



UDC 528.481:622.1

LANDSLIDE SUSCEPTIBILITY MODELLING IN CIANJUR REGENCY USING LANDSLIDE NUMERICAL RISK FACTOR

Anrisa Claresta RIZKY¹, Iqbal Putut Ash SHIDIQ^{1✉}, Putu Perdana Kusuma WIGUNA², Mangapul Parlindungan TAMBUNAN¹, Astrid DAMAYANTI¹, Ramanatalia PARHUSIP¹

¹*Department of Geography, Universitas Indonesia, Depok, Indonesia*

²*Department of Agroecotechnology, Faculty of Agriculture, Udayana University, Badung, Indonesia*

Article History:

- received 14 November 2024
- accepted 4 March 2026

Abstract. Cianjur Regency was often hit by landslides. In 2022, this regency was affected by landslide, leading to several civilian deaths, injuries, along with damaged houses and infrastructure. To minimize the impact, determining landslide susceptibility level was proven to be an essential step in maximally planning disaster management. Therefore, this study aimed to develop landslide susceptibility model in Cianjur Regency using the Geographic Information System (GIS). The landslide susceptibility model was based on Landslide Numerical Risk Factor (LNRF) method using spatial data consisting of historical landslides, the Digital Elevation Model (DEM), geology, soil types, land cover, rainfall, and earthquakes in Cianjur Regency. The accuracy of model was tested using the ROC-Curve method with a value of 0.845 being considered very good. The result showed that most of areas in Cianjur Regency had moderate and high levels of landslide susceptibility, with a percentage of 40% and 46%, respectively. Areas with high level were mostly found in the southeastern part of Cianjur Regency, moderate was evenly distributed, while low levels were in the northeastern and coastal areas.

Keywords: landslide, susceptibility, GIS, LNRF, ROC-Curve, Cianjur Regency.

✉Corresponding author. E-mail: iqbalputut@sci.ui.ac.id

1. Introduction

Landslide is the most frequent natural disaster in West Java Province (Disaster Management Agency of West Java Province, 2024), specifically in Cianjur Regency where 694 incidents occurred between 2018–2023 (Disaster Management Agency Cianjur Regency, 2024). Generally, landslide occurs in mountainous areas with high annual rainfall above 2500 mm/year (Hyunuk et al., 2016). These conditions are often experienced in Cianjur Regency, where the topography ranges from hills to mountains with an elevation of 350 to 2962 meters above sea level (masl). In 2021 and 2022, this regency had more than 3000 mm of rainfall, namely, 3185 mm and 3544 mm, respectively (Central Bureau of Statistics Cianjur Regency, 2024a).

Seismic activity, including high rainfall, has shown significant potential to trigger landslide. In 2022, Cianjur Regency, specifically Cugenang Sub-district, was hit by a fairly severe landslide, which caused by a series of earthquake disaster (Hartini et al., 2022). The earthquake disaster was among the factors that caused 2022 to be the year with the most landslide, accounting for 291 incidents

between 2018 and 2023 (Disaster Management Agency Cianjur Regency, 2022).

Landslide is a type of disaster capable of causing loss in terms of both material and non-material (Sobirin et al., 2017), including severe environmental and infrastructure damage as well as loss of life (National Board for Disaster Management, 2018). Landslide in Cugenang Sub-district occurred in Cianjur Regency, causing a severe impact on life and properties. As reported in the online news site <https://kompas.com/>, the disaster caused severe infrastructure damage on roads, residents' houses, and schools. Additionally, thousands of residents were reported to evacuate due to the damage to their homes (Syahrial, 2022). The disaster also caused thousands of injuries and deaths, showing the need for an effective disaster management plan (Noviandi, 2022).

A good disaster management plan can minimize the severe losses caused by landslide, requiring knowledge of danger source or threat. In this context, mapping landslide susceptibility is among the efforts that can be made in disaster management planning (Sulistyo, 2016). According to Fell et al. (2008), landslide susceptibility refers to the potential

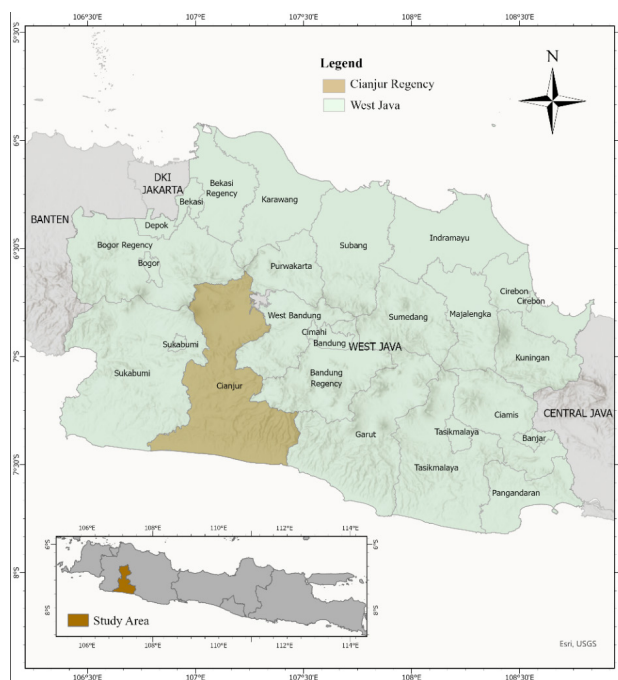
for an incident in an area. This mapping is important to provide an overview of the distribution of prone areas (Abdullah et al., 2019) and determine a mitigation plan.

Significant developments in remote sensing and Geographic Information Systems (GIS) have facilitated the creation of landslide susceptibility maps (Aleotti & Chowdhury, 1999). Landslide susceptibility assessment and mapping based on GIS have been widely carried out by several previous studies with various methods. These include Analytical Hierarchy Process method (Kornejady et al., 2014; Abedini & Tulabi, 2018), Information Value (InfoVal) (Che et al., 2012; Vijith et al., 2009), Frequency Ratio (Lee & Sambath, 2006; Akinci et al., 2011; Reis et al., 2012), Landslide Numerical Risk Factor (LNRF) (Gupta & Joshi, 1990; Saha et al., 2005; Torkashvand et al., 2014; Eslami et al., 2019; Patil & Panhalkar, 2023), Spatial Multi-Criteria Evaluation (Mustikaningrum et al., 2023), Weight of Evidence (Lee & Choi, 2004; Kayastha et al., 2012), Logistic Regression (Lee & Sambath, 2006; Lee & Pradhan, 2007; Althwaynee et al., 2014), Fuzzy (Kanungo et al., 2009), and Artificial Neural Network (Lee et al., 2004; Yesilnacar & Topal, 2005). The LNRF method has been widely used in landslide susceptibility studies (Gupta & Joshi, 1990; Saha et al., 2005; Torkashvand et al., 2014; Eslami et al., 2019; Patil & Panhalkar, 2023). However, there are no studies that have applied LNRF in Indonesia, particularly in Cianjur Regency. The LNRF method is considered suitable for measuring landslide susceptibility, specifically in mountainous areas (Gupta & Joshi, 1990). Therefore, this study aimed to develop landslide susceptibility model for Cianjur Regency using the LNRF method.

2. Methods

2.1. Study area

This study was conducted in Cianjur Regency, astronomically located between 106° 42'–107° 35' East Longitude



Note: North – Bogor and Purwakarta Regency; East – Bandung, West Bandung, and Garut Regency; South – Indian Ocean; West – Sukabumi and Bogor Regency.

