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Landslide modeling using Weight of Evidence-Information Value (WoE-IV) for disaster risk mitigation in the Amprong Sub-Watershed, East Java Province, Indonesia

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Abstract

Landslide disasters predominantly occur in the upstream sections of river basins due to the steeper slopes typically found in these areas compared to the middle and downstream sections of watersheds. This study aims to compile existing landslide event data to serve as training and validation datasets for mapping and modeling purposes. Specifically, it focuses on analyzing 16 landslide-controlling factors in the Amprong Sub-watershed and developing landslide susceptibility maps using the Weight of Evidence - Information Value (WoE-IV) method. The findings reveal that 46% of the Amprong Sub-watershed area is classified as having a high level of landslide susceptibility, 39% as having a moderate level, and 15% as having a low level of susceptibility. The landslide susceptibility mapping using the WoE-IV method achieved an AUC value of 0.887, indicating that this method provides a reliable and accurate prediction of landslide occurrences in the study area.

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INTRODUCTION

Natural disasters are natural phenomena that cannot be entirely prevented. One of the most common natural disasters in Indonesia is landslides, which often result in significant material losses and even fatalities. Several regions in Indonesia are inherently vulnerable to landslides due to the country's volcanically and tectonically active areas and tropical wet climate (Fatmawati, 2007). Between 2008 and 2017, 4,174 landslides were recorded, causing 1,775 fatalities (Fadilah et al., 2019). Landslides typically occur in upstream river sections, where slopes are steeper compared to the middle and downstream sections of watersheds (Hasanah et al., 2014).

The movement of soil and rock masses on slopes is influenced by several factors, including geological conditions, morphology, geological structure, land use, and hydrogeology, all of

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which contribute to slope instability (Pasla et al., 2022). Landslides are driven by triggering and controlling factors. Triggering factors include erosion, rainfall, earthquakes, and human activities, while controlling factors relate to slope composition, such as lithology, geology, slope angles, faults, and joints in rock structures (Afriani, 2020). Additionally, natural geomorphological processes, material characteristics, and surface morphology contribute to slope stability (Masruroh et al., 2020).

Landslide susceptibility refers to the likelihood of landslides occurring in a particular area based on local terrain conditions (Fell et al., 2008). Susceptibility maps, typically produced through cartographic techniques (Yalcin, 2008), represent the potential intensity and distribution of landslides, although they do not account for temporal aspects (Fell et al., 2008). Numerous mapping models for landslide susceptibility have been developed, employing various methods, scales, and evaluation criteria. These range from knowledge-based models to process-based and statistical models. Common approaches include Logistic Regression, Neural Network Analysis, Data Overlay, Index-Based Methods, Weight of Evidence (WoE), and Machine Learning (Coco et al., 2021).

This research utilizes the Weight of Evidence (WoE) and Information Value (IV) methods for mapping landslide susceptibility. The WoE method is a bivariate statistical analysis technique that analyzes the relationship between causative parameters of landslides and observed landslide occurrences. It enables prediction of landslide-prone areas by considering prior and posterior events. In the weighting process, weights are calculated independently for each study area, allowing adjustments based on varying geomorphological settings (Barbieri & Cambuli, 2009). The results of the Information Value calculations indicate the predictive power of features, while the WoE calculations serve as the foundation for deriving these values (Kulkarni, 2021).

The research was conducted in the Amprong Sub-watershed, located in Malang Regency, East Java. Geographically, the Amprong Sub-watershed lies between 112°44'53″ - 112°52'10″ E and 7°59'47″ - 7°53'27″ S, covering an area of 8,423 Ha. This area includes 17 villages in Jabung District and Tutur District, such as Sukolilo, Sidorejo, Kemantren, Pandansari Lor, Sukopuro, Kenongo, and Jabung. The sub-watershed features a mix of plains and hills as it is part of the Bromo Tengger Semeru (BTS) region. The geological structure of the Amprong Sub-watershed comprises unconsolidated rocks with weak grain bonds, making them susceptible to erosion. The area also has thick soils, steep slopes, and high elevations, particularly at the foot of the volcano, which further increases landslide susceptibility (Masruroh et al., 2023). The Weight of EvidenceInformation Value (WoE-IV) method provides a valuable reference for landslide mitigation efforts by the Malang Regency Government and local communities within the Amprong Subwatershed. Effective mitigation is expected to minimize damage and losses caused by landslides in the area.

METHOD

The research method employed for mapping landslide susceptibility involves a quantitative approach using the Weight of Evidence-Information Value (WoE-IV) method to assign weights to each parameter. The study utilizes secondary data, and the data analysis is conducted using descriptive statistical techniques. This analysis categorizes landslide susceptibility levels based on the processed data, enabling the determination of the spatial distribution of susceptibility levels within the study area. Data processing is supported by various software tools, including ArcGIS 10.8, SagaGIS, and Microsoft Excel, to ensure the accuracy and reliability of the results. The research is conducted in the Amprong Sub-watershed, a subwatershed located in Malang Regency, East Java Province, Indonesia. Geographically, the Amprong Sub-watershed is situated between 112°44'53″ - 112°52'10″ E and 7°59'47″ - 7°53'27″ S. The study area is part of the Bromo Tengger Semeru region and overlaps with the Brantas watershed.

