http://journal.uir.ac.id/index.php/JGEET

E-ISSN : 2541-5794
P-ISSN : 2503-216X

Journal of Geoscience,
Engineering, Environment, and Technology
Vol 9 No 4 2024

RESEARCH ARTICLE

The Influence of Slope, Rock Characteristics and Meteorological Data to Landslide: A Case Study in The Northernmost Sumatra, Indonesia

Mochammad V. Idris[1], Umar Muksin[2,3*], Muhammad Syukri[3]

[1]*Meteorology Climatology and Geophysics Agency, Banda Aceh, Indonesia.*
[2]*Tsunami and Disaster Mitigation Research Center, Syiah Kuala University, Banda Aceh, Indonesia.*
[3]*Physics Department, Faculty of Science, Syiah Kuala University, Banda Aceh, Indonesia.*

* Corresponding author : muksin.umar@usk.ac.id
Tel.:+62 812 63289103
Received: Oct 21, 2024; Accepted: Dec 13, 2024.
DOI: 10.25299/jgeet.2024.9.04.19420

Abstract

Landslides are natural disasters that can be caused by high rainfall intensity. Aceh Besar Regency has been hit by landslides 40 times from 2014 to 2023. Aceh Besar Regency serves as an economic connecting route from other cities to the provincial capital of Aceh, Banda Aceh. Therefore, when landslides occur in that area, it will disrupt the economic stability and logistic distribution to other regions. The weighted overlay method maps landslide-prone areas in Aceh Besar Regency. This research aims to create a map of landslide-prone areas in Aceh Besar Regency based on parameters causing landslides, namely slope inclination, rainfall, rock type, soil type, and land cover. The research findings indicate that almost the entire region of Aceh Besar has a moderate to high potential for landslide disasters. The main factor causing landslides in Aceh Besar is its topography, which is dominated by mountains and hills, and the moderate to very high rainfall intensity. The landslide-prone disaster map is validated by landslide incidents recorded by BPBD Aceh Besar from 2014 to 2023, showing results that align with the historical data. This map can be used by relevant authorities and the general public to undertake landslide disaster mitigation in Aceh Besar Regency.

Keywords: Landslide, Disaster, Weighted Overlay, Landslide Parameters, Landslide Susceptibility Map, Aceh Besar.

1. Introduction

Landslides can cause property damage, endanger lives, and damage the surrounding environment (Agustina et al., 2020). Although landslides are a local disaster, many areas in Indonesia are affected, so it is very important to mitigate the disaster (Naryanto et al., 2019, Adi et al., 2024, Andinisari et al., 2024, Ansari et al., 2024). Aceh Besar Regency is one of the areas north of Sumatra Island that experienced 40 landslides from 2014 to 2023 (Firdaus, 2023, Ansari et al., 2024, Asnawi et al., 2020, Asnawi et al., 2022). Naryanto and Akhirianto (2016) stated that landslides are caused by the disruption of soil or rock stability forming the slope.

The disruption of stability on the slope can be influenced by various factors, such as the shape of the slope (especially the slope), the nature of rock or soil forming the slope, and hydrological conditions around the slope (Faizana et al., 2015). Rainfall is also the biggest factor besides slope to trigger landslides, the volume of water that seeps into the ground due to high rainfall can trigger landslides (Campbell, 1975; Larsen et al., 1999, Pasari et al., 2021). In addition to rainfall and slope, rock type is also one of the factors causing landslides, volcanic rock type is the biggest factor causing landslides due to poor permeability. Many cracks in the lithology under the volcanic soil cause water to enter and overload the slope until landslides occur (Simanjuntak & Ansari, 2022, Sembiring et al., 2023).

Naturally, a slope is balanced against the forces acting on it. The slope will also seek a natural balance point to adjust to the forces or disturbances it receives (Khodijah et al., 2022). In some conditions where steep slopes are found, there are often no landslides. This is because the level of slope stability and vegetation in the location is very good (Aini et al., 2018).

This study used landslide parameter weighting to map areas potentially prone to landslides (Arifin et al., 2015). The parameters included in this weighting are slope gradient, rainfall, rock type, soil type, and land cover (Sulistiarto, 2008). After weighting the landslide parameters, the data was processed using a geographic information system (GIS) (Rahmad et al., 2018). Mapping of landslide-prone areas can be classified into 4 categories: low vulnerability, moderate vulnerability, high vulnerability, and very high vulnerability (Susetyo et al., 2023, Nurana et al., 2021 Kuncoro et al., 2024).

Considering the significant impact caused by landslides, efforts are needed to mitigate them. This research, through the analysis and mapping of landslide-prone areas, hopes to significantly contribute to mitigating landslide disasters.

2. Data and Methods

This research was conducted in Aceh Besar Regency, Aceh, Indonesia. The study's location map is in Figure 1. The data for this research utilizes slope inclination data obtained from DEM SRTM 30m (Digital Elevation Model Shuttle Radar Topographic Mission 30m), average annual rainfall data for the period from 2014 to 2023 from the Class IV Climatology Station of Aceh Province, soil and rock type data sourced from the geological map of Banda Aceh sheet in 1981, and land cover map data sourced from Indonesia Geospatial in 2019. The weighted overlay method creates a landslide hazard map. This method assigns scores and weights to several parameters influencing landslides (Khusnawati and Kusuma, 2020).

