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Landslide Mitigation in Cianjur Regency Through Satellite Imagery-Based Mapping

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ABSTRACT

Indonesia is a country with a high frequency of natural disasters due to its location in the tropics and along the pacific ring of fire. Its diverse topography, characterized by numerous mountains and coastal areas, significantly influences land slopes. One common disaster associated with slope differences is landslides-mass movements of soil triggered by various factors, one of which is the steepness of the slope. Cianjur Regency is among the regions with a high risk of landslides. According to data from the West Java Regional Disaster Management Agency (BNPB), Cianjur experiences more than 90 landslides annually. Therefore, mitigation efforts must be carried out based on landslide risk mapping in this region. The purpose of this research is to identify and map landslide-prone areas in Cianjur Regency. Mapping results from 2018 to 2023 indicate that areas with the highest landslide risk are concentrated in northern Cianjur, particularly in the districts of Cugenang, Cipanas, Sukaresmi, and surrounding areas. Mitigation efforts should be prioritized in these districts without neglecting other areas. In addition to the 2018–2023 mapping, a 2025 prediction map can also be developed to guide broader and more comprehensive mitigation efforts, which still indicate a very high risk in northern Cianjur. Furthermore, mapping using the SMORPH method has produced results that closely align with both the annual and predictive mapping approaches, reinforcing the validity of the identified high-risk zones.

Keywords: Landslide, Cianjur, Mapping, Mitigation, SMORPH

ABSTRAK

Indonesia merupakan negara dengan status kebencanaan yang cukup besar, megingat Indonesia berada pada wilayah tropis serta berada pada *ring of fire*. Banyaknya pegunungan dan pantai juga menyebabkan bentuk topografi Indonesia berbeda-beda sehingga mempengaruhi kemiringan wilayah. Salah satu bencana yang sering terjadi adalah longsor. Kabupaten Cianjur merupakan salah satunya daerah dengan resiko longsor yang tinggi. Tujuan dari penelitian ini adalah untuk memetakan daerah yang memiliki resiko longgsor di daerah Cianjur. Dari hasil pemetaan pada tahun 2018-2023, sebagian besar wilayah yang beresiko longsor tinggi berada pada wilayah Cianjur Utara yang mencakup kecamatan Cugenang, Cipanas, Sukaresmi dan lainya. Upaya mitigasi perlu difokuskan pada wilayah-wilayah tersebut. Prediksi pemetaan tahun 2025 juga dapat dilakukan untuk terlaksananya mitigasi dengan cangkupan yang lebih jauh dan luas. Dengan menghasilkan wilayah cangkupan resiko longsor sangat tinggi berada pada wilayah Cianjur Utara. Selain itu, pemetaan dalam upaya mitigasi telah dilakukan juga dengan metode SMORPH yang menghasilkan wilayah cangkupan longsor hampir serupa dengan metode prediksi dan pemetaan tahunan.

Kata kunci: Longsor, Cianjur, Pemetaan, Mitigasi, SMORPH

INTRODUCTION

Geographically and geologically, Indonesia is located between two oceans, the Indian Ocean and the Pacific Ocean and between two continents, Asia and Australia. In addition, Indonesia lies on two major tectonic plates: the Eurasian and Indo-Australian continental plates. Furthermore, as an archipelagic country, Indonesia is situated at the convergence of three tectonic plates: the Australian, Eurasian, and Pacific plates. These conditions make Indonesia one of the countries most vulnerable to natural disasters (Airlangga, 2024).

Indonesia is a country that frequently experiences disasters caused by climate and weather changes, commonly referred to as hydrometeorological disasters. Natural conditions that enable the occurrence of such events are known as potential disasters (Diara et al., 2022). The risk posed by a disaster refers to the potential for losses in a particular area over a specific period. Disaster risks may include disruptions to community activities, loss of a sense of security, displacement of people, damage or loss of property, threats to life, injury, illness, and even death (Onrizal et al., 2020; Amelia et al., 2024).

Landslides are among the most common natural disasters in tropical countries like Indonesia, where high rainfall, steep terrain, and sloping morphology contribute to their frequent occurrence. This type of disaster often affects many regions across the country. Landslides can cause various forms of loss physical, economic, and psychological, for communities directly impacted. Given the ongoing climate instability in Indonesia, especially in recent months, this issue must not be overlooked (Fahriani, 2015).

Landslide disasters can be caused by various factors, which are generally categorized into two types: intrinsic factors and triggering factors (Suprayogo et al., 2020). Landslides are a type of natural disaster involving the rapid and large-scale movement of land masses (Diara et al., 2022). This movement can cause significant damage to affected areas. According to the Directorate of Volcanology and Geological Disaster Mitigation (2005), landslides are also referred to as ground movements. These involve the movement of soil or materials such as clay, sand, gravel, boulders, and mud, which shift down a slope due to the force of gravity (Setiawan et al., 2021; Muslihudin et al., 2022). In West Java alone, 632 landslide incidents have been recorded over the past 10 years, primarily due to the region's topography, which is dominated by steep hills (Iryanti, 2024).