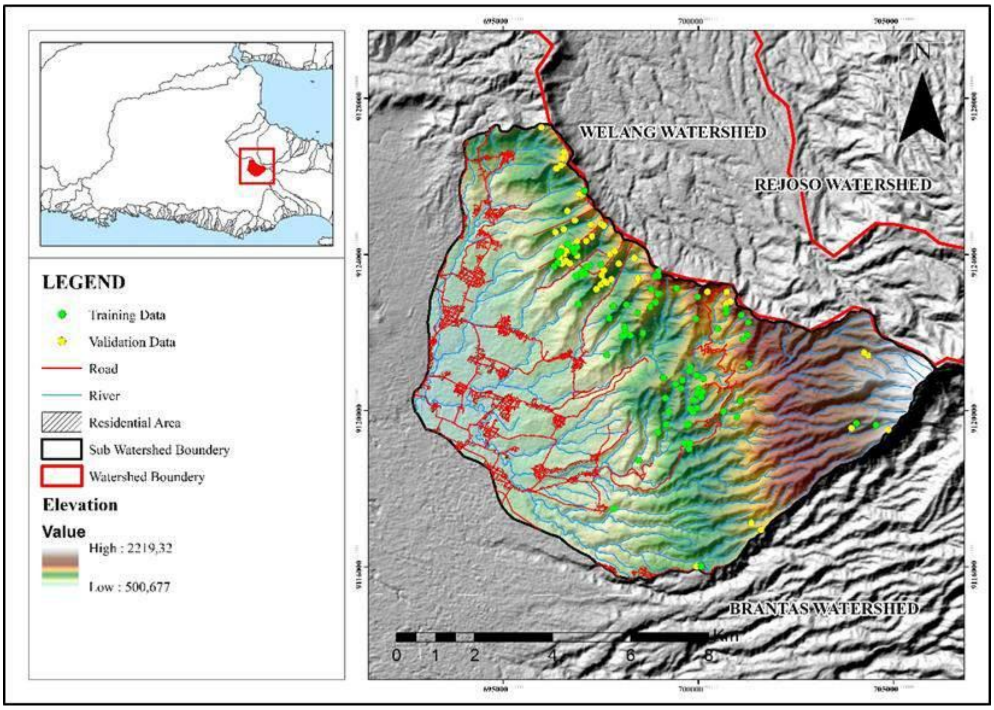


Figure 1. The map of the study area is located within the Amprong Sub-watershed.

The data utilized in this research consist of secondary data, which include sample data and data on controlling factors. Sample data are used as training and validation datasets. Training data are employed to assign weight values to each independent variable influencing landslide controlling factors. Validation data are used to evaluate the performance of the model in determining landslide susceptibility levels in the Amprong Sub-watershed. The specific data utilized in this research are as Table 1.

The Weight of Evidence formula used in this study is as follows (Lin & Hsieh, 2015):

$$WoE = [Ln\ (\%\ Event_i\ /\ \%\ Non\text{-}Event_i)] \times 100,$$

information:
Ln = Natural Logarithm
$\%\ Event_i$ = Percent Event
$\%\ Non\text{-}Event_i$ = Percent Non-Event.
The Information Value (IV) method is utilized to identify various factors that will be applied in mapping landslide susceptibility in the Amprong Sub-watershed area. The formula for Information Value used in this study is as follows (Lin & Hsieh, 2015):

$$IV = \sum i = 1\ [(\%\ Event_i\ /\ \%\ Non\text{-}Event_i) \times Ln\ (\%\ Event_i\ /\ \%\ Non\text{-}Event_i),$$

information:
$\sum i = 1$ = Total Amount
Ln = Natural Logarithm
$\%\ Event_i$ = Percent Event
$\%\ Non\text{-}Event_i$ = Percent Non-Event

Table 1. A table of data required to support the research findings.

Objective	Variable	Data source	Year	Data collection	Data analysis
***Data**					
Training Data	Landslide Inventory Data	Google Earth Imagery image	2011 - 2023	Delineation in Images	Image Interpretation
Data Validation					Test the accuracy of the landslide susceptibility map
Analysis of Factors That Influence Landslides	Geological Map	Geological Map Sheet of G. Bromo (1608-12) (Scale 1 : 50,000)	2013	Data Availability (Existing Data)	(-)
	Distance to Road Map	OSM Data	2021		Euclidean Distance
	Road Density Map				Kernel Density
	River Density Map	Ina-Geoportal Malang Regency	2018		Kernel Density
	Distance to River Map				Euclidean Distance
	Land Use Map				(-)
	Rainfall Map	Persian-CDR Image (Resolution 0.25° x 0.25°)	2013 - 2022	Remote Sensing	Kriging and Derivative Calculation
	NDVI (Normalized Difference Vegetation Index) map	Sentinel 2A Band 8 and Band 4 imagery (10 m x 10 m resolution)	2023		NDVI Analysis and Derivative Calculation
	TWI (Topographic Wetness Index) map	DEMNAS (8 m resolution)	2018		Derivative Calculation
	TPI (Topographic Position Index) map				
	Stream Power Index map				
	Slope Map				
	Curvature Plan Map				
	Curvature Profile Map				
	Elevation Map				
	Slope Aspect Map				

The Landslide Susceptibility Index (LSI) calculation method is employed to determine the level of landslide susceptibility in the Amprong Sub-watershed area. To generate the LSI, all causal factors identified from the IV calculation results are represented as raster maps of WoE weighting values and then summed using the following formula (Indahsari et al., 2022):

$$\mathbf{LSI} = I1 + I2 + \ldots + In,$$

information:

LSI = Landslide Susceptibility Index Results l1, l2, ….. , ln = Parameters that influence landslide events. The IV Value information is presented in Table 2 and research flow diagram is visualized in Figure 2.

Table 2. Information Value Table

IV Value (Information-Value)	Information
< 0.02	Cannot Predict
0.02 – 0.1	Weakly Predictive
0.1 – 0.3	Medium Predictive
0.3 – 0.5	Strong Predictive
> 0.5	Very Strong Predictive