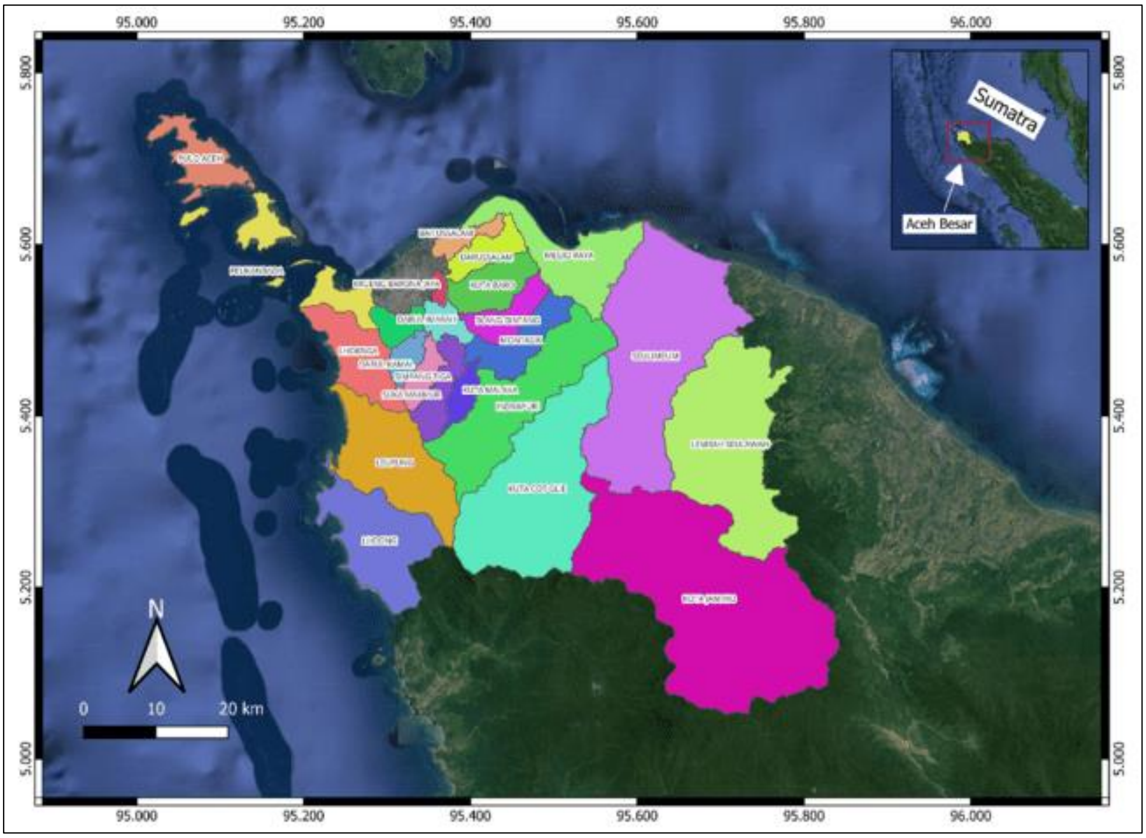

Fig. 1. Administrative map of 23 sub-districts in Aceh Besar Regency.

Table 1. Weight and score for slope inclination.

No	Slope Inclination (%)	Information	Weight	Score
1	0 – 8	Flat		1
2	8 – 15	Sloping		2
3	15 – 25	A bit steep	20%	3
4	25 – 45	Steep		4
5	>45	Very steep		5

Table 2. Weight and score for rainfall.

No	Rainfall (mm/year)	Information	Weight	Score
1	0 – 1500	Very low		1
2	1500 – 2000	low	30%	2
3	2000 – 2500	Moderate		3
4	2500 – 3000	High		4
			30%	
5	>3000	Very High		5

Table 3. Weight and score for rock type.

No	Rock Type	Weight	Score
1	Alluvial		1
2	Sediment	20%	2
3	Volcanic		3

Tabel 4. Weight and score for type of soil.

No	Type of Soil	Weight	Score
1	Regosol		5
2	Andosol, Podzolic		4
3	Brown latosol		3
4	Yellowish brown latosol association	10%	2
5	Alluvial		1

Table 5. Weight and score for land cover

No.	Land Cover	Weight	Score
1	Moor, Rice fields		5
2	Shrubs	20%	4
3	Forest and Plantation		3
4	City or Sttelement	20%	2
5	Ponds, Reservoirs, Waters		1

The modelling of landslide hazard maps using a combination of values from several parameter scores from Table 1 to Table 5 can be formulated as follows:

$$\text{Total score}=(SW \times SS)+(RW \times RS)+(RTW \times RTS)+(TSW \times TSS)+(LCW \times LCS) \quad (1)$$

where SW is slope weight, SS is slope score, RW is rainfall weight, RS is rainfall score, RTW is rock type weight, RTS is rock type score, TSW is type soil weight, TSS is type soil score, LCW is land cover weight, dan LCS is land cover score. Creating landslide hazard maps using the QGIS application involves combining the five parameters contributing to landslides (Puslittanak, 2004, Simanjuntak et al., 2018, Simanjuntak & Ansari, 2023). The process of analyzing slope inclination, rainfall, rock type, soil type, and land cover is conducted by inputting the available data into the QGIS application and weighting and scoring each parameter. After the weighting and scoring process, all the data is merged into one, forming the modelling of the landslide hazard map.