Figure 1. Study area

and 6° 21'–7° 25' South Latitude. The regency, with an area of 361435 ha, consisted of 354 villages, 6 wards, and 32 sub-districts (Central Bureau of Statistics Cianjur Regency, 2024b). Based on geographical location, it has four administrative boundaries, as shown in Figure 1.

2.2. Data and variable

In this study, primary data used were obtained directly by the authors as the first party in the form of field observation. Secondary data were obtained indirectly from agencies and other official sources (Table 1).

Table 1. Data and variable

Data	Variable	Source	Scale
Landslide occurrence	Landslide occurrence	Field observation Disaster Management Agency (BPBD) Cianjur Regency Google Earth Pro image	1:25000
Digital Elevation Model (DEM)	Slope Elevation Topographic curvature Soil wetness Water flow strength	DEMNAS	0.27-arcsecond (equivalent to 8.1 meters)
Monthly rainfall	Annual rainfall	CHIRPS	5000 meter
Geology of Cianjur Regency	Distance from faults Geological formation	Website of the Geological Agency of the Ministry of Energy and Mineral Resources	1:100000
Soil type	Soil type	Center for Agricultural Land Resources Research and Development (BBSDLR)	1:50000
Land Cover	Land cover	Geospatial Information Agency (BIG) OpenStreetMap (OSM)	1:25000
Earthquake occurrence	Earthquake	USGS Earthquake Website	—

Landslide incident data sourced from the Disaster Management Agency Cianjur Regency was used as a reference for sampling. The data contained information on the date and location of Cianjur Regency landslide incident in 2018–2023 in the form of sub-districts and villages. Landslide locations selected for observation were easy to reach and their coordinates were recorded using GPS on cellphones. These coordinate points were used a reference to delineate landslide area. Based on field observations, checks, and adjustments were also carried out, including the appearances on Google Earth Pro images using Disaster Management Agency data. Delineation was carried out when images information and appearance showed traces of landslide (Figure 2). Based on sampling with both methods, data on 80 incidents obtained from 2018 to 2023 were collected, including coordinate points and landslide area. The data were used for training and testing with a ratio of 70:30, consisting of 56 and 24, respectively.



Figure 2. Delineation of landslide

DEM data were processed to meet slope, elevation, topographic curvature, soil wetness conditions, and water flow strength. Meanwhile, geological data including faults and geological formations, were used to calculate distance variables. Independent variables included landslide occurrence incidents, rainfall, soil type, land cover, earthquakes, and population density. While landslide susceptibility and population exposure were dependent variables. Subsequently, ArcGIS Pro software was used to process variables.

2.3. Workflow

The development of landslide susceptibility model started with the creation of thematic maps of each variable, as shown in Figure 3. Thematic maps included landslide in-

cidents inventory, slope, elevation, topographic curvature, soil wetness, water flow strength, rainfall, soil type, land cover, distance from faults, geological formations, and earthquakes. For each variable, the LNRF method was calculated and used for existing landslide area data. All maps created were combined using the overlay method to produce landslide susceptibility map. The map accuracy was tested using the ROC-Curve method through data testing.

2.4. LNRF

Landslide susceptibility model using LNRF method was conducted with ArcGIS Pro software. The calculation started by overlaying landslide area data with each variable using Intersect tool. New polygons in the form of landslide areas were generated based on the variable classes. In the attribute table, landslide area was calculated based on the variable class using the Calculate Geometry tool as the initial step to estimate the LNRF value. Furthermore, the LNRF value was calculated using the Calculate Field tool by determining the ratio between landslide area in a class of a variable and the average landslide area. The LNRF equation used is as follows:

$$\text{LNRF} = \frac{A}{E}, \quad (1)$$

where, A is landslide area in a class of a variable, and E is the average landslide area of all classes of a variable.

LNRF values would be classified into susceptibility levels according to the rules of the LNRF method in a new column. These values were grouped into 3 classes for each thematic data based on their numerical weight (Table 2). After the provisions of LNRF method, a numerical weight of 0 was given for a value <0.67, showing low susceptibility to landslide. A weight of 1 was given to 0.67–1.33, representing moderate, while a weight of 3 for LNRF value >1.33 showed high susceptibility. The values and weights were also filled in the attribute table of each processed variable.

Table 2. LNRF value and weight classification (source: Torkashvand et al., 2014; Gupta & Joshi, 1990)

LNRF value	Weight	Instability level
<0.67	0	Low
0.67–1.33	1	Moderate
>1.33	2	High

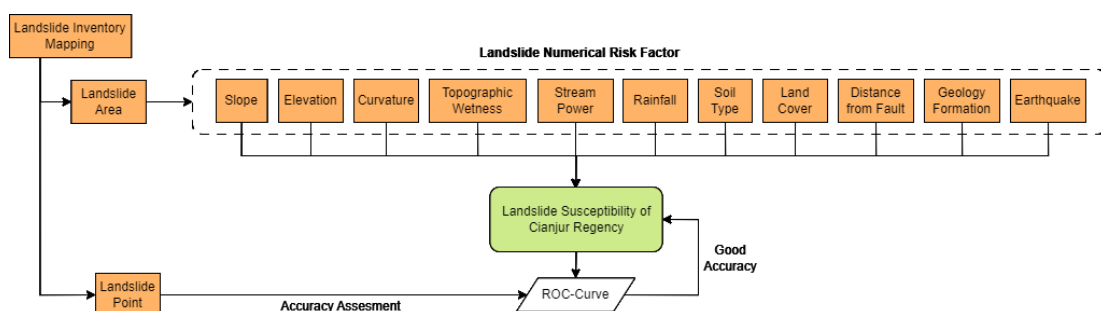


Figure 3. Study workflow

Landslide susceptibility model in Cianjur Regency was performed using ArcGIS Pro software. Modelling was conducted by combining thematic maps and their weights, according to the LNRF method calculation. The combination was performed using the overlay method, specifically Union tool. Subsequently, the numerical weights of each variable were using the Calculate Field tool in the attribute table to produce landslide susceptibility index. The index was classified into susceptibility classes, which were carried out using the Reclassify tool and the Natural Breaks method (Saha et al., 2005). A total of 3 susceptibility classes were produced, comprising low, moderate, and high.

2.5. Accuracy assessment

ROC (Receiver Operating Characteristic) Curve was the accuracy test method in the graph form, which was used to evaluate the performance of a classification system. It could also be used to evaluate the accuracy of a prediction model (Swets, 1988). Area under the ROC-Curve (AUC) was used to measure the performance of a classification model in distinguishing two conditions (Fawcett, 2006; Hanley & McNeil, 1982). In this study, the classification model was the level of landslide susceptibility of the LNRF model, with 2 conditions measured through the ROC-Curve being accurate and inaccurate predictions of landslide incidents. AUC was calculated by determining the area under the ROC curve, where a greater value showed improved performance (Swets, 1988). Specifically, the AUC value determined how susceptibility model was created to classify landslide presence or absence (Cantarino et al., 2019). The ROC-Curve was used to test susceptibility level accuracy in Cianjur Regency LNRF model using 30% of landslide incidents used as data testing.

3. Results and discussion

3.1. LNRF value

In this study, the LNRF value referred to the area of the existing landslide incident, which occurred in 2018–2023. Moreover, the presence of wider landslide in a variable class correlated with higher LNRF value. This contributed to greater weight, which could be, interpreted as more unstable slope or higher potential for landslide in an area (Gupta & Joshi, 1990).