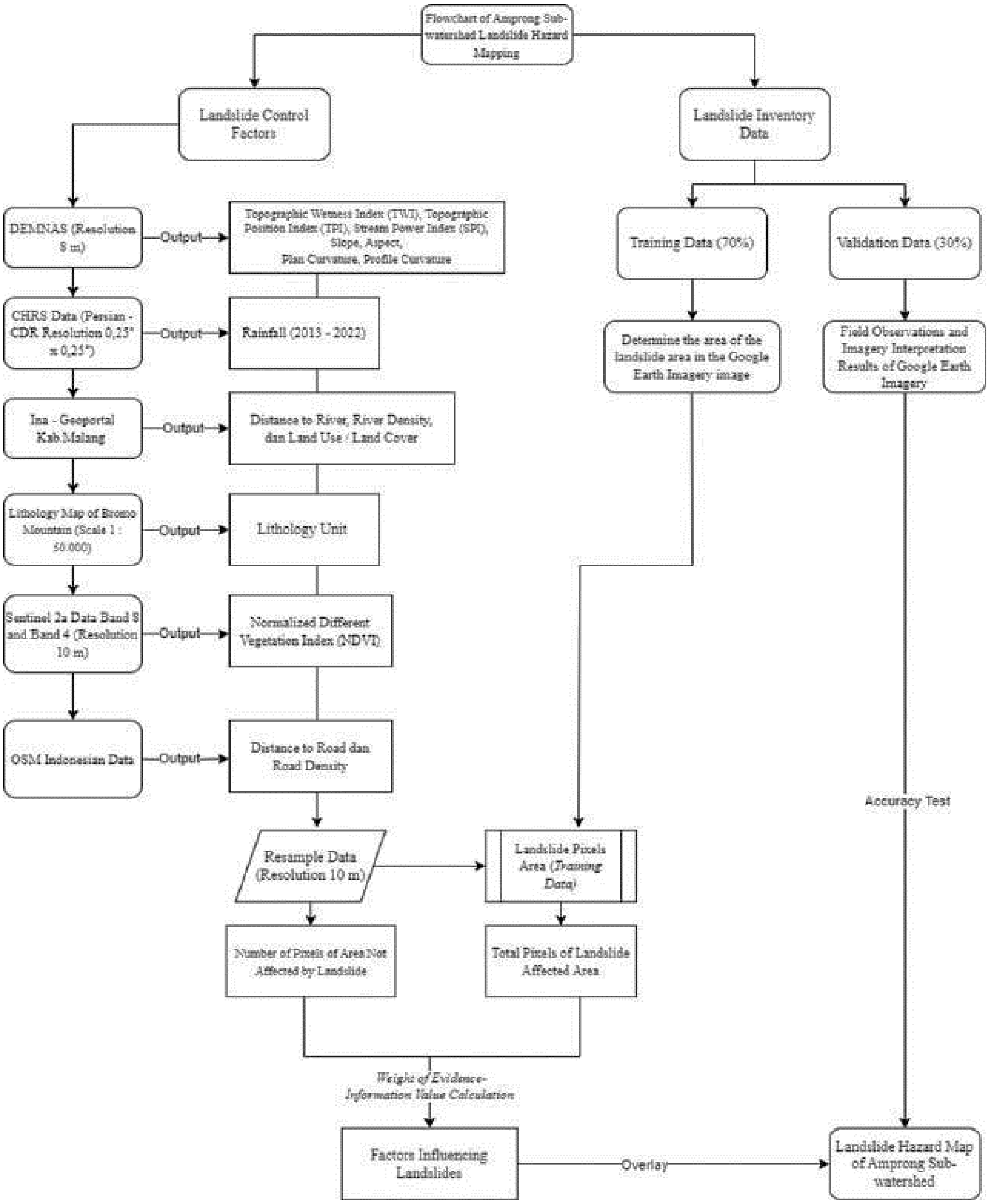


Figure 2. Research flow diagram

RESULT AND DISCUSSIONS

1. Characteristics of Observed Landslides

A landslide inventory map is the simplest map used to display the location and type of landslides. The data presented on this map is crucial for identifying hazards, risks, and the level of vulnerability to landslides (Masruroh et al., 2023). Landslide inventory data were obtained through the interpretation of Google Earth imagery. The resulting data represent polygons of landslide-affected areas within the study area. Below (Figure 3) are the visualized results of the landslide inventory data mapping in the Amprong Sub-watershed area:

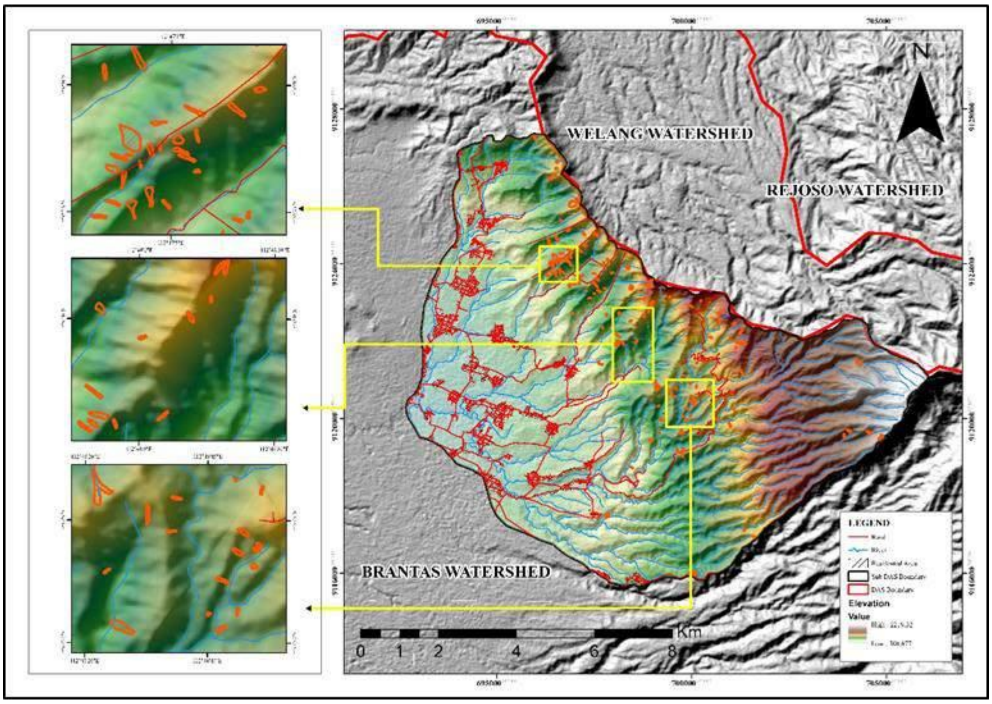


Figure 3. Visualization of landslide inventory data collection in the Amprong Sub-Watershed Area

The results of the landslide data visualization indicate that landslides in the Amprong Sub-watershed area predominantly occur on the upper slopes. Many of the landslide-prone areas are located at altitudes ranging from 1,000 to 1,500 meters above sea level. The landslides identified in the study area are mainly active. These findings suggest that landslides are frequently located on hillsides with steep slopes. A total of 144 landslide areas were identified in the research area. Of these 144 points, 70% (104 landslide data points) were used as training data, while 30% (40 landslide data points) were used for validation. The smallest landslide area recorded was 51 m^2, and the largest was 23,938 m^2.

