. This area also produces gaps that let the rainwater fill and cause infiltration. This will cause obsolete processes to go on intensively.

5.6 Slope

The slope parameter is shown in Figure 9. This parameter is built based on van Zuidam's (1985) classification. The highest WoE value is on the steep slope because it has low stability, which causes soil movement. The lowest WoE is on the flat slope and very low because both

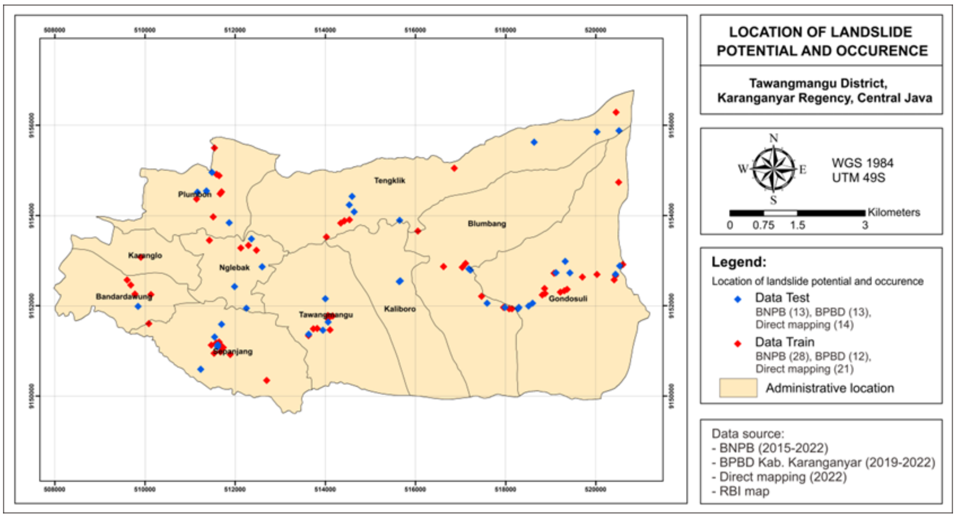

FIGURE 2. Index map of research location.

TABLE 1. Result of WoE weighing and parameter of AUC value (Wirawan *et al.*, 2022)..

Parameters	**Class**	**WoE**	**AUC**
Distance from the Fault	0-50	-378	0.621
	>50-100	462	
	>100-150	310	
	>150-200	-728	
	>200-250	-4089	
	>250	-4085	
Slope	Flat (0 - 2)	-4305	0.717
	Gentle slope (> 2 - 4)	-4332	
	More gentle slope (> 4 - 8)	-2177	
	Slightly steep slope (> 8 - 16)	-1565	
	Steep slope (> 16 - 35)	446	
	More steep slope (> 35 - 55)	1267	
	Very steep slope (> 55)	-4294	
Land Use	Crops	1079	0.638
	Built area	601	
	Bare ground	1317	
	Grass	601	
	Forest	-739	
Lithology	Lawu Andesite Lava 2	159	0.673
	Pre-Lawu Andesite Lava 1	891	
	Lawu Andesite Lava 1	-658	
	Lawu Andesite Lava 4	172	
	Lawu Andesite Lava 3	-787	
	Pre-Lawu Andesite Breccia	-265	
	Andesite Intrusion	600	
	Floatstone	1168	
	Lawu Andesite Lava 5	-1115	
	Pre-Lawu Andesite Lava 2	-4240	
	Pre-Lawu Andesite Lava 3	-4193	

FIGURE 3. Soil movement case in Ngeblak Village (above) and Gondosuli Village (below).

classes have excellent slope stability. Moreover, the steep slope also has a very low WoE value because it is covered by very tight vegetation that protects the area from intense obsolescence.