Slopes are considered to have a significant influence on landslide in Cianjur Regency. Approximately 34.33% of the regency's total area, equivalent to 124804 hectares, consists of terrain with relatively gentle slopes, ranging from 16% to 30% (Figure 4a). Based on the results, landslide occurred most frequently within this slope range (LNRF value = 1.47), followed by areas with steep slope at 31–70% (LNRF value = 4.12), respectively, indicating high susceptibility. Landslide could be found in the least amount in areas with slopes of 2–7% (LNRF value = 0.05). Meanwhile, an elevation of 500–1500 masl

or areas considered high hills (Zuidam, in Damayanti et al., 2020) was considered to be conditions with high instability, showing higher potential for landslide (LNRF value = 5.55) compared to others. As seen in Figure 4b, the area within that elevation range also covers the largest expanse in Cianjur Regency.

Table 3. LNRF value of each variable

Variable	Class	Land-slide area (Ha)	LNRF value	Weight	Instability level
Slope	<2%	0.00	0	0	Low
	2–7%	0.08	0.05	0	Low
	8–15%	0.26	0.17	0	Low
	16–30%	2.29	1.47	2	High
	31–70%	6.40	4.12	2	High
	71–140%	1.72	1.11	1	Moderate
	> 140%	0.12	0.08	0	Low
Elevation	< 50 masl	0	0	0	Low
	50–100 masl	0	0	0	Low
	100–200 masl	0	0	0	Low
	200–500 masl	0.81	0.45	0	Low
	500–1500 masl	10.06	5.55	2	High
	1500–3000 masl	0	0	0	Low
Topographic curvature	Concave	3.72	1.28	1	Moderate
	Flat	2.67	0.92	1	Moderate
	Convex	2.35	0.81	1	Moderate
Soil wetness index	<5	5.76	1.59	2	High
	5–10	4.99	1.38	1	Moderate
	> 10	0.12	0.03	0	Low
Stream power index	<0	3.30	0.91	1	Moderate
	0–2	4.39	1.21	1	Moderate
	>2	3.19	0.88	1	Moderate
Distance from fault	1000 m	0.69	1.09	2	High
	2000 m	0.94	1.49	1	Moderate
	3000 m	0	0	0	Low
	4000 m	0.12	0.19	0	Low
	5000 m	0	0	0	Low
	6000 m	0.66	1.05	1	Moderate
	7000 m	1.32	2.08	2	High
	8000 m	1.56	2.47	2	High
	9000 m	0.49	0.78	0	Low

Continued Table 3

Vari- able	Class	Land- slide area (Ha)	LNRF value	Weight	Instability level
	10000 m	0	0	0	Low
	>10000 m	1.18	1.86	2	High
Geolo- gical forma- tion	Basal lava flow of mount gegerbentang	0	0	0	Low
	Basaltic- andesite lava flow	0	0	0	Low
	Youngest LAVA flow	0	0	0	Low
	alluvial	0	0	0	Low
	Alluvium and coastal deposits	0	0	0	Low
	Andesite	0	0	0	Low
	Horenblenda andesite	0	0	0	Low
	Pyroxene andesite	0.10	0.07	0	Low
	Clay, marl, quartz sandstone member	0.03	0.02	0	Low
	Limestone member	0	0	0	Low
	Sandstone member	0	0	0	Low
	Sandstone- siltstone member	0	0	0	Low
	Breccia member	0	0	0	Low
	Breccia and sandstone member	0	0	0	Low
	Kadupandak member	0	0	0	Low
	Marl and quartz sandstone member	0	0	0	Low
	Sindangkerta member	0	0	0	Low
	Upper part of bentang formation	0	0	0	Low

Continued Table 3

Vari- able	Class	Land- slide area (Ha)	LNRF value	Weight	Instability level
	Lower part of bentang formation	0	0	0	Low
	Young volcanic rocks	0	0	0	Low
	Reef limestone	0	0	0	Low
	Tuffaceous sandstone	0	0	0	Low
	Breccia and lava of mount Kencana and Mount Limo	0	0	0	Low
	Tuffaceous breccia	0.65	0.48	0	Low
	Cantayan	0	0	0	Low
	Old volcanic rock deposits	0	0	0	Low
	Breccia and lava deposits of Mount Gede	0	0	0	Low
	Pyroclastic deposits	1.04	0.76	1	Moderate
	Staircase and lake deposits	0	0	0	Low
	Old staircase deposits	0	0	0	Low
	Bentang formation	0.39	0.29	0	Low
	Beser formation	0.01	0.01	0	Low
	Bojonglopang formation	0	0	0	Low
	Cimandiri formation	0	0	0	Low
	Jampang formation	0	0	0	Low
	Jatiluhur formation	0	0	0	Low
	Koleberes formation	4.28	3.15	2	High
	Nyalindung formation	0	0	0	Low
	Lava	0	0	0	Low
	Andesite lava	0	0	0	Low

End of Table 3

Variable	Class	Land-slide area (Ha)	LNRF value	Weight	Instability level
	Lava and lahar of mount Patuha	0	0	0	Low
	Mangerite	0	0	0	Low
	Old volcanic products	4.38	3.22	2	High
	Talus and landslide deposits	0	0	0	Low
	Tufaan clay unit	0	0	0	Low
	Vitrophyres	0	0	0	Low
Earth-quake	M 1.607–3.807	0.60	0.28	0	Low
	M 3.807–4.561	5.78	2.66	2	High
	M 4.561–5.364	0.11	0.05	0	Low
	M 5.364–6.507	0	0	0	Low
	M 6.507–7.821	4.38	2.01	2	High
Soil type	Alluvial	0	0	0	Low
	Andosol	0.72	0.33	0	Low
	Escarpment	0	0	0	Low
	Gleisol	0.30	0.14	0	Low
	Cambisol	6.22	2.86	2	High
	Latosol	0	0	0	Low
	Lithosol	0	0	0	Low
	Mediterranean	0.79	0.36	0	Low
	Podzolic	2.85	1.31	1	Moderate
	Regosol	0	0	0	Low
Land cover	Rice fields and dry fields	0.90	0.41	0	Low
	Forests and plantations	6.92	3.17	2	High
	Shrubs and vacant land	3.06	1.40	1	Moderate
	Built-up land	0	0	0	Low
	Water bodies	0	0	0	Low
Rainfall	2900–3000	0	0	0	Low
	>3000	10.88	2	2	High

Areas with cambisol soil were considered to have a high potential for landslide (LNRF value = 2.86). Cambisol cover the largest area in Cianjur Regency, indeed, this soil type is found across a significant portion of the regency (Figure 4g). Cambisol soil originated resulting from light

or moderate weathering of parent material, without a significant amount of clay, organic matter, aluminum, and/or iron compounds (Britannica, 2011b). Similarly, Chen et al. (2010) stated that landslide could occur when the percentage of clay in a type of soil was >2.5%. In comparison, other types of soil had fairly stable slopes and a smaller chance of landslide. Cianjur Regency was found to be dominated by more than 3000 mm/year annual rainfall (Figure 4f). Therefore, areas with rainfall of more than 3000 mm/year in this regency were considered to have a high potential for landslide. This condition followed the theory of determining landslide susceptible areas by the Department of Public Works, Directorate General of Spatial Planning (2007). The theory stated that areas with rainfall of more than 2500 mm/year could become areas susceptible to landslide.