2. Landslide Controlling Factors

This research utilizes secondary data to identify landslide controlling factors. Based on these factors, the key determinants influencing landslide occurrence in the Amprong Sub-watershed area will be identified. The results of the data processing provide visualizations of 16 landslide control factors, presented in Figure 4-6, which include 6 maps of topographic control factors: Slope Map, Topographic Position Index (TPI) Map, Plan Curvature Map, Profile Curvature Map, Slope Aspect Map, and Elevation Map. Hydrological controlling factors are represented by 5 maps: Distance to River Map, River Density Map, Topographic Wetness Index (TWI) Map, Rainfall Map, and Stream Power Index (SPI) Map. The anthropogenic factors are depicted in 5 maps: Geological Map, Land Use Map, Normalized Difference Vegetation Index (NDVI) Map, Distance to Road Map, and Road Density Map.

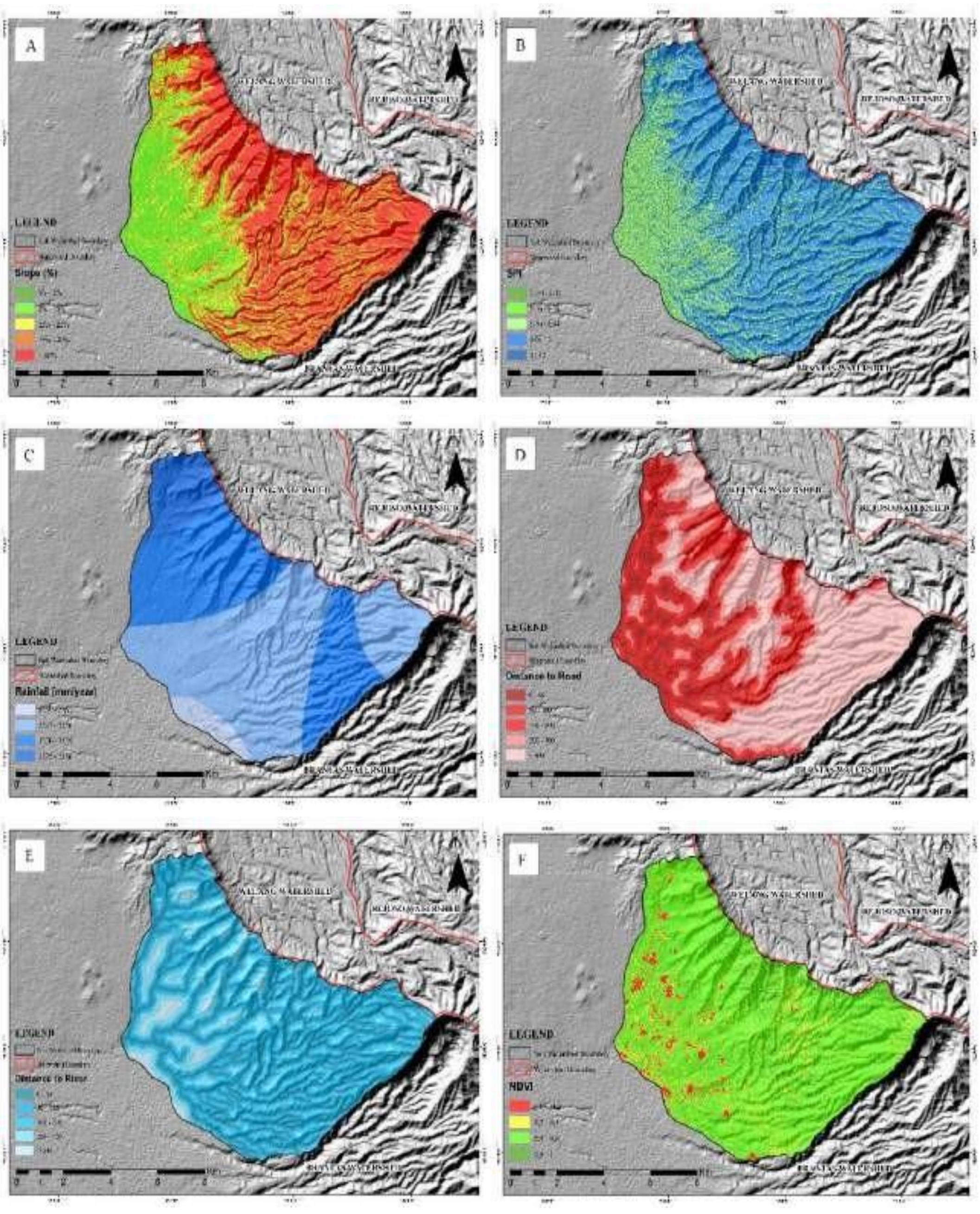


Figure 4. a) Slope, b) SPI (Stream Power Index), c) Rainfall, d) Distance to Road, e) Distance to River, f) NDVI (Normalized Difference Vegetation Index).