3. Results and Discussion

3.1 Parameters of Landslide Prone Areas

3.3.1 Effect of Slope

Slope inclination measures the steepness of a terrain surface relative to the horizontal, expressed in degrees or percentages (Lesmana et al., 2021, Simanjuntak et al., 2024). Puslittanak, in 2004, classified slope inclination in percentage as follows: 0 to 8 is flat terrain, 8 to 15 is gentle terrain, 15 to 25 is moderately steep terrain, 25 to 45 is steep terrain, and more than 45 is highly steep terrain.

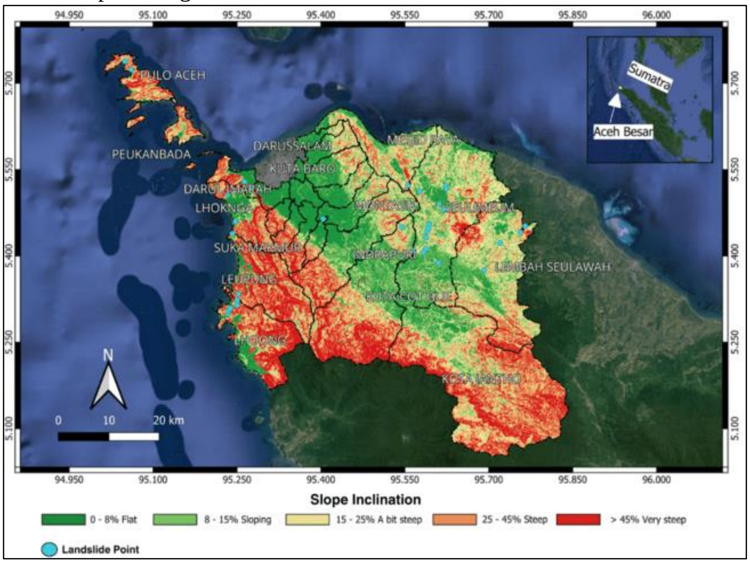

Fig. 2. Historical data on landslides that occurred in Aceh Besar Regency, dominated by slopes of 15 to more than 45%.

The influence of slope inclination on landslides is that the greater the percentage of slope inclination, the steeper it is, the faster landslides will occur, and the greater the volume of landslide material produced (Muhajir et al., 2021, Saputra et al., 2022). Slope inclination data was obtained from DEM SRTM 30m for Aceh Besar Regency. Figure 2 shows the processed data of landslide incidents in Aceh Besar, which is plotted on the slope inclination map using the QGIS application.

The slope inclination in Aceh Besar Regency varies widely from 0 to more than 45% due to the topographic conditions of Aceh Besar, located in hilly and mountainous areas. Based on the historical landslide incidents in Aceh Besar Subdistrict from 2014 to 2019, they were predominantly occurring on slopes with inclinations between 15 and more than 45%. Landslide incidents also occurred on slopes with inclinations between 8 and 15%, attributed to other factors, namely high rainfall during those incidents.

1. Influence of Rock Type on Landslides

Rock type is one of the parameters that causes landslides. Volcanic rocks are easily weathered, causing the material to be easily carried away by water during high rainfall intensity (Widagdo et al., 2021). The rock type map is based on comprehensive geological data from the Banda Aceh sheet by Bennet in 1981. This thorough research reveals that Aceh Besar Regency is an area with a rock structure dominated by volcanic rocks and sediments, influenced by the topography surrounded by mountains and hills. Figure 3 shows that volcanic rocks and sediments dominate more than 50% of the rock distribution in Aceh Besar Regency, while other areas consist of alluvial rocks.

Based on the historical landslide incidents in Aceh Besar Subdistrict from 2014 to 2019, these incidents were predominantly in areas with volcanic rock types. However, several landslide incidents occurred in areas with alluvial and sedimentary rock types, such as in Peukan Bada, Suka Makmur, and Darul Imarah. These incidents were caused by other landslide parameters, namely high rainfall during incidents.

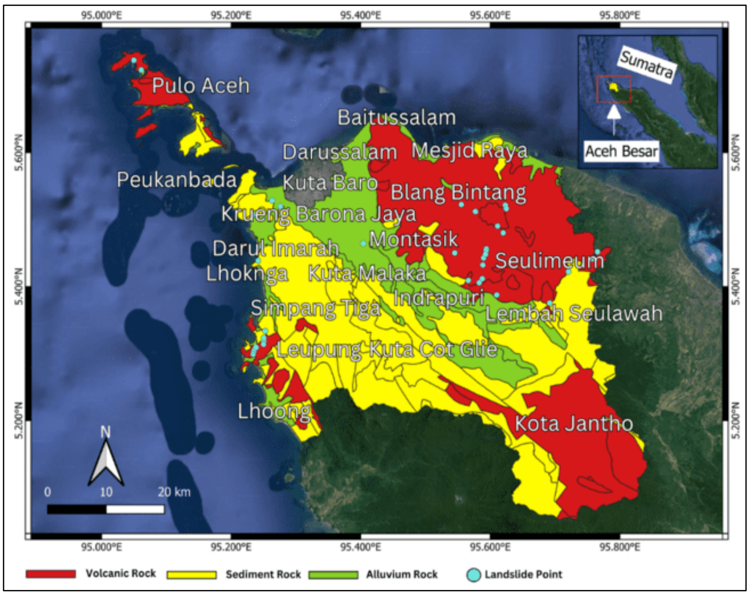

Fig. 3. Historical data on landslides that occurred in Aceh Besar Regency, dominated by volcanic rocks.