Land cover in Cianjur Regency was found to be dominated by forest and plantation (Figure 4h), where most landslide occurred from 2018 to 2023. This phenomenon led to the formation of forests and plantations being considered to have a high level of instability (LNRF value = 3.17). Land cover in the form of shrubs and empty land was also considered less stable at a lower level, while vegetation, particularly trees acted as a slope retainer (Afriani, 2019). However, forests and plantations were mostly located on steep slopes. A steeper slope correlated with greater potential for slope instability due to the high volume and speed of runoff, which increased transport energy (Abedini & Tulabi, 2018; Arsyad, 1989).

Measurement of erosion strength by runoff water flow was carried out through the Stream Power Index (SPI) (Moore et al., 1991). When the map between the existing landslide and the SPI (Figure 4e) was combined, landslide in Cianjur Regency were evenly distributed across all classes of SPI values. Therefore, all SPI classes were given the same weight of 1, and a similar uniformity was observed in the height variable. Thus, it can be interpreted that regardless of the power or erosive force of runoff in this regency, the potential for landslides tends to remain the same, specifically, at a moderate level. The same applies to the aspect of topographic curvature comprising concave, flat, and convex (Figure 4c), the results showed that there was the same level of landslide potential across all conditions. This occurred occasionally because concave curvature tended to have a higher landslide potential than others due to the possibility of saturated soil conditions (Ayalew et al., 2004).

Based on soil wetness condition variable assessed using the Topographic Wetness Index (TWI), areas with TWI <5 had an LNRF value = 1.59, showing a high level of instability. This showed that areas with TWI <5, characterized by "dry" or unsaturated soil, had a higher potential for landslide compared to others. Areas with such conditions account for the largest percentage in Cianjur Regency compared to areas with other TWI values (Figure 4d). Along with the increase in the TWI value, which showed highly saturated soil conditions, LNRF value decreased indicating a reduction in the potential for landslide. This

showed that the function of TWI method was to determine the zone spatial distribution serving as the source of the emergence of runoff influencing landslide (Wilson & Gallant, 2000).

In geological variables, landslide in Cianjur Regency between 2018–2023 were mostly found in areas composed of the Koleberes Formation (LNRF value = 3.15) and Old Volcanic Products (LNRF value = 3.22). Areas with these geological formations were considered to have higher slope instability than others. The Kaliberes Formation is the geological formation with the third-largest area of accumulation in Cianjur Regency, following the Bentang Formation (Tmptb) and the Mount Gede Breccia and Lahar Deposits (Qyg) (Figure 4k). The Koleberes Formation was composed of sedimentary and volcanic rocks, which were part of volcanic rocks, comprising tuff sandstone, and are less dense (Wahyuni & Sukiyah, 2023; Agustin & Bronto, 2019). Old Volcanic Products (Qob) in Cianjur Regency consist of breccia, lava, and lahar, composed of andesite and basalt. However, Old Volcanic Products (Qot) consisted of pyroxene

andesite breccia and andesite lava (Sudjatmiko, 2003). These formations were materials from volcanic eruptions that had been cooling for millions of years.

Based on geological structure, Cianjur Regency was traversed by several faults/fractures (Figure 4j). Previous studies have shown that the closer an area is to the geological structure, the greater the potential for landslide (Saha et al., 2005; Erener & Düzgün, 2010; Torkashvand et al., 2014; Patil & Panhalkar, 2023). At a distance of 0–1000 m from the fault, this regency had a high level of instability. At 1000–2000 m, the instability decreased to a moderate level, and at 3000–5000 m, there was low instability. At a distance of 0–5000 m, closer fault correlated with more instability, thereby increasing the potential for landslide. However, high LNRF values were found in areas further from the fault.

In relation to faults as geological structures, seismic activity, particularly earthquakes, was also considered to influence landslide in Cianjur Regency. Table 3 showed that landslide often occurred in areas included in the