5.7 Lithology

The lithology parameter is shown in the geology map in Figure 10. The three highest WoE values are in the limestone unit's floatstone, Pra Lawu 1 lava unit, and andesite intrusion. Floatstone of limestone units consists of floatstone with low durability and many porosition, so it causes obsolescence. The lava unit of Pra Lawu 1 andesite consists of andesite lava which has been obsoleted because of the low vegetation cover, and andesite breccia is constructed by loose material in which the rainwater enters and causes obsolescence. Andesite intrusion consists of hornblende andesite that is easily obsolete because there is too much hornblende mineral that is not rainwater resistant. The lowest WoE value is in the lava unit of Pra Lawu 2 andesite, which consists of andesite lava and andesite breccia with andesite lava of Pra Lawu 3 that contains pyroxene andesite. Those lithologies have a very low soil movement susceptibility because they are covered by tight vegetation, so they appear in good condition.

5.8 Land use

The parameter of land use is shown in Figure 11. The classification is based on Badan Standardisasi Nasional (2010). Based on Table 1, The higher WoE value is in the empty field. A little vegetation cover makes obsolete and intensive processes very intensive, so there is an easy soil movement case. The lowest WoE value is in the forest class, as it has a very tight vegetation cover and can protect the area from rainwater that triggers obsolescence and infiltration.

5.9 Susceptibility zoning of soil movement

According to the Table 1, 7 parameters have an AUC value >0.60. All of them are lithology, land use, elevation, distance from the fault, index of vegetation density, slope, and slope direction. The distance from the river parameter has an AUC value <0.60, so it does not really influence the soil movement case. Test data processed those 7 parameters with the result AUC value as 0.757. Therefore, the zoning model of soil movement susceptibility was quite good. It refers to the division of the AUC index value for zoning soil movement susceptibility by Pamela *et al.* (2018). The zoning map of soil movement susceptibility is shown in Figure 12. There is an anomaly in the northeast where the area is in the high elevation and steep slope. However, it has a susceptibility zone of low soil movement. It is because the area has tight vegetation cover so that the trigger of soil movement is small.

6 CONCLUSION

The research location is divided into 4 zones of soil movement susceptibility. These are the high susceptibility zone, medium susceptibility zone, low susceptibility zone, and very low susceptibility zone. The high susceptibility zone (29.86) is mostly in the northwest, southwest, south, and east. That is because those areas have obsolete lithology and steep slopes. The medium susceptibility zone (25.88%) is mostly in the middle and Southeast because they have

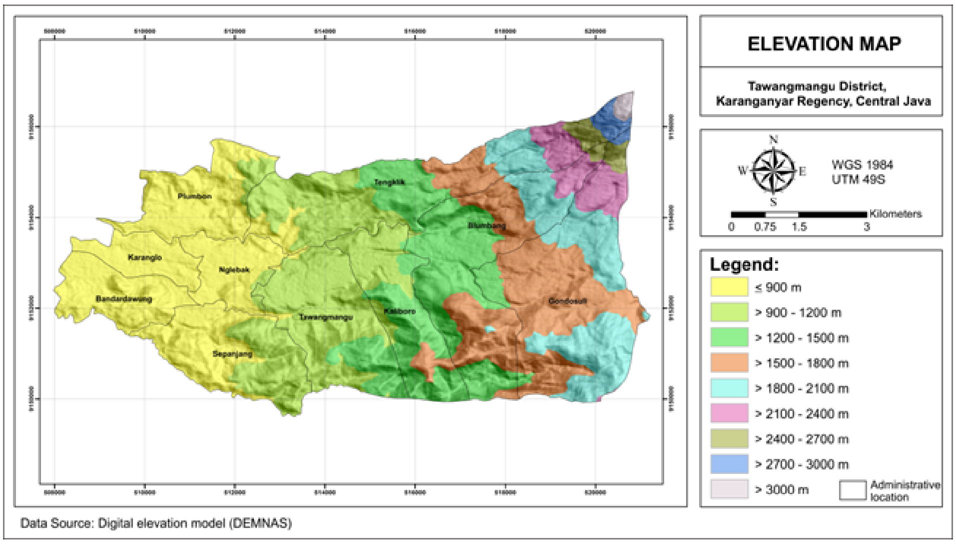

FIGURE 4. Parameter map of elevation of Tawangmangu district (Wirawan *et al.*, 2022).