2. Soil Conditions in the Landslide Areas

The type of soil is closely related to erosion (Miftachurroifah et al., 2023), as the properties of the soil play a crucial role in the vulnerability level of an area to erosion, with several aspects of its relationship being soil texture, soil structure, and humus content. Erosion is the process of soil or mineral erosion influenced by water or wind, occurring naturally or as a result of human activities (Sumarna, 2015).

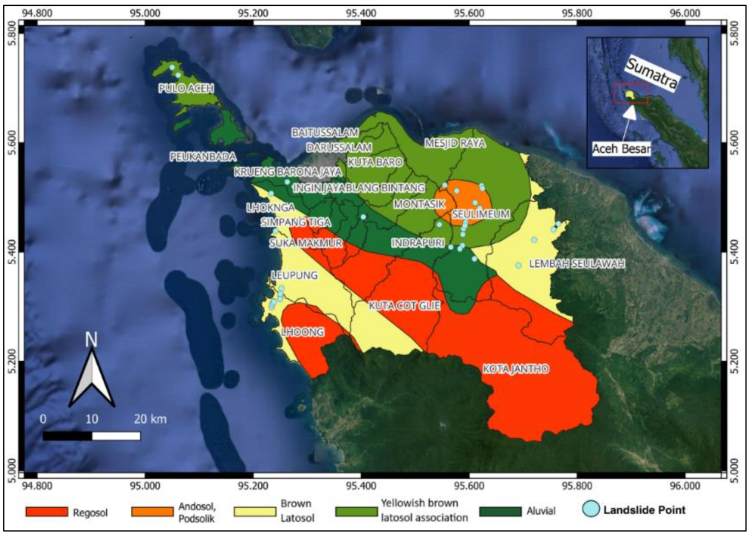

Fig. 4. Historical data on landslides that occurred in Aceh Besar Regency, dominated by the Latosol Soil Type and the Yellowish-Brown Latosol Association.

The soil type mapping, based on data from the Food and Agriculture Organization (FAO) of the United Nations, reveals a diverse landscape in Aceh Besar Regency, as shown in Figure 4. The southern region, dominated by Regosol soil types, is prone to erosion. The eastern and western regions, characterized by brown latosol soil types, are primarily clay soil. The central and northern regions, dominated by alluvial and associated brownish-yellow latosol soil types, have relatively lower erosion levels.

This diversity underscores the need for a nuanced approach to land management and disaster risk reduction. Based on the historical landslide incidents in Aceh Besar Subdistrict from 2014 to 2019, the majority occurred in brown latosol soil types, with 16 landslide incidents and 10 landslide incidents in areas with andosol and podzolic soil types. Landslide incidents also occurred in areas with soil types that are not prone to landslides but were caused by other landslide parameters, namely high rainfall and steep to very steep slope inclinations.

3. The Relationship Between Land Cover and Landslide

The mapping of land cover uses data sourced from the Indonesian Geospatial Agency in 2019. Land cover is closely related to the level of soil stability and vegetation density. One effect of land cover is to act as a barrier to the rate of erosion by rainwater and to prevent soil materials from descending down the slope (Susetyo et al., 2023).

Figure 5 shows that land cover in the Aceh Besar region is highly diverse, with almost 50% consisting of forests and plantations. In some areas, land use is depicted as dry fields, rice fields, and shrubland, where such land use increases the likelihood of landslides due to the easily movable nature of paddy fields. Land use for settlements, ponds, and reservoirs is minimal compared to others. Based on the historical landslide incidents in Aceh Besar Subdistrict from 2014 to 2019, landslides predominantly occurred in areas with land cover, such as rice fields and shrubland.

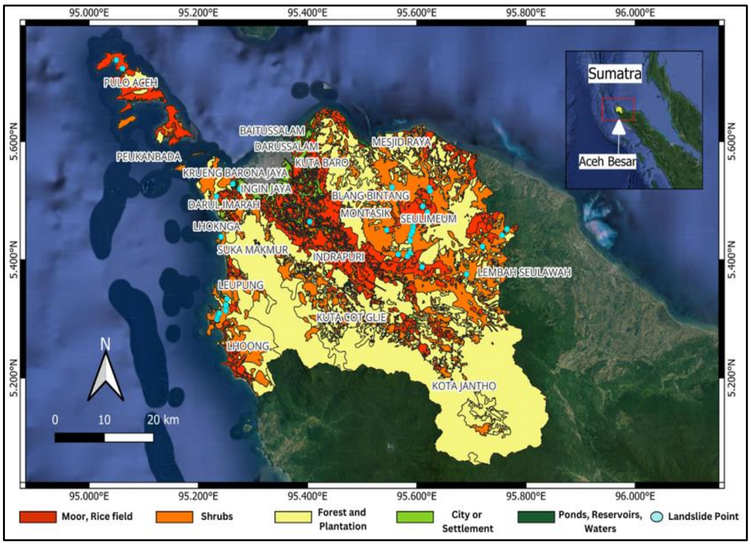

Fig. 5. Historical data on landslides that occurred in Aceh Besar Regency, dominated by areas with land cover as rice fields and shrubs.