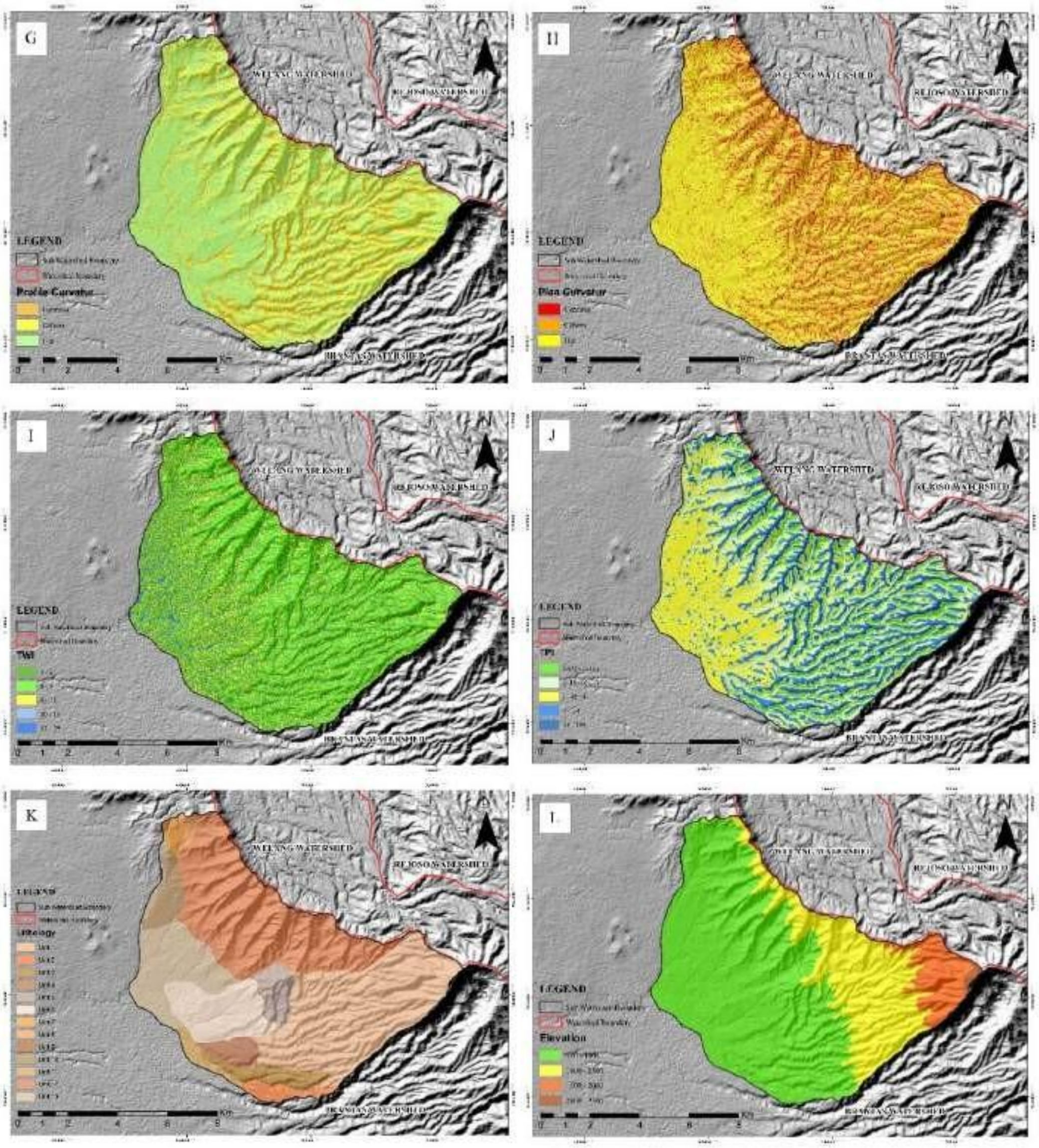
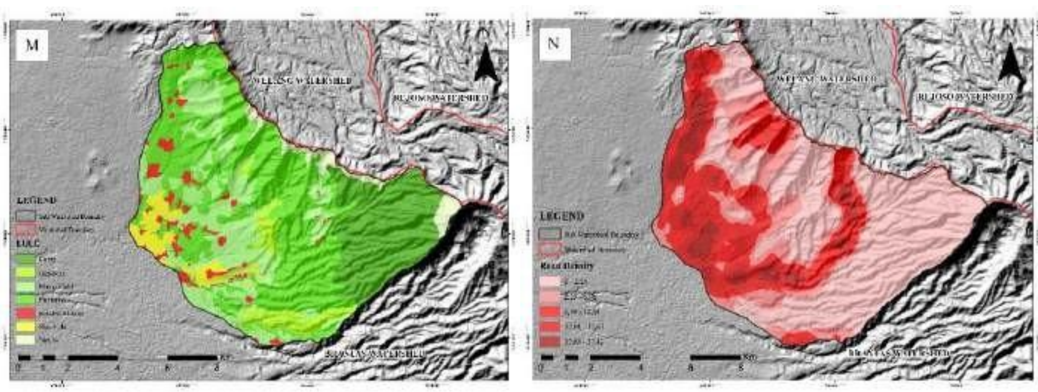


Figure 5. g) Profile Curvature, h) Plan Curvature, i) TWI (Topographic Wetness Index), j) TPI (Topographic Position Index), k) Geology, l) Elevation.



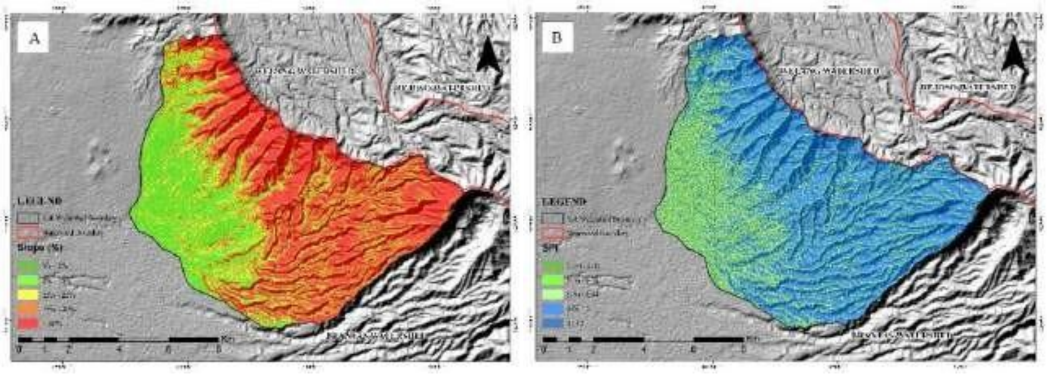


Figure 6. m) Land Use, n) Road Density, o) River Density, p) Slope Aspect.