Many areas in Indonesia have a high level of vulnerability to landslides, one of which is Cianjur Regency. This is supported by data from the Cianjur Regency Regional Disaster Management Agency in 2020, which reported that out of 170 recorded disasters, approximately 66% or 112 incidents were landslides. The regency ranks 11th nationally in terms of high disaster risk. Landslides continue to occur frequently, as reflected in a recent incident in Simpang Village, Pasirkuda District, Cianjur Regency, on July 29, 2023, which resulted in one fatality (Fahlevi, 2023). Therefore, mitigation efforts in this area are urgently needed (Nurjanah & Mursalin, 2022). By conducting detailed mapping beforehand, authorities can identify areas with the highest landslide potential, allowing mitigation efforts to be more focused and effective.

METHODOLOGY

The implement disaster mitigation, particularly in Cianjur Regency, mapping must first be carried out using satellite imagery based on the required data. The resulting maps will include data from six different years. In addition, long-term mitigation efforts are possible, making the prediction of a 2025 landslide map feasible. This allows the mitigation process to have broader and longer-term coverage. Furthermore, this research also employs the SMORPH method, which utilizes slope gradient and slope shape data.

The research area, Cianjur Regency, is located at 106°42' East Longitude and between 6°21' to 6°25' South Latitude, with a total area of 361,434.98 hectares and an elevation ranging from 7 to 2,962 meters above sea level. This research covers the entire Cianjur Regency. Several tools and materials are required in this research, including computer equipment, ArcMap software, SPSS software, Microsoft Excel, and Microsoft Word. ArcMap is used to integrate multiple data sources in order to generate the desired map. Microsoft Excel is used to process rainfall data prior to importing it into ArcMap. SPSS software is utilized to process prediction data using the Ekspert Moderena model. All resulting data are then compiled and presented using Microsoft Excel and Microsoft Word.

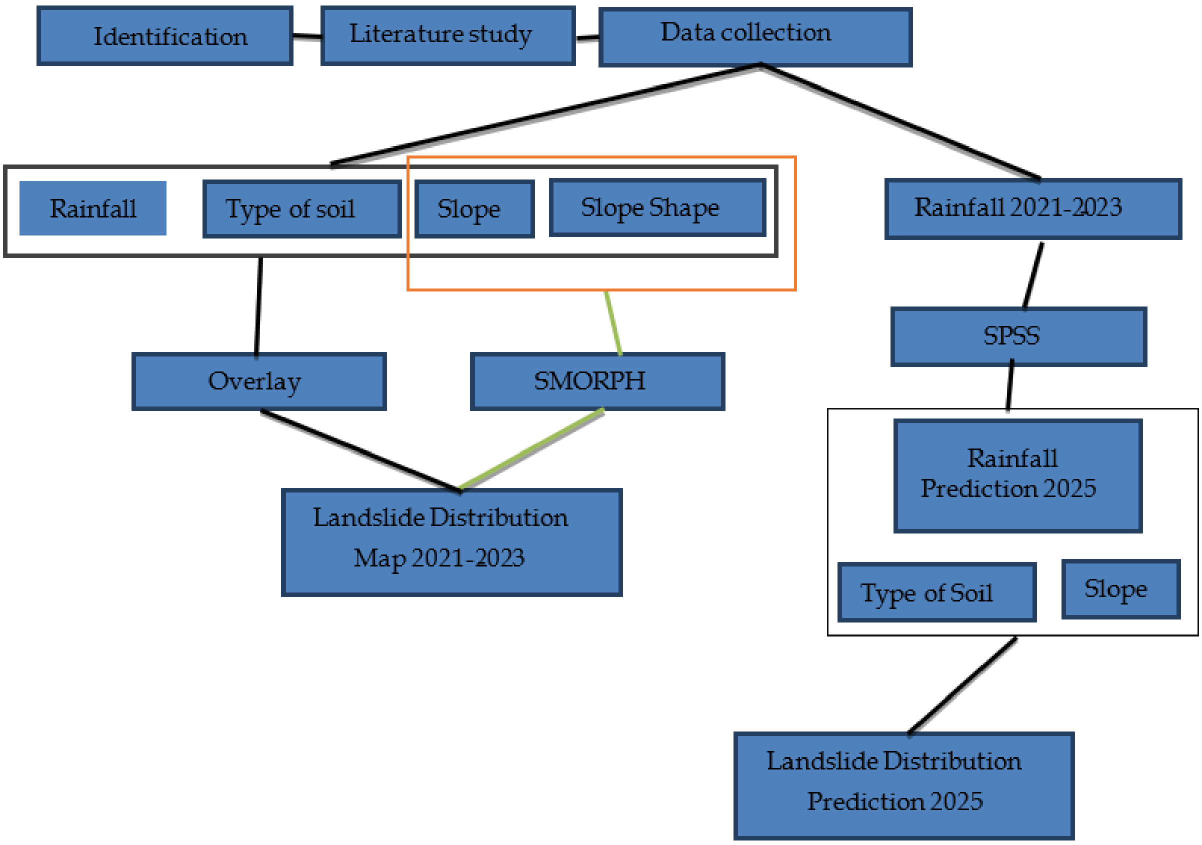


Figure 1. Research flow

The first step in this research is mapping the research area. This process requires several types of data, including soil type, slope gradient, and rainfall. These three datasets serve as the basis for mapping landslide-prone areas. The method used in this research is the overlay technique, which combines the three datasets using the Intersect tool in ArcMap. This mapping will produce six different maps for different years, distinguished primarily by variations in rainfall data.