4. The Relationship Between Rainfall and Landslides

The rainfall map of Aceh Besar Regency is based on direct observation data from rain monitoring stations distributed in each Subdistrict in Aceh Besar. The data was obtained from the Climatology Stations of Aceh Province as annual averages from 2014 to 2023. Rainfall data is interpolated using the Inverse Distance Weighted (IDW) Interpolation method to estimate values at specific locations based on known values at each point, resulting in the rainfall map of Aceh Besar Regency.

High to very high-intensity rainfall in Figure 6 is distributed in several Subdistricts, namely Lhoong, Kota Jantho, Seulimeum, Lembah Seulawah, Leupung, Lhoknga, Kuta Cot Glie, and Suka Makmur, while other Subdistricts are in areas with very low to moderate intensity. Rainfall impacts landslides by triggering them through the addition of slope load and a decrease in soil shear strength. High rainfall intensity affects soil conditions by increasing the water content, saturating the soil and causing landslides (Bujung et al., 2019). Based on the historical landslide events in Aceh Besar Subdistricts from 2014 to 2019, landslides occurred in areas with moderate to high rainfall intensity.

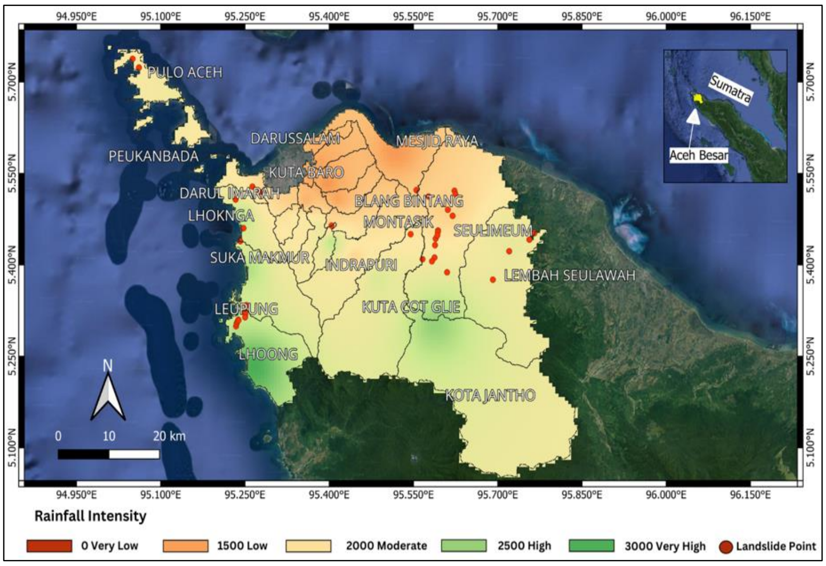

Fig. 6. Historical data on landslides that occurred in Aceh Besar District, dominated by areas with moderate to high rainfall intensity.

Landslide events in Aceh Besar Regency are directly proportional to the slope gradient and rainfall intensity, so the higher the rainfall intensity and the steeper the slope gradient, the faster the surface flow velocity and the larger the surface water volume (Martono, 2004).

3.3.2 Analysis of Landslide Prone Areas in Aceh Besar Regency

Based on the mapping, weighting, and classification of scores for landslide disaster factors, a landslide-prone area map has been created by combining all scores at each point in the Aceh Besar region. Figure 7 is a map of landslide-prone areas in Aceh Besar Regency verified by historical landslide data in Aceh Besar and classified into 5 potential categories: very low, low, moderate, high, and very high.

The research results indicate that historical landslide incidents in the Aceh Besar region are scattered at points with high to very high vulnerability levels. However, there are incidents in areas with low to moderate vulnerability due to the monthly average rainfall during the landslide incidents reaching 551 mm, categorized as very high for the monthly average (Qalbi and Fitrohim, 2023).

Tabel 6. Location of the Aceh Besar Landslide Event 2014 to 2016 (Firdaus, 2023).

No	Date	Landslide	Subdistrict	No	Date	Landslide	Subdistrict
1	4 Nov 2014	3	Lhoong	20	10 Aug 2020	1	Pulo Aceh
2	13 June 2016	1	Leupung	21	11 Sept 2020	1	Pulo Aceh
3	16 July 2016	1	Seulimeum	22	22 Nov 2020	1	Seulimeum
4	26 Feb 2017	1	Seulimeum	23	12 Jan 2021	1	Kuta Cot Glie
5	28 Mar 2017	1	Seulimeum	24	13 Jan 2021	1	Seulimeum
6	1 Jan 2018	1	Seulimeum	25	20 Jan 2021	1	Lembah Seulawah
7	18 Nov 2018	1	Seulimeum	26	20 Jan 2021	1	Seulimeum
8	19 Nov 2018	1	Seulimeum	27	20 Jan 2021	1	Suka Makmur
9	22 Nov 2018	1	Seulimeum	28	20 Jan 2021	1	Kuta Cot Glie
10	10 Dec 2018	1	Lhoong	29	9 July 2021	1	Lhoong
11	8 June 2019	1	Leupung	30	10 Aug 2021	1	Lhoong
12	9 June 2019	1	Kuta Cot Glie	31	19 Sept 2022	1	Darul Imarah
13	16 Feb 2020	1	Seulimeum	32	19 Sept 2022	1	Peukan Bada
14	7 May 2020	1	Leupung	33	16 Oct 2022	1	Lhoong
15	7 May 2020	1	Lembah Seulawah	34	23 Jan 2023	1	Seulimeum
16	7 May 2020	1	Lhoknga	35	26 Jan 2023	1	Lembah Seulawah
17	7 May 2020	1	Lhoong	36	1 Feb 2023	1	Seulimeum
18	10 Aug 2020	2	Lhoong	37	10 Feb 2023	1	Seulimeum
19	10 Aug 2020	1	Peukan Bada				