3. Weight of Evidence – Information Value (WoE – IV) Calculation Results

Calculations using the Weight of Evidence (WoE) method are employed to determine the relationship between landslide trigger factors and landslide occurrences. The information value provides insights into the controlling factors that have a significant influence on landslide events in the Amprong Sub-watershed area. The results of the Weight of Evidence - Information Value (WoE-IV) method calculations are based on the number of landslide and non-landslide pixels, using the total area of the landslide inventory data and the total area of each landslide-controlling factor as references. The following Table 3 presents the results of the WoE calculation between the controlling factors and landslide events:

Table 3. Weight of Evidence – Information Value (WoE – IV) calculation results

Parameter	Class	Number of Events	Number of Non-Events	Presentation of Events (%)	Percentage of Non-Events (%)	WoE	IV
Slope	0% - 2%	0	5541	0.0003	0.0066	-3.2388	0.0205
	2% - 15%	19	204396	0.0098	0.2432	-3.2091	0.7490
	15% - 25%	50	139396	0.0259	0.1659	-1.8588	0.2603
	25% - 40%	148	188441	0.0765	0.2242	-1.0751	0.1588
	> 40%	1717	302582	0.8878	0.3601	0.9025	0.4763
Amount		1934	840356				1.6649
TPI	(-65) - (-14)	227	97889	0.1174	0.1165	0.0076	0.0000
	(-14) - (-4)	290	190417	0.1499	0.2266	-0.4129	0.0316
	(-4) - 4	380	294767	0.1965	0.3508	-0.5795	0.0894
	4 - 14	646	161376	0.3340	0.1920	0.5535	0.0786
	14 - 104	391	95907	0.2022	0.1141	0.5718	0.0503
Amount		1934	840356				0.2500
Distance to River							
	0 - 50	370	235553	0.1913	0.2803	-0.3820	0.0340
	50 - 100	271	200949	0.1401	0.2391	-0.5345	0.0529
	100 - 200	871	255702	0.4504	0.3043	0.3921	0.0573
	200 - 400	420	126006	0.2172	0.1499	0.3704	0.0249
	> 400	2	22146	0.0010	0.0264	-3.2380	0.0820
Amount		1934	840356				0.2511
Distance to Road	0 - 50	68	131604	0.0352	0.1566	-1.4938	0.1814
	50 - 100	313	82311	0.1618	0.0979	0.5022	0.0321
	100 - 200	433	125505	0.2239	0.1493	0.4049	0.0302
	200 - 400	155	155936	0.0801	0.1856	-0.8395	0.0885
	> 400	965	345000	0.4990	0.4105	0.1951	0.0172

Parameter	Class	Number of Events	Number of Non-Events	Presentation of Events (%)	Percentage of Non-Events (%)	WoE	IV
Amount		1934	840356				0.3494
NDVI	(-1) - 0.2	10	28931	0.0052	0.0344	-1.8958	0.0555
	0.2 - 0.4	150	95361	0.0776	0.1135	-0.3806	0.0137
	0.4 - 0.6	1347	656382	0.6965	0.7811	-0.1146	0.0097
	0.6 - 1	427	59682	0.2208	0.0710	1.1342	0.1699
Amount		1934	840356				0.2487
SPI	(-14) - (-9)	5	43432	0.0026	0.0517	-2.9953	0.1471
	(-9) - (-5)	111	55993	0.0574	0.0666	-0.1492	0.0014
	(-5) - 0.04	156	232876	0.0807	0.2771	-1.2342	0.2425
	0.04 - 3	1473	451005	0.7616	0.5367	0.3501	0.0787
	3 - 12	189	57050	0.0977	0.0679	0.3643	0.0109
Amount		1934	840356				0.4805
TWI	3 - 6	768	377158	0.3971	0.4488	-0.1224	0.0063
	6 - 8	1016	284913	0.5253	0.3390	0.4379	0.0816
	8 - 10	132	126462	0.0683	0.1505	-0.7907	0.0650
	10 - 13	12	30483	0.0062	0.0363	-1.7658	0.0531
	13 - 29	6	21340	0.0031	0.0254	-2.1023	0.0469
Amount		1934	840356				0.2529
Land Use	Jungle	298	158056	0.1541	0.1881	-0.1994	0.0068
	Meadow	14	43286	0.0072	0.0515	-1.9623	0.0869
	Plantation	1433	352963	0.7410	0.4200	0.5676	0.1822
	Settlement	0	31795	0.0003	0.0378	-4.9860	0.1874
	Ricefield	0	35051	0.0003	0.0417	-5.0835	0.2107
	Shrubs	93	31484	0.0481	0.0375	0.2496	0.0027
	Moor / Farm	96	187721	0.0496	0.2234	-1.5041	0.2613
Amount		1934	840356				0.9379
Aspect	North	70	30041	0.0362	0.0357	0.0124	0.0000
	East	8	26430	0.0041	0.0315	-2.0286	0.0554
	Northeast	38	24048	0.0196	0.0286	-0.3760	0.0034
	Southeast	253	85665	0.1308	0.1019	0.2494	0.0072
	West	361	153520	0.1867	0.1827	0.0215	0.0001
	Northwest	729	161740	0.3769	0.1925	0.6722	0.1240
	Southwest	126	150030	0.0651	0.1785	-1.0081	0.1143
	South	228	151485	0.1179	0.1803	-0.4247	0.0265
	North	121	57397	0.0626	0.0683	-0.0877	0.0005
Amount		1934	840356				0.3314
Rainfall	2259 - 2267	0	29237	0.0003	0.0348	-4.9021	0.1693
	2267 - 2270	576	427866	0.2978	0.5091	-0.5362	0.1133
	2270 - 2275	1278	309966	0.6608	0.3689	0.5831	0.1702
	2275 - 2286	80	73287	0.0414	0.0872	-0.7459	0.0342
Amount		1934	840356				0.4870
Plan Curvature	Concave	534	145931	0.2761	0.1737	0.4637	0.0475
	Flat	939	495462	0.4855	0.5896	-0.1942	0.0202
	Convex	461	198963	0.2384	0.2368	0.0068	0.0000
Amount		1934	840356				0.0677
Profile Curvature	Concave	295	143062	0.1525	0.1702	-0.1098	0.0019
	Flat	1004	480300	0.5191	0.5715	-0.0962	0.0050
	Convex	635	216994	0.3283	0.2582	0.2402	0.0168
Amount		1934	840356				0.0238
Elevation	500 - 1000	828	556911	0.4281	0.6627	-0.4369	0.1025
	1000 - 1500	982	217094	0.5078	0.2583	0.6757	0.1685