The first dataset needed is the slope gradient, which is obtained from satellite imagery managed by the Ministry of Energy and Mineral Resources of the Republic of Indonesia. Before the overlay process can be conducted, the slope data must go through a classification stage to ensure accurate mapping results. The slope classification used in this research is presented in Table 1.

Table 1. Slope classification

No	Slope (%)	Criteria	Score	Weight
1	0 – 8	Very low	1	4
2.	8 – 15	Low	2	
3	15 – 25	Currently	3	
4	25 – 45	high	4	
5	> 45	Very high	5	

(Rakuasa, 2024)

Next is the rainfall data, which serves as comparative data across different years. Since rainfall in a given area can vary from year to year, this research uses rainfall data from three different years. Similar to the slope data, rainfall data must also be classified before being used in the overlay process. The rainfall classification used in this research is shown in Table 2.

Tabel 2. Rainfall classification

No	Rainfall	Criteria	Score	Weight
1	1511	Low	1	3
2	1603	Currently	2	
3	1794	High	4	
4	1827	Very high	5	

(Gaurav & Singh, 2022)

The last dataset is soil type, which is equally important for landslide mapping, as the characteristics of certain soil types can influence the occurrence of landslides. Soil type data in this research was obtained from the WorldSoilType.com website and is provided in .SHP format. Like other datasets, soil type also requires classification. Various literature sources offer different classification systems as shown in Table 3.

Tabel 3. Soil type classification

No	Type of soil	Criteria	Score	Weight
1	Non Calcic Brown	Sensitive	1	2
2	Andosol	A bit sensitive	2	
3	Lithosol	Very sensitive	3	

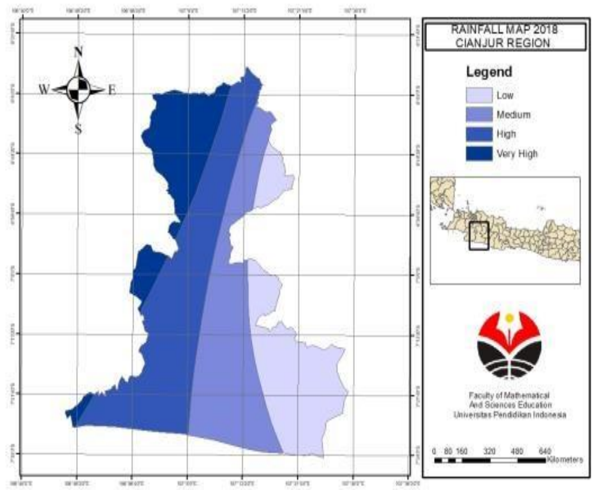
(Yassar et al., 2020)

This research will produce four landslide hazard maps. Three of these maps are generated using the overlay method, which combines three datasets: soil type, rainfall, and slope gradient. The key difference among these three maps lies in the use of rainfall data from different years, specifically from 2018 to 2023. The fourth map is a prediction map, which is based on projected rainfall data for the year 2025.

For the prediction process, SPSS software is used, employing the Expert Moderna Model. The steps involve inputting monthly rainfall data from 2018 to 2023 sequentially into SPSS to generate the predicted rainfall for 2025. The output from SPSS is rainfall data in Excel format, which is then converted into a .shp map file. This predicted rainfall map is combined with the soil type and slope gradient data using the overlay method to produce the 2025 landslide-prone area distribution map.

RESULTS AND DISCUSSION

Based on the data obtained, this research uses rainfall data from the months of January, February, March, October, November, and December each year, as these months typically experience high rainfall intensity. The distribution of rainfall during these six months for the period 2021–2023 can be shown in Figure 2.



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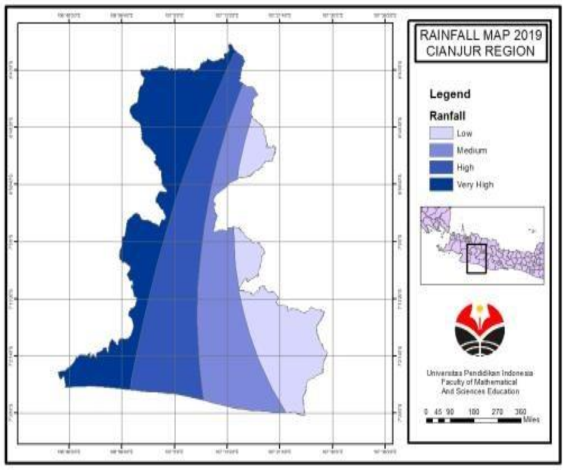

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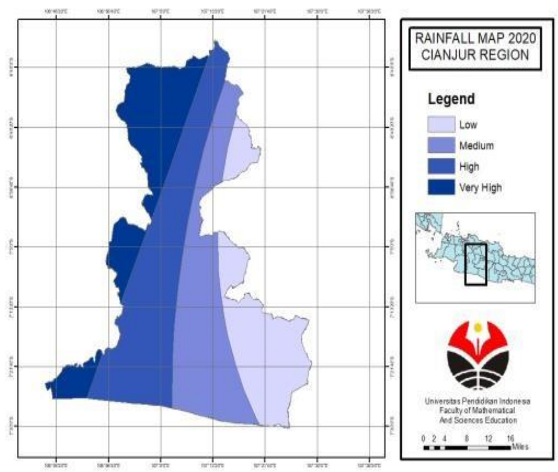