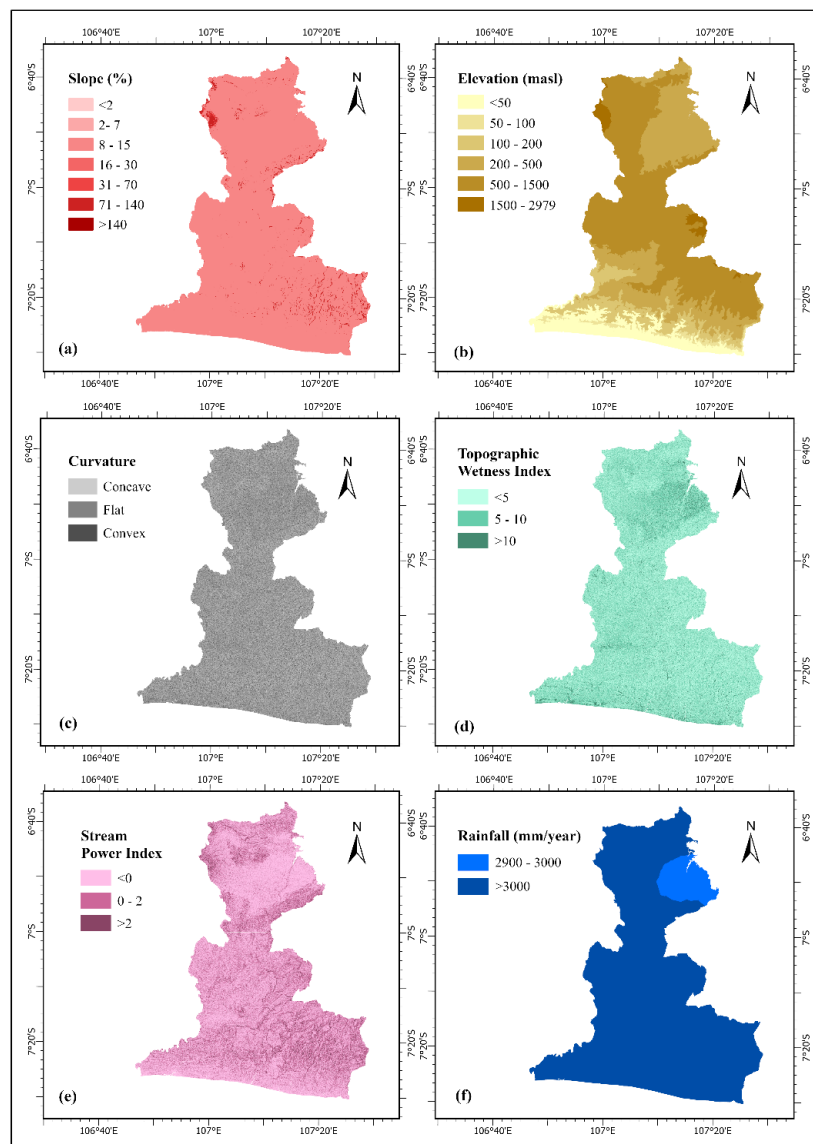


Figure 4. To be continued

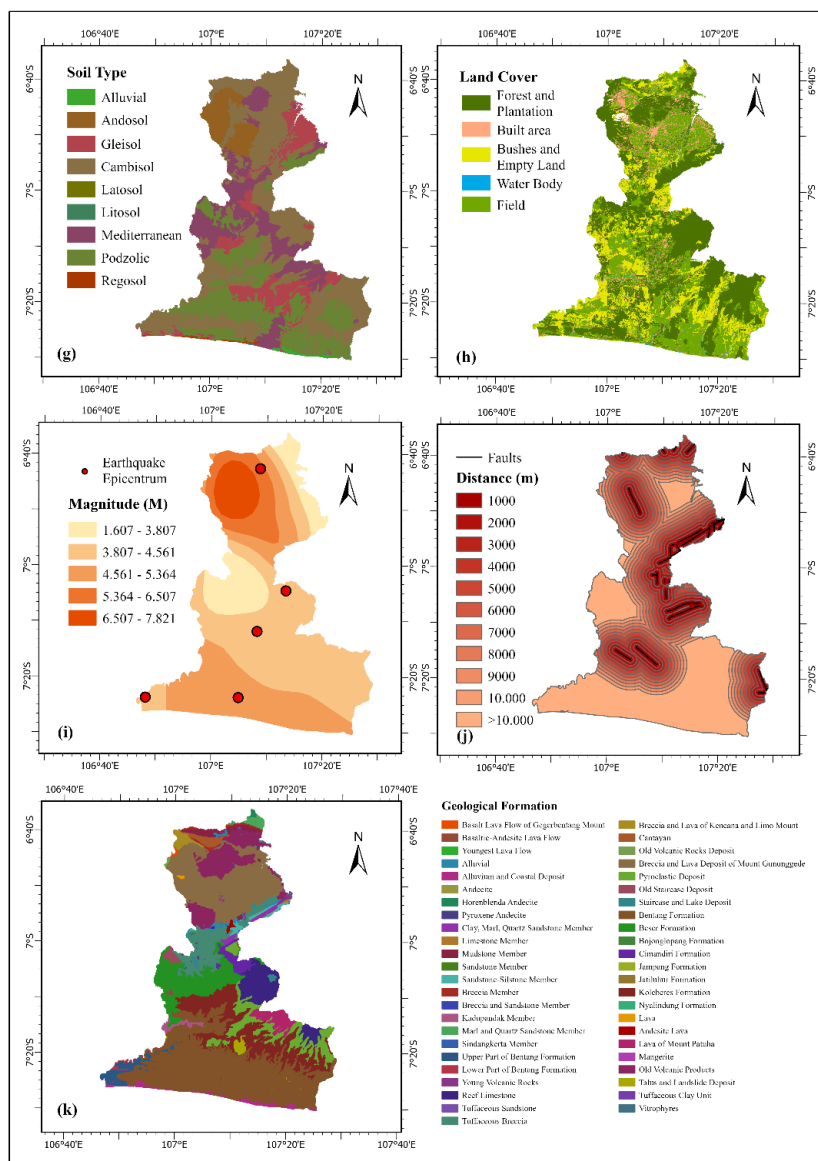


Figure 4. Physical condition map of Cianjur Regency: a) Slope; b) Elevation; c) Curvature; d) Topographic Wetness Index (TWI); e) SPI; f) Rainfall; g) Soil type; h) Land cover; i) Earthquake; j) Distance from faults; k) Geology formation

earthquake zone with a strength of M 3.808–4.561 (LNRF value = 2.66) and 6.508–7.821 (LNRF value = 2.01). Therefore, the two areas with these characteristics had the greatest potential for landslide compared to areas included in zones with other magnitudes.

3.2. Landslide susceptibility model

Based on landslide susceptibility map, the southeastern part of Cianjur Regency showed high susceptibility. This area was predominantly covered by forests and plantations, where land cover in the vegetation form showed potential to be a slope retainer. However, in these areas, the slopes tended to be steep with larger and faster surface flows contributing to transport energy (Arsyad, 1989). Additionally, land cover in the form of rice fields was common in the northern and southeastern parts.

Rice fields on fairly steep slopes could trigger landslide because the soil was saturated (Volcanology and Geological Hazard Mitigation Center, 2003). The types of soil often found in the southeastern part of Cianjur Regency were Kambisol and Mediterranean. In the southeast, conditions tended to be steep, and the Cambisol soil conditions in areas with steep slopes were thin lead (Dharmawan et al., 2021; Tufaila & Alam, 2014). Meanwhile, Mediterranean soil was from the weathering of alkaline sedimentary rocks and limestone (Syarif et al., 2018). Based on the USDA Soil Taxonomy classification, Mediterranean soil was included in the Alfisol order, which tended to have a low humus content (Britannica, 2011a). The low humus content caused the soil structure to become fragile. The physical conditions in the southeastern part of Cianjur Regency caused the southeastern part to have a high potential for landslide.

The northern part of Cianjur Regency was dominated by areas with a high level of landslide susceptibility. The condition of land cover in the high landslide prone area was the same as in the southeast, which was dominated by forests, plantations as well as rice, and dry fields. The slope conditions were also similar to those in the southeastern area but tended to be gentler. The dominant soil type in the area was also almost the same as the southeast part, namely Mediterranean soil. In this northern area, a fault or fracture could be found, namely the Cugenang Fault. This active fault was one of the causes of high susceptibility, triggering rock cracking (Abedini & Tulabi, 2018). Additionally, the activity of Cugenang Fault caused an

earthquake in Cianjur Regency in 2022, followed by landslide in the area. The disaster led to the northern region being classified as a zone with a fairly large earthquake strength, namely M 6.508–7.821 (Figure 4i). This was because earthquake with a greater strength would suddenly release large amounts of energy to trigger ground cracks (Highland & Bobrowsky, 2008; Sonker et al., 2022).

Based on the cross-section of Cianjur Regency, areas with high landslide susceptibility tend to be in the plateau to hills (Figure 6). Regarding LNRF value, the elevation class of 500–1500 masl was considered to have a high level of instability. This was in line with susceptibility conditions shown in the cross-section of Cianjur Regency. From cross-section presented in Figure 6, areas at an elevation of 0–500 masl had a low to moderate level of susceptibility. Cross-section line A–B was a pseudo line drawn from the north to the south of Cianjur Regency, while line C–D was a pseudo line drawn from the southeast to the south (Figure 5). The cross-section of lines A–B showed that areas with a high level of landslide susceptibility were at an elevation of 500–1500 masl. However, not all areas at this elevation had a high level of landslide susceptibility. The conditions observed in lines C–D were similar but showed slight differences. Areas located at an elevation of 500–1500 masl tended to have a high susceptibility level, but a small part of the area had moderate level.

Regarding landslide susceptibility areas, most of Cianjur Regency had moderate and high levels (Figure 7). Approximately 46% covering 164,533 ha was classified as having high susceptibility. Meanwhile, areas with moderate and low levels were found, covering 40% and 49,803 ha (14%), respectively. Based on comparison with other areas, there was no landslide found in areas with low susceptibility. Areas with high susceptibility had the largest existing landslide, with a percentage reaching 94% of the total area. Meanwhile, landslide found in low susceptibility areas were only 6% of the total area of existing incidents.