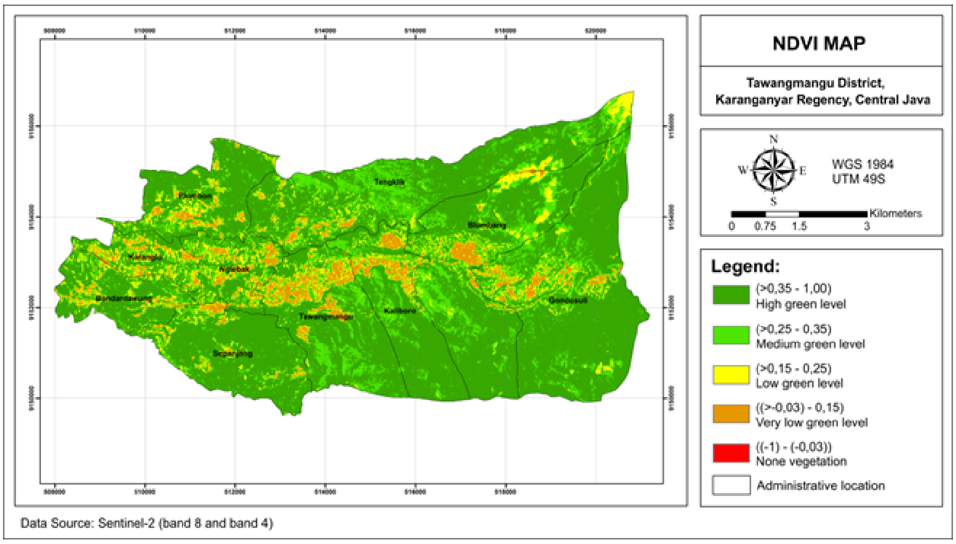

FIGURE 5. Parameter map of Index of Vegetation Density in Tawangmangu district (Wirawan *et al.*, 2022).

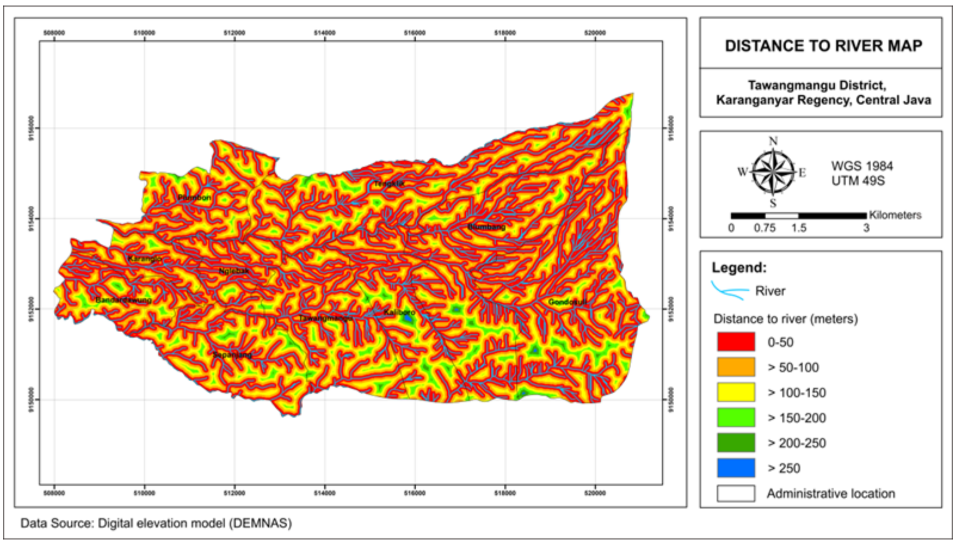

FIGURE 6. Parameter map of distance from the river in Tawangmangu district (Wirawan *et al.*, 2022).