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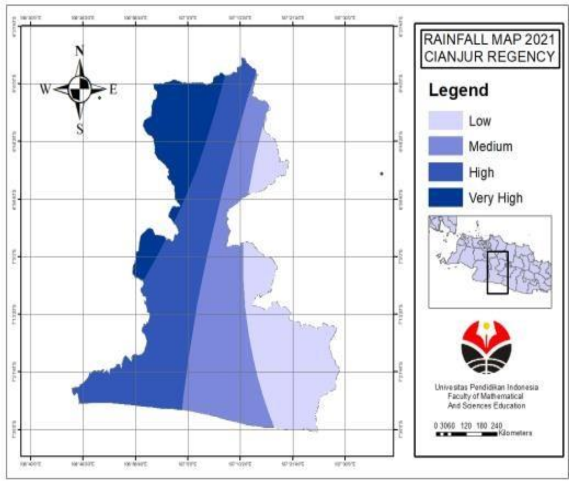

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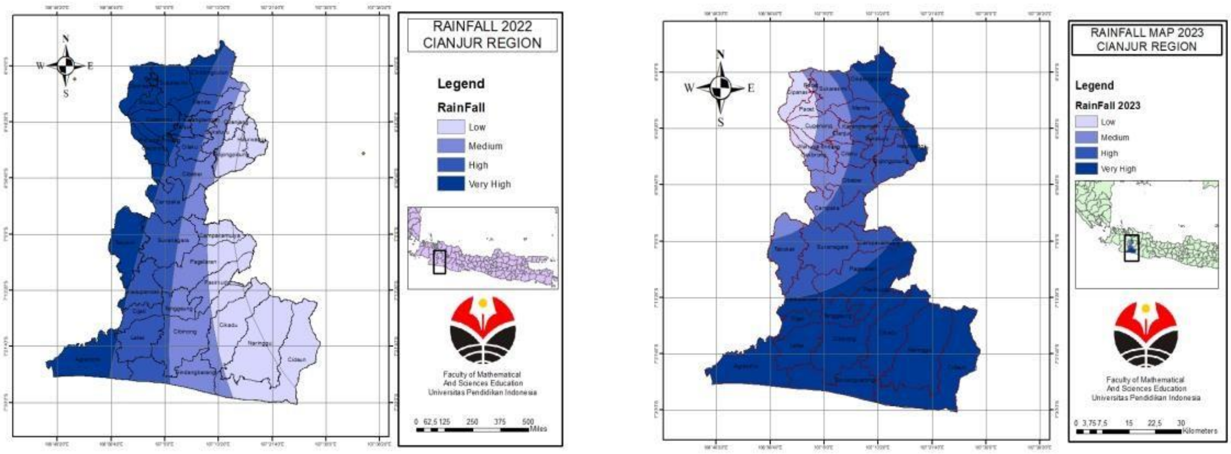


(e) (f)

Figure 2. Rainfall map rainfall in 2021-2023 in the 6 months

The Cianjur region is located in the southern part of West Java Province, directly below the Bogor area. According to existing theories, Bogor experiences high rainfall frequency, which naturally affects surrounding regions, including Cianjur. Rainfall data for Cianjur is processed from three nearby stations: the Citeko BMKG Station, the West Java BMKG Station, and the Bandung City BMKG Station. Data from these stations are used to generate rainfall information for the Cianjur area. The rainfall map shows four rainfall classes in Cianjur, ranging from low to very high. Based on the map, there are two areas in Cianjur that consistently experience very high rainfall intensity. From 2018 to 2022, the northern part of Cianjur including the districts of Cipanas, Pacet, Cugenang, Warungkondang, and Gekbrong recorded very high rainfall for five consecutive years. However, in 2023, the pattern shifted, with high rainfall intensity occurring in the southern part of Cianjur, particularly in the districts of Naringgul, Bojong Wangi, Cipicung, and Bojong.

In addition, slope data were obtained from the website of the Ministry of Energy and Mineral Resources. The topographic description illustrates the elevation and contour conditions of Cianjur Regency. The lowland areas have slopes ranging from 0% to 8%, covering coastal zones, river alluvial plains, and lava plains. Beyond these, there are gently undulating hills characterized by a slope of 8% to 15%. Furthermore, the region includes moderately undulating hills with slopes between 15% and 25%. Cianjur Regency also features slightly rugged hills, where the surface is moderately rough with slopes ranging from 25% to 40%. In addition, there are rugged to very rugged hills, with surface contours that are rough or highly uneven, and slopes exceeding 40%.