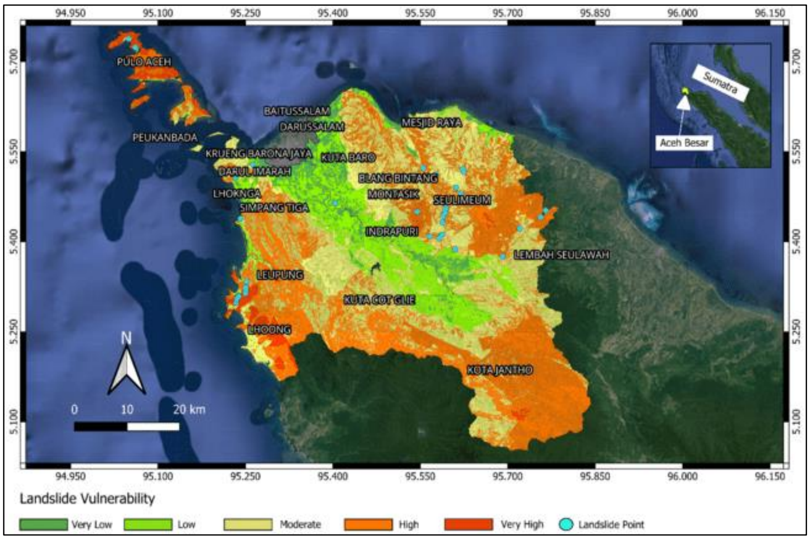

Fig. 7. Historical Landslide Data in Aceh Besar District Plotted to Verify Analysis of Landslide Prone Areas.

Areas with a high to very high potential for landslides cover more than 50% of the regions in Kota Jantho, Lhoong, Pulo Aceh, Lembah Seulawah, Seulimeum, Kuta Cot Glie, Seulimeum, some parts of Indrapuri, and Leupung. Regions with a moderate to high potential for landslides include some parts of Indrapuri, Darul Imarah, 50% of the areas in Kuta Malaka, Suka Makmur, Simpang Tiga, Darul Kamal, Lhoknga, Peukanbada, Darul Imarah, Montasik, Blang Bintang, Baitussalam, Darussalam, Mesjid Raya, and Kuta Baro. Areas with a very low to low potential for landslides include Ingin Jaya, Krueng Barona Jaya, more than 50% of the areas in Darul Imarah, some parts of Baitussalam, Darussalam, Mesjid Raya, Kuta Baro, Blang Bintang, Montasik, and Indrapuri. The main factor triggering landslides in Aceh Besar Regency is steep to very steep slope inclination. High to very high rainfall intensity in areas with slope inclinations above 25% causes the soil to become saturated, leading to surface runoff. Land use also significantly influences surface runoff that the land cannot retain, resulting in soil movement down the slope. The recorded landslide disaster events by the Regional Disaster Management Agency (BPBD) of Aceh Besar occurred 40 times from 2014 to 2023, as shown in Table 6, in areas highly vulnerable to landslide disasters. This proves the research aligns with historical data on landslide disasters in Aceh Besar Regency.

Conclusion

Based on the research results, landslide-prone areas in Aceh Besar Regency are classified into 5 classifications: very low, low, moderate, high, and very high vulnerability. The research findings indicate that almost all areas in Aceh Besar fall into the moderate to high vulnerability level for landslides. The landslide-prone area map produced by the research was validated with landslide disaster reports recorded by BPBA Aceh Besar, showing results consistent with historical data. Future research should include additional parameters such as rock weathering, soil depth, and layer structure to obtain more accurate results. The findings of this research can be utilized by relevant government agencies and the wider community for landslide disaster mitigation.

Acknowledgments

We thank Climatology Stations of Aceh Province for providing rainfall data; Aceh Besar Regional Disaster Management Agency for providing landslide occurrence data; Indonesia Geospatial for providing slope and land cover data; and Mr Bennet, J.D. for the geological data information. We thank the Quantum GIS (QGIS) application developer for his open-source application so that this landslide susceptibility map was created without reducing respect for other parties who were not mentioned.

Conflicts of Interest

The authors declare no conflict of interest.

References

Adi, S. P., Simanjuntak, A. V., Supendi, P., Wei, S., Muksin, U., Daryono, D., ... & Sinambela, M. (2024). Different Faulting of the 2023 (Mw 5.7 and 5.9) South-Central Java Earthquakes in the Backthrust Fault System. Geotechnical and Geological Engineering, 1-13.

Agustina, L., Syawreta, A., & Irawan, A.M. (2020). Analisis ambang batas hujan untuk pengembangan sistem peringatan dini tanah longsor (studi kasus Kecamatan Pejawaran, Kabupaten Banjarnegara, Provinsi Jawa Tengah), Jurnal dialog penanggulangan bencana, 11(1), 2087-636X.

Aini, Q. Kopa, R. & Har, R. (2018). Analisis kestabilan lereng studi kasus kelongsoran ruas Jalan Sicincin-Malalak KM 27.6 Kecamatan Malalak, Kabupaten Agam, Jurnal Bina Tambang, 3(2), doi: https://doi.org/10.24036/bt.v3i2.10109.