Parameter	Class	Number of Events	Number of Non-Events	Presentation of Events (%)	Percentage of Non-Events (%)	WoE	IV
	1500 - 2000	124	62770	0.0641	0.0747	-0.1527	0.0016
	2000 - 2500	0	3581	0.0003	0.0043	-2.8023	0.0112
Amount		1934	840356				0.2839
River Density	0 - 0.82	0	18625	0.0003	0.0222	-4.4512	0.0975
	0.82 - 2.32	544	101337	0.2813	0.1206	0.8470	0.1361
	2.32 - 3.64	1168	272125	0.6039	0.3238	0.6233	0.1746
	3.64- 4.96	137	253379	0.0708	0.3015	-1.4484	0.3341
	4.96 - 7.8	85	194890	0.0440	0.2319	-1.6633	0.3126
Amount		1934	840356				1.0549
Road Density	0 - 2.25	932	385825	0.4819	0.4591	0.0484	0.0011
	2.25 - 6.98	386	148243	0.1996	0.1764	0.1235	0.0029
	6.98 - 12.04	478	141015	0.2472	0.1678	0.3872	0.0307
	12.04 - 17.63	138	106654	0.0716	0.1269	-0.5722	0.0316
	17.63 - 27.42	0	58619	0.0003	0.0698	-5.5977	0.3890
Amount		1934	840356				0.4554
Geology	Unit 1	236	251248	0.1220	0.2990	-0.8961	0.0074
	Unit 2	60	17980	0.0310	0.0214	0.3716	0.0036
	Unit 3	0	27936	0.0003	0.0332	-4.8566	0.0020
	Unit 4	0	20345	0.0003	0.0242	-4.5395	0.0180
	Unit 5	92	29068	0.0476	0.0346	0.3186	0.0041
	Unit 6	0	77766	0.0003	0.0925	-5.8804	0.0054
	Unit 7	0	7919	0.0003	0.0094	-3.5959	0.0033
	Unit 8	0	5977	0.0003	0.0071	-3.3146	0.0021
	Unit 9	0	1290	0.0003	0.0015	-1.7813	0.0023
	Unit 10	0	27445	0.0003	0.0327	-4.8389	0.0089
	Unit 11	0	14223	0.0003	0.0169	-4.1815	0.0043
	Unit 12	1546	257719	0.7994	0.3067	0.9580	0.0011
	Unit 13	0	101440	0.0003	0.1207	-6.1461	0.0215
Amount		1934	840356				0.0840

4. Selection of Controlling Factors Influencing Landslide Events

Determining the controlling factors that influence landslide events is a crucial step in the overlay processing procedure to assess the level of landslide vulnerability in the study area. Based on the results of the Information Value calculation, 8 out of the 16 landslide control factors were identified as having a strong to very strong influence on landslide events in the Amprong Sub- watershed area. In the strong and very strong predictive categories, the identified parameters exert a significant influence on landslide events in the Amprong Sub-watershed. Based on Table 4, parameters with values in the strong and very strong categories include slope (1.66), river density (1.05), land use (0.94), rainfall (0.49), road density (0.46), distance to the road (0.35), and slope aspect (0.33). The sum of each class of landslide control factors can impact the magnitude of the Information Value (IV) obtained, thereby providing insights into the predictive power of the parameters calculated for each class.

Table 4. Information Value Results

IV	Parameter
Slope	**1.665**
River Density	**1.054**
Landuse	**0.9379**
Rainfall	**0.487**
SPI	**0.4805**
Road Density	**0.4554**
Distance to Road	**0.349**
Aspect	**0.3314**
Elevation	0.2839
TWI	0.2529
Distance to River	0.251
TPI	0.25
NDVI	0.2487
Geology	0.084
Plan Curvature	0.0677
Profile Curvature	0.0238

5. Landslide Susceptibility Results

A landslide susceptibility map for the Amprong Sub-watershed was developed using 8 key variables identified through the Information Value (IV) calculation, which were found to have a strong to very strong predictive influence on landslide events. The map in Figure 7 was created through an overlay process using the weighted sum tool in ArcGIS 10.8 software. Susceptibility levels were classified into low, moderate, and high categories, based on the National Disaster Management Authority (BNPB) framework. The natural break method was applied to the weighted sum raster results to effectively classify landslide susceptibility, optimizing variance within and between classes.