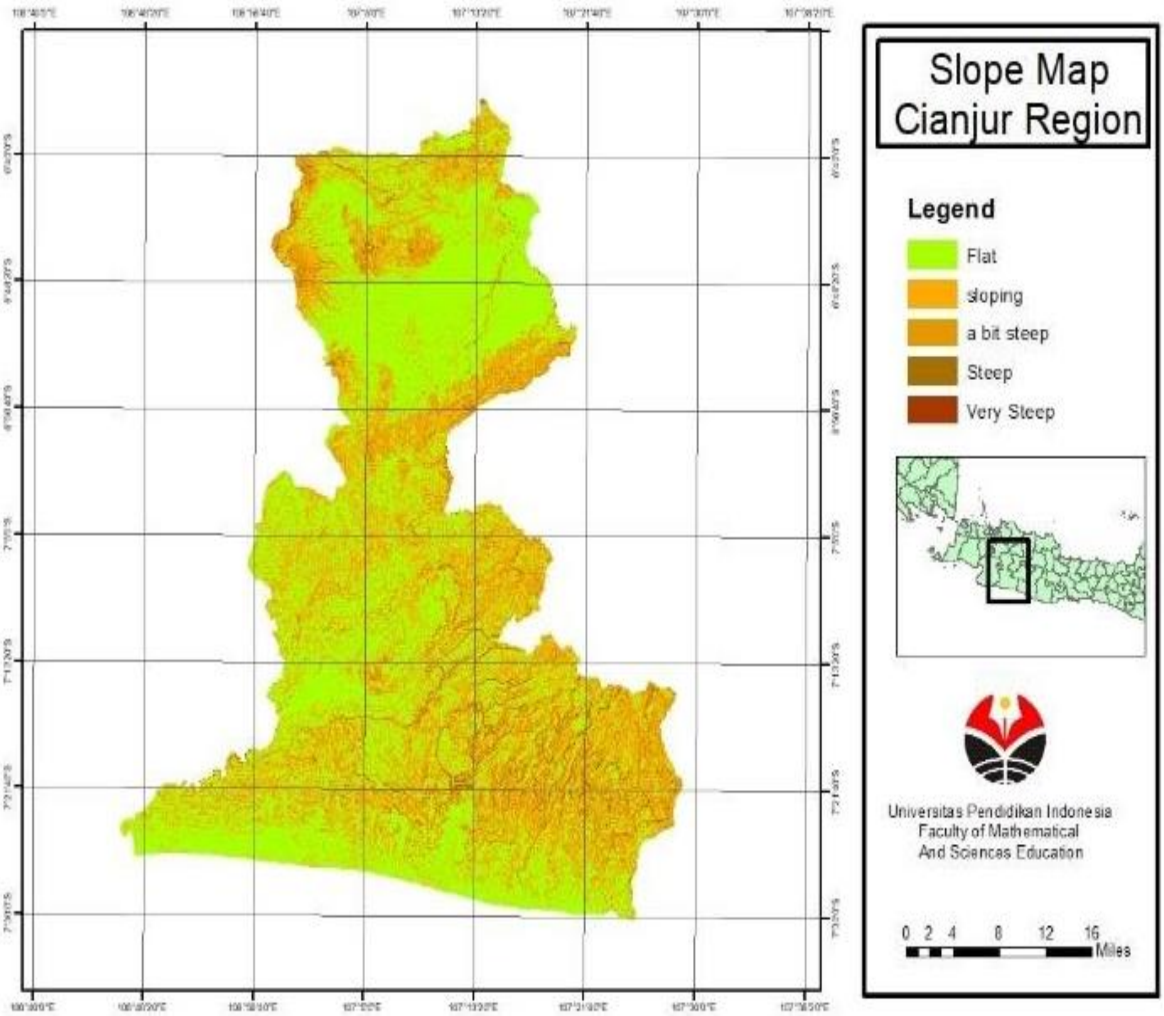
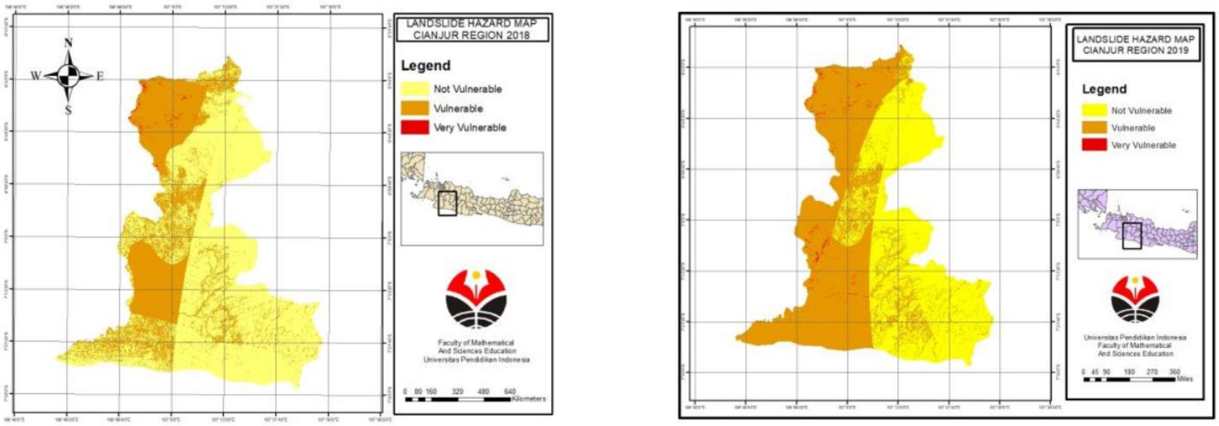


Figure 3. Slope map

Overlay

The three datasets are processed and overlaid using a scoring system applied to each element, enabling the generation of distinct landslide distribution maps for each year. The mapping results can be shown in Figure 4.