Akhirianto, N.A. & Naryanto, H.S. (2016). Kajian kapasitas dan persepsi masyarakat terhadap bencana tanah longsor di Desa Margamukti, Kecamatan Pangalengan, Kabupaten Bandung, Jurnal Riset Kebencanaan Indonesia, 2(2), 117-126, 2443-2733.

Andinisari, R., Simanjuntak, A. V., & Dhanarsari, R. A. (2024, July). Absolute locations of earthquakes in eastern java determined by using a minimum 1D P-wave velocity model. In AIP Conference Proceedings (Vol. 3077, No. 1). AIP Publishing.

Ansari, K., Walo, J., Simanjuntak, A. V., & Wezka, K. (2024). Crustal deformation from GNSS measurement and earthquake mechanism along Pieniny Klippen Belt, Southern Poland. Arabian Journal of Geosciences, 17(6), 180.

Ansari, K., Walo, J., Simanjuntak, A. V., & Wezka, K. (2024). Evaluation of recent Tectonic movement in Northeast Japan by using long-term GNSS and Tide Gauge Measurements. Journal of Structural Geology, 105258.

Arifin, A.F. Kahar, S. & Sasmito, B. (2015). Studi area longsor Kota Depok dengan metode pembobotan parameter, Jurnal Geodesi Undip, 4(3), 2337-845X.

Asnawi, Y., Gunaya, M., Prayitno, S., Simanjuntak, A., & Muksin, U. (2024). Simulation of Earthquake Intensity for Tsunami Prediction And Disaster Risk Management. Geomate Journal, 26(118), 17-24.

Asnawi, Y., Simanjuntak, A. V., Umar, M., Rizal, S., & Syukri, M. (2020). A microtremor survey to identify seismic vulnerability around Banda Aceh using HVSr analysis. Elkawnie: Journal of Islamic Science and Technology, 6(2), 342-358.

Asnawi, Y., Simanjuntak, A., Muksin, U., Rizal, S., Syukri, M. S. M., Maisura, M., & Rahmati, R. (2022). Analysis of microtremor H/V spectral ratio and public perception for disaster mitigation. Geomate Journal, 23(97), 123-130.

Bujung, D.P.A.P., Turangan. A.E., & Sarajar. A.N. (2019). Pengaruh intensitas curah hujan terhadap kuat geser tanah. Jurnal Tekno, 17(72), 47-51.

Campbell, R.H., (1975). Soil slips, debris flows, and rainstorms in the santa monica mountains and vicinity, Southern California, U.S. Geological Survey Professional Paper 851.

Faizana, F. Nugraha, A.L. & Yuwono, B.D. (2015) Pemetaan risiko bencana tanah longsor Kota Semarang, Jurnal Geodesi Undip, 4(1), 2337-845X.

Firdaus, (2023). Laporan kejadian bencana tanah longsor tahun 2016 sampai dengan 2023 Kecamatan Lembah Seulawah, Seulimeum dan Muara Tiga, Kabupaten Aceh Besar, Provinsi Aceh. Badan Penanggulangan Bencana Daerah (BPBD) Aceh Besar, 2023.

Indonesia Geospasial. (2014). Retrieved December 25, 2023, from https://www.indonesia-geospasial.com/2020/01/download-dem-srtm-30-meter-se-indonesia.html

Indonesia Geospasial. (2019). Retrieved December 25, 2023, from https://www.indonesia-geospasial.com/2020/09/download-shp-tutupan-lahan-tahun-2019.html

Khodijah, S. Monica, U.S. Ersyari, J. Khoirullah, N. & Sophian, R.I. (2022). Analisis kestabilan lereng menggunakan metode kesetimbangan batas dalam kondisi statis dan dinamis pada pit x, tanjung enim, sumatra selatan. Padjadjaran Geoscience Journal, 6(4). 1030-1037. 2597-4033.

Khusnawati, N.A. & Kusuma, A.P. (2020). Sistem informasi geografis pemetaan potensi wilayah peternakan menggunakan weighted overlay, Jurnal MNEMONIC, 3(2).

Kuncoro, D., Asnawi, Y., Halauwet, Y., Simanjuntak, A., & Susilo, A. (2024). Seismotectonic Analysis of Mw 7.6 2023 South Molucca Intermediate-Depth Earthquake. Geomate Journal, 27(120), 9-16.

Larsen, M.C., Conde, M.T.V. & Clark, R.A. (1999). Landslide hazards associated with flash-floods, with examples from the December 1999 disaster in Venezuela, NATO science series, 77, 259–275. doi: https://doi.org/10.1007/978-94-010-0918-82 5.

Lesmana, D., Fauzi, M., & Sujatmoko, B. (2021). Analisis kemiringan lereng daerah aliran sungai kampar dengan titik keluaran waduk plta Koto Panjang', Jurnal Online Mahasiswa FTEKNIK, 8, 1–7.

Martono., (2004). Pengaruh intensitas hujan dan kemiringan lereng terhadap laju kehilangan tanah pada tanah regosol kelabu, Universitas Diponegoro, Semarang.

Miftachurroifah. Astutik., S. Kurnianto., F.A. Mujib., M.A., & Pangastuti, E.I., (2023). Pemetaan daerah rawan bencana tanah longsor dengan metode weighted overlay di Kecamatan Silo Kabupaten Jember, Majalah Pembelajaran Geografi, 6(1), 47-61.