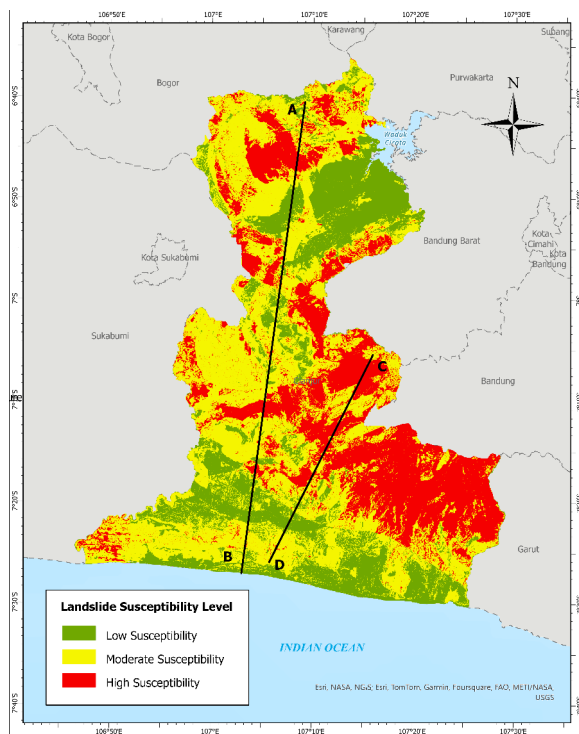


Figure 5. Landslide susceptibility map of Cianjur Regency

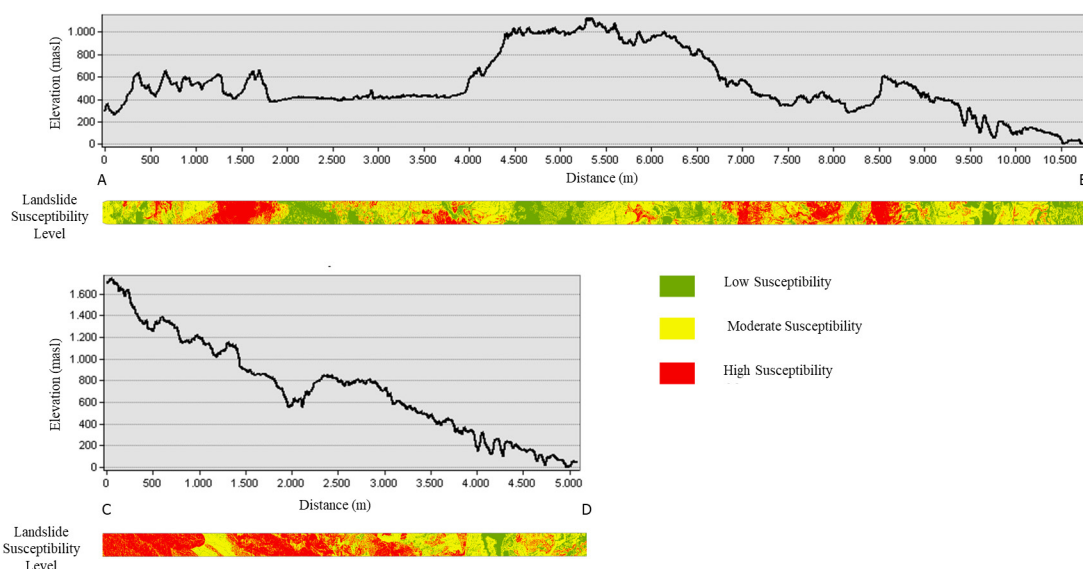


Figure 6. Cross-section of Cianjur Regency

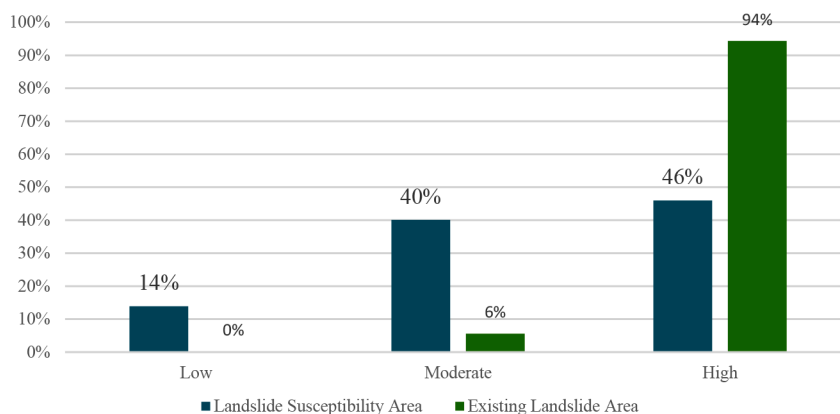


Figure 7. Comparison of area percentage based on landslide susceptibility level and existing landslide occurrence

3.3. Model accuracy

Landslide susceptibility model of Cianjur Regency created using the LNRF method had an AUC value of 0.845, as shown in Figure 8. According to Trifonova et al. (2013), this value showed that model obtained was good and could be used as landslide susceptibility map for Cianjur Regency. The results also showed that the LNRF method was suitable for modeling landslide susceptibility for Cianjur Regency area. The AUC value was higher when compared to the value produced by Patil and Panhalkar (2023). Therefore, landslide susceptibility model of Cianjur Regency created using the LNRF method had slightly better accuracy.

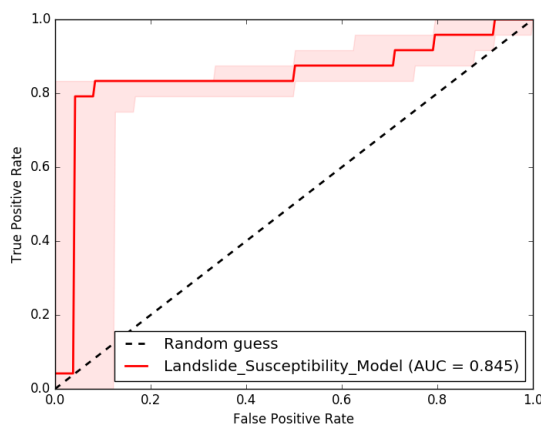


Figure 8. Results of landslide susceptibility model accuracy test with ROC-Curve

4. Conclusions

In conclusion, this study investigated the development of landslide susceptibility model using variables in the form of physical factors. These included height, slope, topographic curvature, soil wetness, water flow strength, soil type, land cover, rainfall, geological formation, distance from faults, and earthquakes. By calculating LNRF value, these variables showed their contributions to the occurrence of landslide but at different levels, namely high, moderate, and low. The model was considered accurate

enough to be used as landslide susceptibility model. Additionally, it showed that most areas in Cianjur Regency had moderate and high levels, and only a small part had low level of landslide susceptibility.

References

- Abdullah, A. F., Aimrun, W., Nasidi, N. M., Hazari, K., Sidek, L. M., & Selamat, Z. (2019). Modelling erosion and landslides induced by farming activities at hilly areas, Cameron Highlands, Malaysia. *Jurnal Teknologi*, 81(6), 195–204. <https://doi.org/10.11113/jt.v81.13795>
- Abedini, M., & Tulabi, S. (2018). Assessing LNRF, FR, and AHP models in landslide susceptibility mapping index: A comparative study of Nojian watershed in Lorestan province, Iran. *Environmental Earth Sciences*, 77(11), Article 405. <https://doi.org/10.1007/s12665-018-7524-1>
- Agustin, F., & Bronto, S. (2019). Volcanostratigrafi Inderaan Jauh Kompleks Gunungapi Gede dan Sekitarnya, Jawa Barat, Indonesia [Remotely sensed volcano stratigraphy of the Gede volcanic complex and surroundings, West Java, Indonesia]. *Jurnal Geologi dan Sumberdaya Mineral*, 20(1), 9–16. <https://doi.org/10.33332/jgsm.geologi.v20i1.386>
- Akinci, H., Doğan, S., Kiliçoğlu, C., & Serhan Temiz, M. (2011). Production of landslide susceptibility map of Samsun (Turkey) city center by using frequency ratio method. *International Journal of the Physical Sciences*, 6(5), 1015–1025.
- Aleotti, P., & Chowdhury, R. (1999). Landslide hazard assessment: Summary review and new perspectives. *Bulletin of Engineering Geology and the Environment*, 58, 21–44. <https://doi.org/10.1007/s100640050066>
- Arsyad, S. (1989). *Konservasi Air dan Tanah* [Water and soil conservation]. Institut Pertanian Bogor.
- Ayalew, L., Yamagishi, H., & Ugawa, N. (2004). Landslide susceptibility mapping using GIS-based weighted linear combination, the case in Tsugawa area of Agano River, Niigata Prefecture, Japan. *Landslides*, 1(1), 73–81. <https://doi.org/10.1007/s10346-003-0006-9>
- Britannica. (2011a). Alfisol. In *Encyclopedia Britannica*. <https://www.britannica.com/science/Alfisol>
- Britannica. (2011b). Cambisol. In *Encyclopedia Britannica*. <https://www.britannica.com/science/Cambisol>
- Cantarino, I., Carrion, M. A., Goerlich, F., & Martinez Ibañez, V. (2019). A ROC analysis-based classification method for land-