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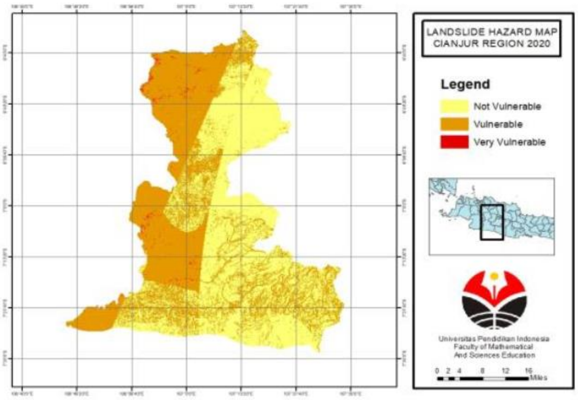

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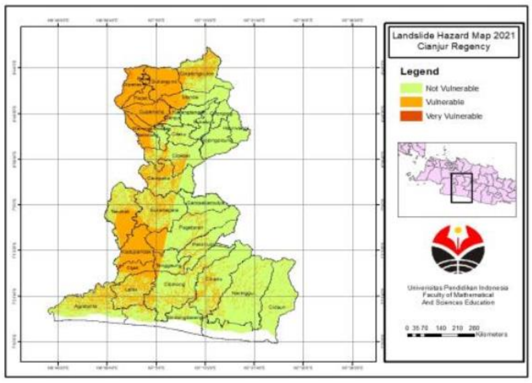

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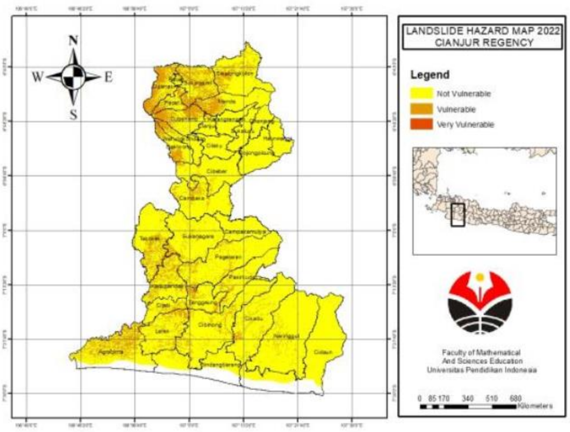

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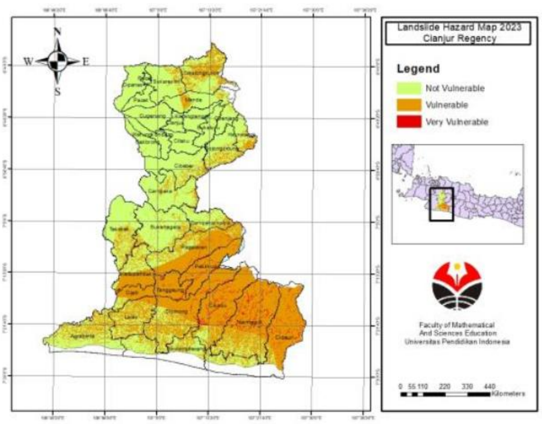

(f)

Figure 4. Landslide map

Among the three landslide-prone maps with different time spans, the results show varying distributions of landslide-prone areas. These differences are primarily due to the variation in rainfall frequency each year. When presented in tabular form, the data can be summarized on Table 4. Based on the mapping and specifications described above, the Cianjur area has experienced both increases and decreases in landslide-prone areas over the past six years. These fluctuations are likely influenced by variations in annual rainfall, which appears to be the primary factor affecting the distribution of landslide-prone zones (Pratiwi et al., 2016; Nurfalaq & Jumardi, 2019). The table presents area specifications ranging from not prone to very prone to landslides. In 2019, the landslide-prone area reached its highest level, covering 15.2% of the total area, equivalent to 54,938.12 hectares. In contrast, 2022 recorded the lowest percentage of areas classified as very prone to landslides among the six years analyzed.

An analysis of the maps shows that from 2018 to 2022, several sub-districts consistently appeared in the prone to very prone categories each year. These include Cipanas, Pacet, Sukaresmi, Warungkondang, Cugenang, and Gekbrong. Meanwhile, in 2023, the largest concentration of areas categorized as prone to very prone shifted to South Cianjur, particularly in the districts of Cikadu, Cidaun, Naringgul, Pasirkuda, Cibinong, and Tanggeung.