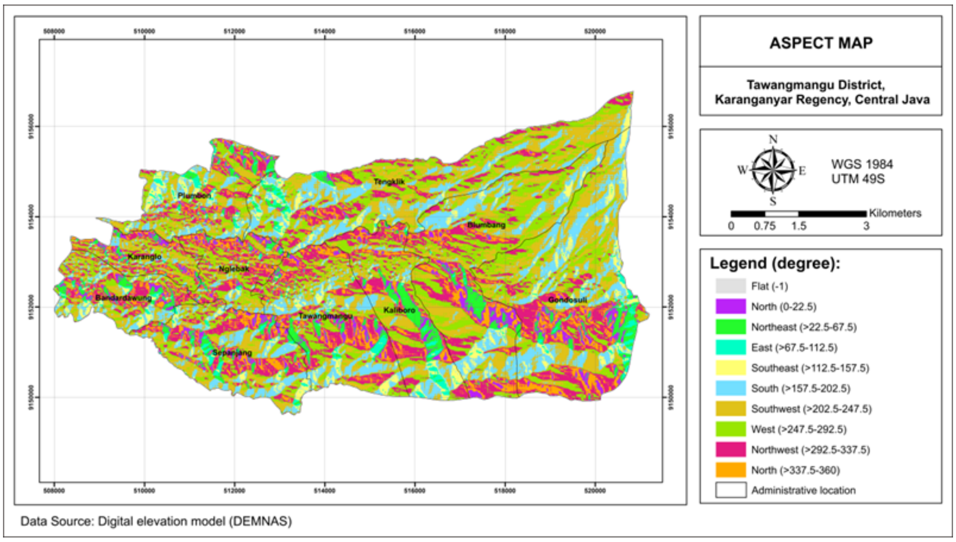

FIGURE 7. Parameter map of slope direction in Tawangmangu district (Wirawan *et al.*, 2022).

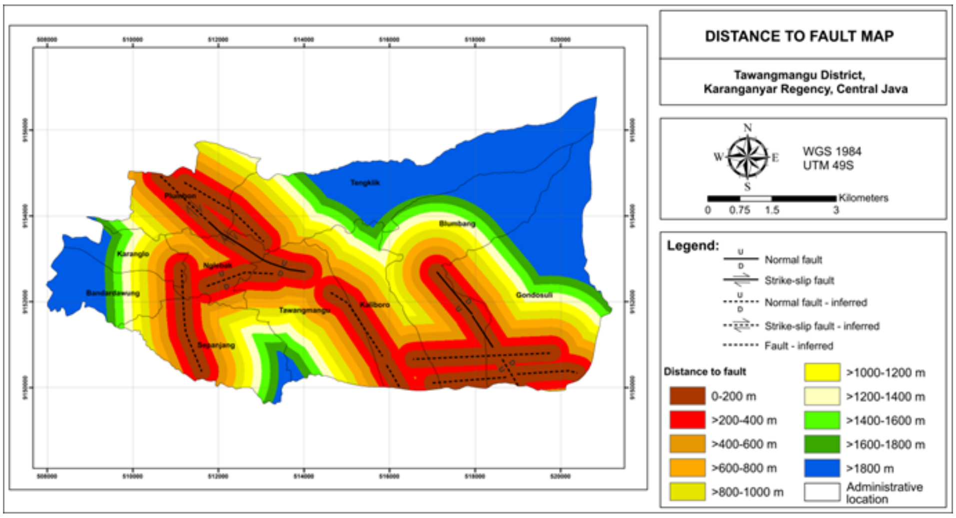

FIGURE 8. Parameter map of distance from the fault in Tawangmangu district (Wirawan *et al.*, 2022).