- slide susceptibility maps. *Landslides*, 16(2), 265–282. <https://doi.org/10.1007/s10346-018-1063-4>
- Central Bureau of Statistics Cianjur Regency. (2024a). *Jumlah Curah Hujan di Stasiun Pacet (mm), 2020–2022* [Rainfall at Pacet Station (mm), 2020–2022]. <https://cianjurkab.bps.go.id/indicator/151/182/1/jumlah-curah-hujan-di-stasiun-pacet.html>
- Central Bureau of Statistics Cianjur Regency. (2024b). *Kabupaten Cianjur Dalam Angka 2024* [Cianjur Regency in numbers 2024]. <https://cianjurkab.bps.go.id/publication/2024/02/28/b9cc2c5d142d55e0985d83ba/kabupaten-cianjur-dalam-angka-2024.html>
- Che, V. B., Kervyn, M., Suh, C. E., Fontijn, K., Ernst, G. G. J., Del Marmol, M. A., Trefois, P., & Jacobs, P. (2012). Landslide susceptibility assessment in Limbe (SW Cameroon): A field calibrated seed cell and information value method. *Catena*, 92, 83–98. <https://doi.org/10.1016/j.catena.2011.11.014>
- Damayanti, A., Angin, F., Adib, A., & Irfan, M. (2020). Geomorphological characteristic of landslide hazard zones in Sukaram Village, Cisolok Subdistric, Sukabumi Regency. *IOP Conference Series: Earth and Environmental Science*, 412, Article 012009. <https://doi.org/10.1088/1755-1315/412/1/012009>
- Department of Public Works, Directorate General of Spatial Planning. (2007). *Pedoman Penataan Ruang Kawasan Rawan Bencana Longsor* [Guidelines for spatial planning in Landslide-Prone Areas]. <https://jdih.pu.go.id/internal/assets/assets/produk/PermenPUPR/2007/07/PermenPU22-2007.pdf>
- Dharmawan, I. W. S., Ridwan, M., & Suparna, N. (2021). Jenis Tanah, Komposisi dan Keanekaragaman Jenis Tegakan Pada Pengusahaan Hutan Alam Secara Konvensional dan RIL [Soil types, composition and diversity of stand types in conventional and RIL natural forest management]. *Jurnal Ilmu Lingkungan*, 19(3), 555–564. <https://doi.org/10.14710/jil.19.3.555-564>
- Disaster Management Agency Cianjur Regency. (2022). *Laporan Kinerja Instansi Pemerintah (LKIP) 2022 BPBD Kabupaten Cianjur* [Government Agency Performance Report of Cianjur Regency].
- Disaster Management Agency Cianjur Regency. (2024). *Dokumen Rencana Penanggulangan Bencana Kabupaten Cianjur 2025–2029* [Cianjur Regency disaster management plan document 2025–2029].
- Disaster Management Agency of West Java Province. (2024). *BARATA: Kejadian Per Bencana* [Events per disaster].
- Erener, A., & Düzgün, H. S. B. (2010). Improvement of statistical landslide susceptibility mapping by using spatial and global regression methods in the case of more and Romsdal (Norway). *Landslides*, 7(1), 55–68. <https://doi.org/10.1007/s10346-009-0188-x>
- Eslami, M., Shadfar, S., Mohammadi Torkashvand, A., & Pazira, E. (2019). Assessment of density area and LNRF models in landslide hazard zonation (case study: Alamout watershed, Qazvin Province, Iran). *Acta Ecologica Sinica*, 39(2), 173–180. <https://doi.org/10.1016/j.chnaes.2018.08.001>
- Fawcett, T. (2006). An introduction to ROC analysis. *Pattern Recognition Letters*, 27(8), 861–874. <https://doi.org/10.1016/j.patrec.2005.10.010>
- Fell, R., Corominas, J., Bonnard, C., Cascini, L., Leroy, E., & Savage, W. Z. (2008). Guidelines for landslide susceptibility, hazard and risk zoning for land use planning. *Engineering Geology*, 102(3–4), 85–98. <https://doi.org/10.1016/j.enggeo.2008.03.022>
- Gupta, R. P., & Joshi, B. C. (1990). Landslide hazard zoning using the GIS approach: A case study from the Ramganga catchment, Himalayas. *Engineering Geology*, 28(1–2), 119–131. [https://doi.org/10.1016/0013-7952\(90\)90037-2](https://doi.org/10.1016/0013-7952(90)90037-2)
- Hanley, J. A., & McNeil, B. J. (1982). The meaning and use of the area under a receiver operating characteristic (ROC) curve. *Radiology*, 143, 29–36. <https://doi.org/10.1148/radiology.143.1.7063747>
- Hartini, K., Prihapsari, S., Hartanto, G., & Rohmah, A. (2022). *Penanganan Gempa Cianjur 2022* [2022 Cianjur Earthquake Response]. Ministry of Public Works and Public Housing.
- Highland, L. M., & Bobrowsky, P. (2008). *The landslide handbook: A guide to understanding landslides*. U.S. Geological Survey. <https://doi.org/10.3133/cir1325>
- Hyunuk, A., Minseok, K., & Giha, L. (2016). Survey of spatial and temporal landslide prediction methods and techniques. *Korean Journal of Agricultural Science*, 43(4). <https://doi.org/10.7744/kjoas.20160053>
- Kanungo, D. P., Arora, M. K., Sarkar, S., & Gupta, R. P. (2009). A fuzzy set based approach for integration of thematic maps for landslide susceptibility zonation. *Georisk*, 3(1), 30–43. <https://doi.org/10.1080/17499510802541417>
- Kayastha, P., Dhital, M. R., & De Smedt, F. (2012). Landslide susceptibility mapping using the weight of evidence method in the Tinau Watershed, Nepal. *Natural Hazards*, 63(2), 479–498. <https://doi.org/10.1007/s11069-012-0163-z>
- Kornejady, A., Heidary, K., Sarparast, M., Gh, K., & Mombeini, M. (2014). Performance assessment of two “LNRF” and “AHP-area density” models in landslide susceptibility zonation. *Journal of Life Science and Biomedicine*, 4(3), 169–176.
- Lee, S., & Choi, J. (2004). Landslide susceptibility mapping using GIS and the weight-of-evidence model. *International Journal of Geographical Information Science*, 18(8), 789–814. <https://doi.org/10.1080/13658810410001702003>
- Lee, S., & Pradhan, B. (2007). Landslide hazard mapping at Selangor, Malaysia using frequency ratio and logistic regression models. *Landslides*, 4(1), 33–41. <https://doi.org/10.1007/s10346-006-0047-y>
- Lee, S., & Sambath, T. (2006). Landslide susceptibility mapping in the Damrei Romel area, Cambodia using frequency ratio and logistic regression models. *Environmental Geology*, 50(6), 847–855. <https://doi.org/10.1007/s00254-006-0256-7>
- Lee, S., Ryu, J.-H., Won, J.-S., & Park, H.-J. (2004). Determination and application of the weights for landslide susceptibility mapping using an artificial neural network. *Engineering Geology*, 71(3–4), 289–302. [https://doi.org/10.1016/S0013-7952\(03\)00142-X](https://doi.org/10.1016/S0013-7952(03)00142-X)
- Moore, I. D., Grayson, R. B., & Ladson, D. A. R. (1991). Digital terrain modelling: A review of hydrological, geomorphological, and biological applications. *Hydrological Processes*, 5(1), 3–30. <https://doi.org/10.1002/hyp.3360050103>
- Mustikaningrum, M., Widhatama, A. F., Widantara, K. W., Ibrohim, M., Hibatullah, M. F., Larasati, R. A. P., Utami, S., & Hadmoko, D. S. (2023). Multi-hazard analysis in Gunungkidul regency using the spatial multi-criteria evaluation. *Forum Geografi*, 37(1), 35–45. <https://doi.org/10.23917/forgeo.v37i1.19041>
- National Board for Disaster Management. (2018). *Data Bencana Indonesia 2018* [Indonesian Disaster Data 2018].
- Noviandi, F. (2022). *Jenazah Korban Gempa Cianjur Ditemukan Lagi di Lokasi Longsor Cijedil Cugenang, Identitas Laki-laki* [The body of a Cianjur earthquake victim was found again at The Cijedil Cugenang Landslide Site, identified as a man.]. *Tribun Jabar*. <https://jabar.tribunnews.com/2022/12/20/jenazah-korban-gempa-cianjur-ditemukan-lagi-di-lokasi-longsor-cijedil-cugenang-seorang-laki-laki>
- Patil, A. S., & Panhalkar, S. S. (2023). Remote sensing and GIS-based landslide susceptibility mapping using LNRF method in part of Western Ghats of India. *Quaternary Science Advances*, 11, Article 100095. <https://doi.org/10.1016/j.qsa.2023.100095>