Table 4. Landslide hazard map specifications

Year	Class	Presentation (%)	Area (Ha)
2018	Not Vulnerable	39,8	143.851,12
	Vulnereble	52,4	189.391,93
	Very Vulnereble	7,8	28.191,93
2019	Not Vulnerable	31,9	114.936,32
	Vulnereble	52,9	191.199,1
	Very Vulnereble	15,2	54.938,12
2020	Not Vulnerable	29,3	105.900,45
	Vulnereble	57,1	206.379,37
	Very Vulnereble	13,6	49.155,16
2021	Not Vulnerable	43,9	178.187,44
	Vulnereble	47,5	171.681,62
	Very Vulnereble	8,6	31.083,41
2022	Not Vulnerable	49,7	179.633,18
	Vulnereble	43,9	158.669,96
	Very Vulnereble	6,4	23.131,84
2023	Not Vulnerable	34,3	123.972,20
	Vulnereble	54,4	196.920,63
	Very Vulnereble	9,3	33.613,45

Predictions

Landslide mitigation is more effective when carried out on a broad scale and over the long term. Therefore, predictive landslide mapping for the coming year is essential to estimate which areas are likely to be affected, allowing for timely and appropriate mitigation efforts. The data used in this prediction are the same as those used in the previous mappings, with the main difference being the rainfall data, which is updated and inputted into SPSS for future projections. Rainfall data from 2018 to 2023 serves as the reference for generating the 2025 rainfall prediction. This predicted rainfall data is then overlaid with two other datasets to produce the following landslide prediction that can be shown in Figure 5.

Table 5 presents the landslide predictions for 2025, showing that highly vulnerable areas cover 20,240.36 hectares or 5.6% of the total area, while areas not at risk of landslides account for 44.8% or 165,537.22 hectares of the entire Cianjur region. A visual analysis of the 2025 landslide prediction map indicates that most of the highly vulnerable areas are concentrated in West Cianjur, while the rest of the region is predominantly categorized as not vulnerable. This pattern may also be influenced by previous rainfall predictions. The sub-districts most prone to landslides are Cugenang, Pacet, Cipanas, and Warungkondang.

Tabel 5. Mapped details of landslide risk areas in 2025

Landslide prone class	Area (Ha)	Percentage (%)
Not vulnerable	165.537,22	44,80
Vulnerable	175.657,40	49,60
Very vulnerable	20.240,36	5,60
Total	**361.434,98**	**100%**

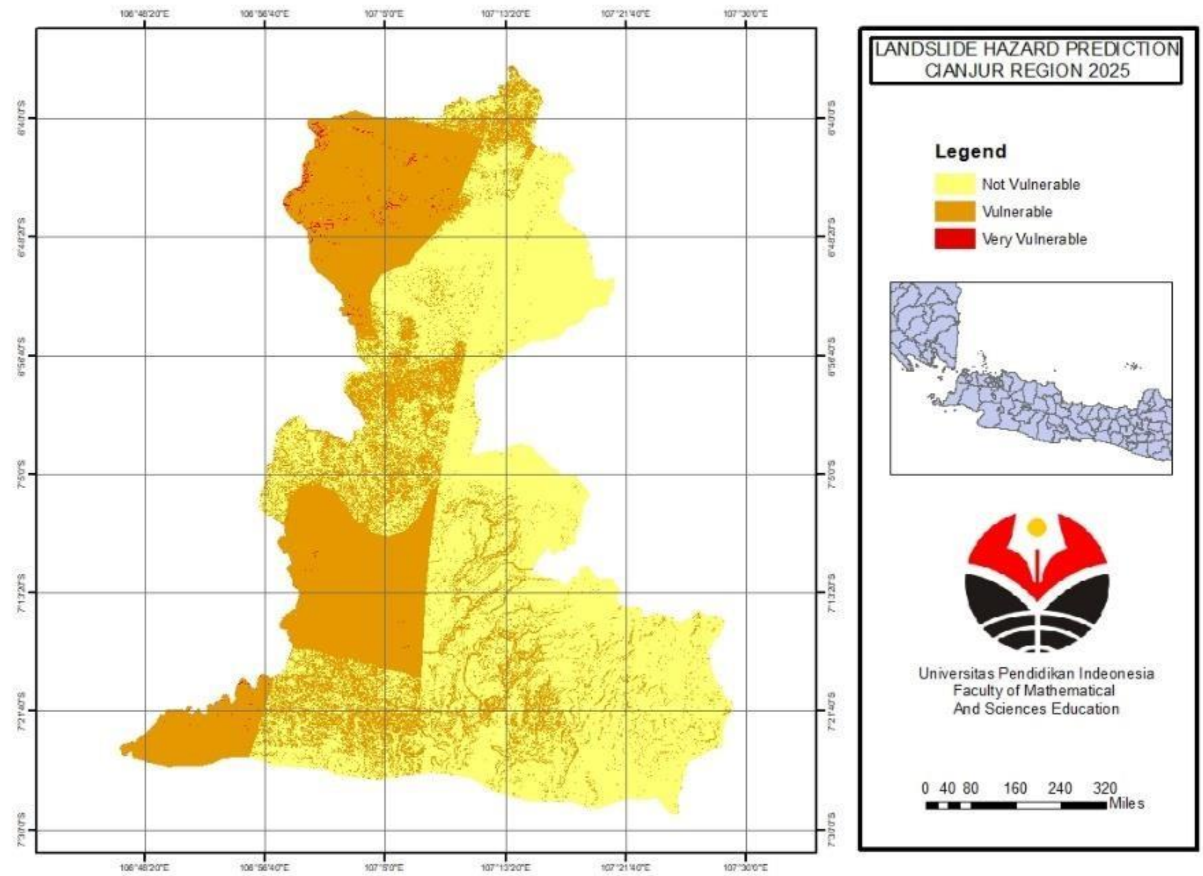

Figure 5. Landslide hazard prediction

SMORPH

In implementing mitigation efforts, mapping using the Overlay method is not sufficient on its own. The SMORPH method is also necessary to provide a more accurate depiction of areas with a high risk of landslides (Ristya, 2019). This method relies on two primary data components: slope gradient and slope benthic. These two maps are combined to generate a new landslide distribution map based on the SMORPH classification.