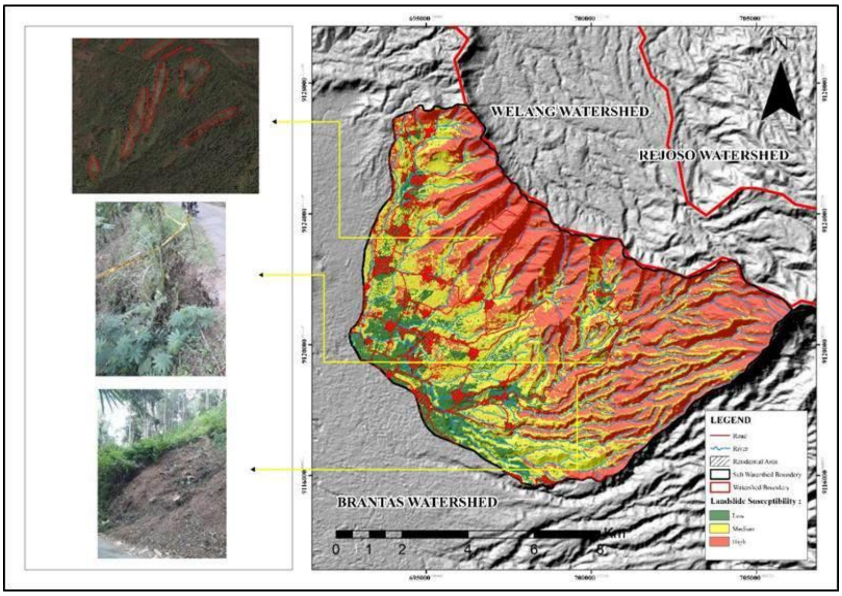


Figure 7. Results of Landslide Susceptibility Mapping in the Amprong Sub-Watershed using the Weight of Evidence - Information Value (WoE - IV) method

Table 4 presents the total area for each level of landslide vulnerability. It shows that the high vulnerability area dominates with a total of 3964 Ha, the moderate vulnerability area covers 3266 Ha, and the low vulnerability area spans 1246 Ha. A total of 46% of the Amprong Sub- Watershed area is classified as highly vulnerable to landslides, while 39% falls under moderate vulnerability and 15% is considered low vulnerability. This classification is influenced primarily by slope parameters, which have a significant impact on landslide events in the area. The Amprong Sub-Watershed is mostly composed of very steep slopes, particularly in the hilly regions around the Taji Village Administrative Area.

Table 4. Information Value Results

Landslide Susceptibility Levels	Area (Ha)	Area (%)
Low	1246	14,73
Medium	3266	38,61
High	3946	46,65

The results from the Information Value method calculations reveal the correlation between several variables and landslide occurrences in the Amprong Sub-Watershed. Each coefficient value reflects the degree of association between the variables considered in this study. The findings indicate that land use, slope angle, river density, distance to roads, road density, slope aspect, and rainfall are the parameters most significantly influencing landslide events in the area.

6. Accuracy Test

Validation of the generated map is a crucial step in assessing and identifying vulnerable areas, as well as determining the quality of the model. Without validation, the model results would not be applicable. The accuracy of the model is tested using the AUC method to evaluate its predictive performance in forecasting landslides. In the validation process of the landslide susceptibility map, prediction rate curves derived from each susceptibility map are utilized. The success rate is calculated using 70% of the training data, while the prediction map is generated from 30% of the validation data.

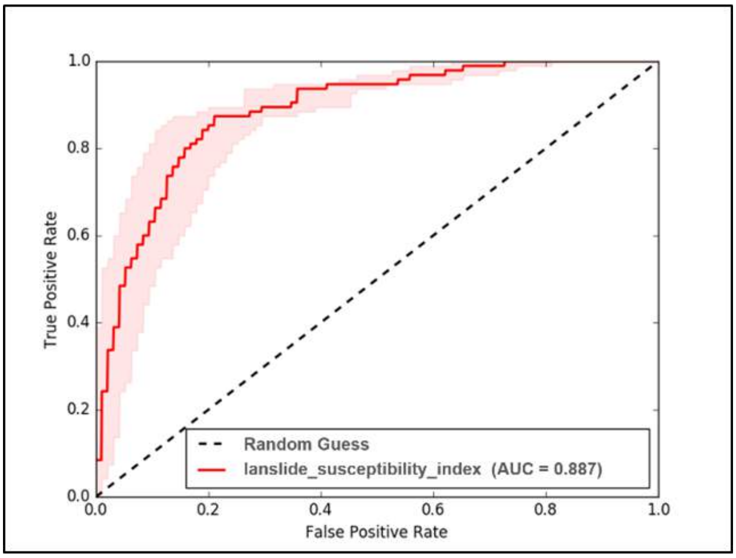


Figure 8. AUC curve showing the percentage accuracy of the resulting landslide susceptibility map

Figure 8 demonstrates accuracy testing through the Receiver Operating Characteristic (ROC) curve. The ROC curve is a scatter plot that illustrates the accuracy level in the trade-off between True Positive (TP) and False Positive (FP) rates. The TP rate is commonly referred to as sensitivity, while the (1-FP) rate is termed specificity (Masruroh et al., 2023). Landslide susceptibility mapping using the Weight of Evidence – Information Value (WoE – IV) method produces an AUC value of 0.887. This AUC value falls within the range of good classification values. It can be concluded that the use of the Weight of Evidence - Information Value (WoE - IV) method for mapping landslide susceptibility in the Amprong Sub-watershed area is relatively effective in predicting landslide events.

CONCLUSION

Landslide inventory data, particularly training data, has a significant impact on the WoE – IV calculation results during mapping data processing. These calculations influence the visualization of landslide vulnerability levels in the Amprong Sub-watershed area. Mapping of landslide vulnerability in the Amprong sub-watershed using the Weight of Evidence - Information Value method yields a distribution of landslide vulnerability across different vulnerability classes: 46% at high landslide vulnerability, 39% at moderate vulnerability, and 15% at low landslide susceptibility.

The accuracy of the vulnerability model is represented by an AUC value of 0.887. The core concept of the WoE (Weight of Evidence) method involves using historical data to assess the likelihood of future events. As such, the weighting process focuses on each landslide area for each parameter, using data from historical landslide occurrences. The results of the WoE assessment influence the coefficient values generated during the IV calculation, which in turn reflect the degree of association between the variables and landslide events in the Amprong Sub-watershed.

AUTHOR CONTRIBUTIONS

MF led the conceptualization, methodology development, and initial drafting of the manuscript. HM conducted data collection and statistical analysis. LYI contributed to result interpretation and manuscript revision. SB provided supervision, critical feedback, and final approval. All authors contributed substantially and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

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