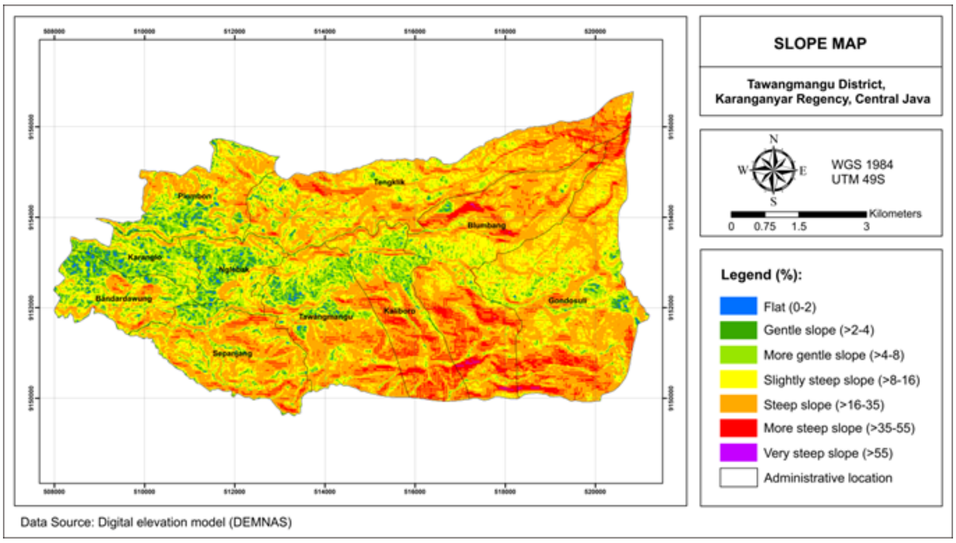

FIGURE 9. Parameter map of slope in Tawangmangu district (Wirawan *et al.*, 2022).

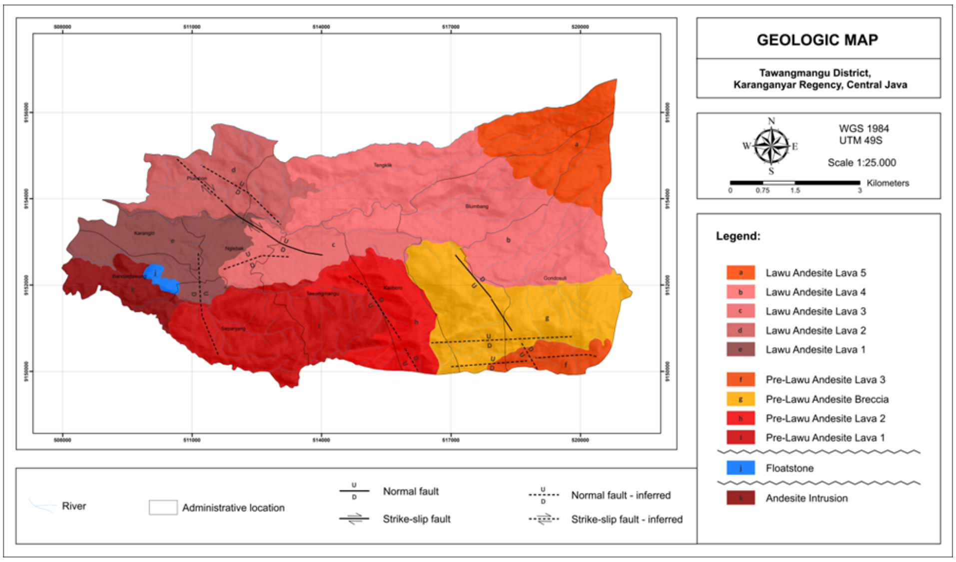

FIGURE 10. Geological map of Tawangmangu district (Wirawan *et al.*, 2022).