- Sobirin, Sitanala, F. TH. R., & Ramadhan, M. (2017). Analisis potensi dan Bahaya Bencana Longsor Menggunakan Modifikasi Metode Indeks Storie di Kabupaten Kebumen Jawa Tengah [Analysis of landslide potential and hazards using modified Storie Index method in Kebumen Regency, Central Java]. In *8th Industrial Workshop and National Seminar Politeknik Negeri Bandung* (pp. 59–64). IRONS. <https://jurnal.polban.ac.id/proceeding/article/view/699/552>
- Reis, S., Yalcin, A., Atasoy, M., Nisanci, R., Bayrak, T., Erduran, M., Sancar, C., & Ekercin, S. (2012). Remote sensing and GIS-based landslide susceptibility mapping using frequency ratio and analytical hierarchy methods in Rize province (NE Turkey). *Environmental Earth Sciences*, 66(7), 2063–2073. <https://doi.org/10.1007/s12665-011-1432-y>
- Saha, A. K., Gupta, R. P., Sarkar, I., Arora, M. K., & Csaplovics, E. (2005). An approach for GIS based statistical landslide susceptibility zonation-with a case study in the Himalayas. *Landslides*, 2(1), 61–69. <https://doi.org/10.1007/s10346-004-0039-8>
- Sonker, I., Tripathi, J. N., & Swarnim. (2022). Remote sensing and GIS-based landslide susceptibility mapping using frequency ratio method in Sikkim Himalaya. *Quaternary Science Advances*, 8, Article 100067. <https://doi.org/10.1016/j.qsa.2022.100067>
- Sudjatmiko. (2003). *Peta Geologi Lembar Cianjur, Jawa Barat* [Geological Map of Cianjur Plate, West Java].
- Sulistyo, B. (2016). Peranan Sistem Informasi Geografis Dalam Mitigasi Bencana Tanah Longsor [The role of geographic information systems in landslide disaster mitigation]. In *National Seminar "Disaster mitigation in regional development planning"*. Hazairin University, Bengkulu. <https://doi.org/10.13140/RG.2.2.16705.97128>
- Swets, J. A. (1988). Measuring the accuracy of diagnostic systems. *Science*, 240(4857), 1285–1293. <https://doi.org/10.1126/science.3287615>
- Syahrial, M. (2022). 58.362 Orang Korban Gempa Cianjur Masih Mengungsi, Ini Daftar Kebutuhan yang Bisa Disalurkan ke Pendopo Kabupaten Cianjur [58.362 Cianjur earthquake victims are still displaced, here's a list of needs that can be distributed to the Cianjur Regency Hall]. Kompas. <https://bandung.kompas.com/read/2022/11/22/184814078/58362-orang-korban-gempa-cianjur-masih-mengungsi-ini-daftar-kebutuhan-yang>
- Syarif, M., Sampebulu, V., Tjaronge, M. W., & Nasruddin. (2018). Analysis of the physical properties of alternative cement made from recycled waste material. *International Journal of Civil Engineering and Technology (IJCET)*, 9(9), 1441–1450.
- Torkashvand, A. M., Irani, A., & Sorur, J. (2014). The preparation of landslide map by Landslide Numerical Risk Factor (LNRF) model and Geographic Information System (GIS). *Egyptian Journal of Remote Sensing and Space Science*, 17(2), 159–170. <https://doi.org/10.1016/j.ejrs.2014.08.001>
- Trifonova, O. P., Lokhov, P. G., & Archakov, A. I. (2013). Metabolic profiling of human blood. *Biochemistry (Moscow) Supplement Series B: Biomedical Chemistry*, 7, 179–186. <https://doi.org/10.1134/S1990750813030128>
- Tufaila, M., & Alam, S. (2014). Karakteristik Tanah dan Evaluasi Lahan Untuk Pengembangan Tanaman Padi Sawah Di Kecamatan Oheo Kabupaten Konawe Utara [Soil characteristics and land evaluation for paddy field development in Oheo District, North Konawe Regency]. *Agriplus*, 24(2), 184–194.
- Vijith, H., Rejith, P. G., & Madhu, G. (2009). Using InfoVal method and GIS techniques for the spatial modelling of landslide susceptibility in the upper catchment of river Meenachil in Kerala. *Journal of the Indian Society of Remote Sensing*, 37, 241–250. <https://doi.org/10.1007/s12524-009-0028-4>
- Volcanology and Geological Hazard Mitigation Center. (2003). *Pengenalan Gerakan Tanah* [Introduction to ground movement]. https://www.esdm.go.id/assets/media/content/Pengenalan_Gerakan_Tanah.pdf
- Wahyuni, S., & Sukiyah, E. (2023). Karakteristik Geomorfologi Dalam Penentuan Lokasi Rawan Bencana Longsor Di Kecamatan Cisewu, Kabupaten Garut, Provinsi Jawa Barat [Geomorphological characteristics in determining landslide-prone locations in Cisewu district, Garut Regency, West Java Province]. *Jurnal GEOMINERBA*, 8(1), 16–24. <https://doi.org/10.58522/ppsdms22.v8i1.114>
- Wilson, J. P., & Gallant, J. C. (2000). Digital terrain analysis. In *Terrain analysis: Principles and applications* (pp. 1–27). Wiley.
- Yesilnacar, E., & Topal, T. (2005). Landslide susceptibility mapping: A comparison of logistic regression and neural networks methods in a moderate scale study, Hendek region (Turkey). *Engineering Geology*, 79(3–4), 251–266.