Visually, the areas in Cianjur that are classified as vulnerable to very vulnerable according to the SMORPH method are located in both the northern and southern regions. In the north, this includes the districts of Cugenang, Sukaresmi, Cipanas, Warungkondang, Pacet, Mande, and Gekbrong. Meanwhile, in the south, it includes the districts of Cidaun, Naringgul, Cibinong, Pasirkuda, and Tanggeung. When viewed in terms of spatial distribution, the SMORPH method indirectly integrates the mapping data from the previous six years. In addition, this method also highlights parts of Central Cianjur that are at risk of landslides.

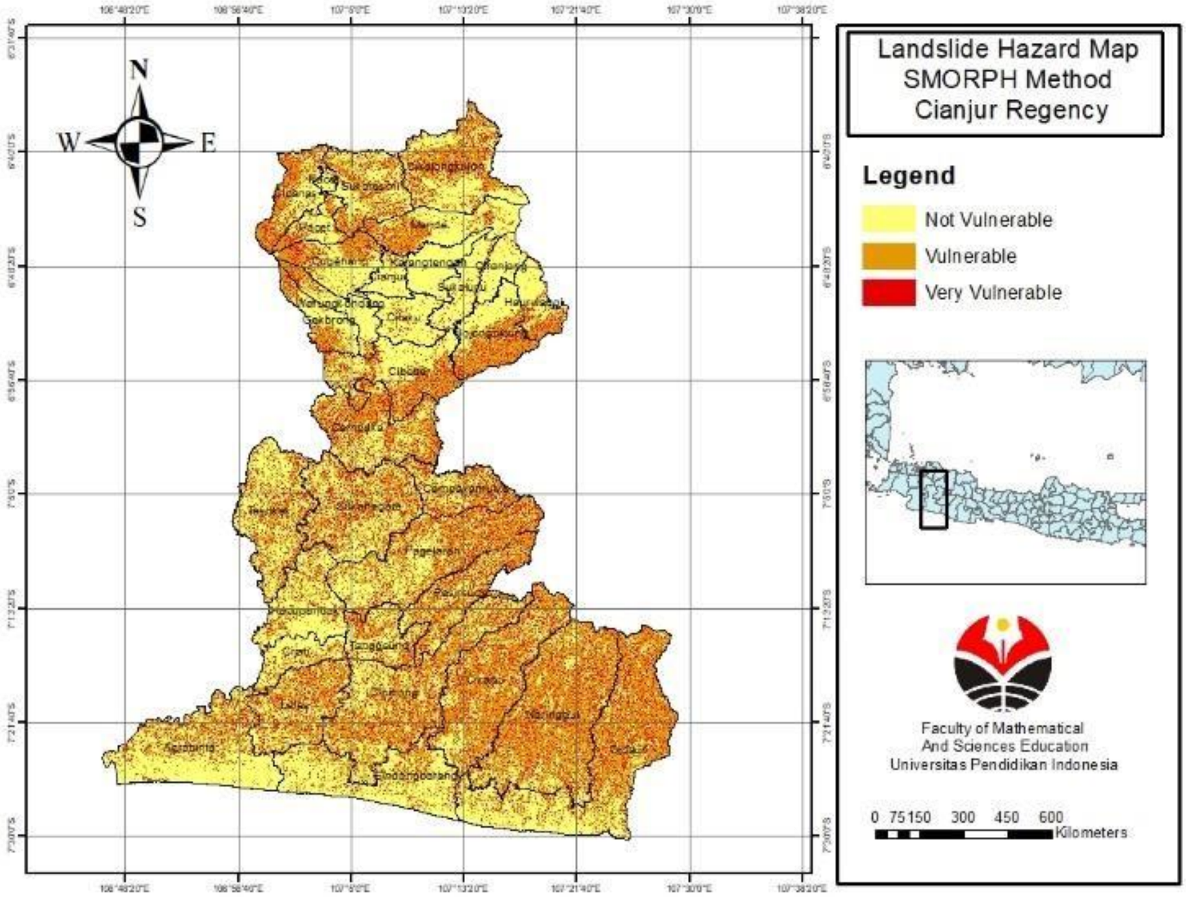

Figure 6. Landslide hazard map

CONCLUSION

Based on the results and findings, it can be concluded that in the last 6 years, the North Cianjur Region has a very vulnerable landslide risk area covering the districts of Cugenang, Pacet, Cipanas and Warungkondang. The data was reconfirmed using the Overlay method where in this method North Cianjur also has a very vulnerable landslide area with coverage in the 4 districts. Data from the predictions also show the same thing where the districts of Cugenang, Pacet, Cipanas and Waringkondang have very high landslide areas. Therefore, landslide disaster mitigation efforts can be carried out in districts with high-risk areas such as in the 4 districts.

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