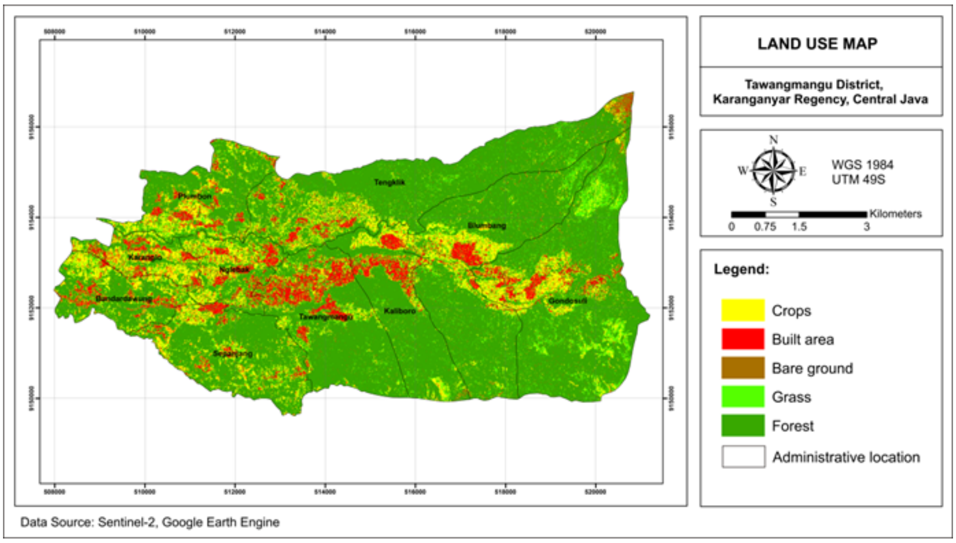

FIGURE 11. Parameter map of land use in Tawangmangu district (Wirawan *et al.*, 2022).

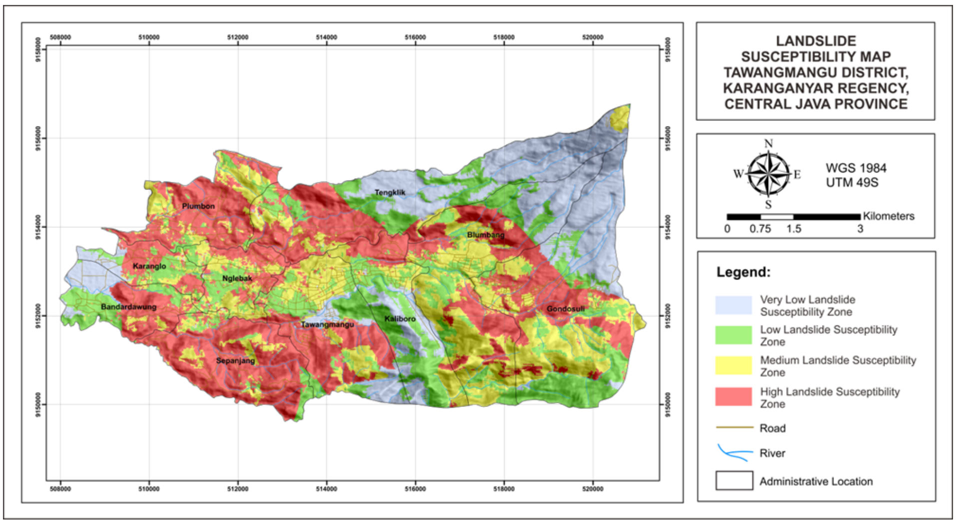

FIGURE 12. Map of Susceptibility Zoning of Soil Movement in Tawangmangu district (Wirawan *et al.*, 2022).

steep slopes and lithology that is quite obsolete. The low susceptibility zone (24. 57%) is mostly on the edge of the Southeast because it has declivous slopes – quite steep and fresh lithology. A very low susceptibility zone (19.68%) is mostly on the edge of the West and Northeast because they have flat slopes – very flat and covered by tight vegetation. The accuracy of the soil movement susceptibility zoning model is shown by the AUC value as 0.757. Therefore, the model is considered quite good. The parameter with a considerable influence is the slope because it has the highest AUC value compared to the other parameters.

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