Muhajir, M., Ismail, N., Syahreza, S., & Simanjuntak, A. V. (2021). Pemutakhiran Zona Musim (ZOM) Provinsi Aceh Menggunakan Data Blending Berbasis Non-Hirarki K-Means Clustering. Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat, 18(1), 35-41.

Naryanto, H.S., Soewandita, H., Ganesha, D., Prawiradisastra, F., & Kristijono, A., (2019) Analisis penyebab kejadian dan evaluasi bencana tanah longsor di desa banaran, kecamatan pulung, kabupaten ponorogo, provinsi jawa timur tanggal 1 april 2017, Jurnal ilmu lingkungan, 17(2), 272. doi: https://doi.org/10.14710/jil.17.2.272-282.

Nurana, I., Simanjuntak, A. V., Umar, M., Kuncoro, D. C., Syamsidik, S., & Asnawi, Y. (2021). Spatial Temporal Condition of Recent Seismicity In The Northern Part of Sumatra. Elkawnie: Journal of Islamic Science and Technology, 7(1), 131-145.

Pasari, S., Simanjuntak, A. V., Neha, & Sharma, Y. (2021). Nowcasting earthquakes in Sulawesi island, Indonesia. Geoscience Letters, 8, 1-13.

Pasari, Sumanta, Andrean VH Simanjuntak, Anand Mehta, Neha, and Yogendra Sharma. "A synoptic view of the natural time distribution and contemporary earthquake hazards in Sumatra, Indonesia." Natural Hazards 108 (2021): 309-321.

Pusat Penelitian dan Pengembangan Tanah dan Agroklimat (Puslittanak)., (2004). Laporan Akhir Pengkajian Potensi Bencana Kekeringan, Banjir dan Longsor di Kawasan Satuan Wilayah Sungai Citarum-Ciliwung, Jawa Barat Bagian Barat Berbasis Sistem Informasi Geografi. Bogor. Published report.

Qalbi. H.B & Fitrohim., (2023). Laporan intensitas curah hujan tahun 2014 sampai dengan 2023 Kabupaten Aceh Besar, Provinsi Aceh. Stasiun Klimatologi Provinsi Aceh, 2023.

Rahmad, R. Suib, S. & Nurman, A. (2018). Aplikasi SIG untuk pemetaan tingkat ancaman longsor di Kecamatan Sibolangit, Kabupaten Deli Serdang, Sumatera Utara, Majalah Geografi Indonesia, 32(1), 1.

Saputra, R.T. Utami, S.R. & Agustina, C., (2022). Hubungan kemiringan lereng dan persentase batuan permukaan terhadap longsor berdasarkan hasil simulasi, Jurnal Tanah dan Sumberdaya Lahan, 9(2), 339-346, 2549-9793.

Sembiring, G.N., Nasution, Z., & Ibrahim, D. (2023). Identifikasi Batuan dan Tanah pada Kawasan Longsor di Desa Naman Teran Kabupaten Karo Provinsi Sumatera Utara, Jurnal Serambi Engineering, 8(2), 5643-5649. 2541-1934.

Simanjuntak, A. V., & Ansari, K. (2022). Seismicity clustering of sequence phenomena in the active tectonic system of backthrust Lombok preceding the sequence 2018 earthquakes. Arabian Journal of Geosciences, 15(23), 1730.

Simanjuntak, A. V., & Ansari, K. (2023). Spatial time cluster analysis and earthquake mechanism for unknown active fault (Kalatoa fault) in the Flores Sea. Earth Science Informatics, 16(3), 2649-2659.

Simanjuntak, A. V., & Ansari, K. (2024). Multivariate hypocenter clustering and source mechanism of 2017 Mw 6.2 and 2019 Mw 6.5 in the South Seram subduction system. Geotechnical and Geological Engineering, 1-14.

Simanjuntak, A. V., & Olymphia, O. (2017). Perbandingan Energi Gempa Bumi Utama dan Susulan (Studi Kasus: Gempa Subduksi Pulau Sumatera dan Jawa). Jurnal Fisika Flux: Jurnal Ilmiah Fisika FMIPA Universitas Lambung Mangkurat, 14(1), 19-26.

Simanjuntak, A. V., Muksin, U., & Sipayung, R. M. (2018, December). Earthquake relocation using HypoDDMethod to investigate active fault system in Southeast Aceh. In Journal of Physics: Conference Series (Vol. 1116, No. 3, p. 032033). IOP Publishing.

Simanjuntak, A. V., Palgunadi, K. H., Supendi, P., Muksin, U., Gunawan, E., Widiyantoro, S., ... & Ida, R. (2024). The western extension of the Balantak Fault revealed by the 2021 earthquake cascade in the central arm of Sulawesi, Indonesia. Geoscience Letters, 11(1), 35.

Sulistiarto, B. (2008). Studi Tentang Identifikasi Longsor dengan Menggunakan Citra Landsat dan Aster. Surabaya: Program Studi Teknik Geomatika – ITS.

Sumarna, D., (2015). Identifikasi erosi dan pengaruhnya terhadap lapisan tanah subur pada lahan pertanian produktif studi kasus: Daerah Aliran Sungai (DAS) Citarum Hulu, Seminar Nasional Sains dan Teknologi, 1–13. 2460-8416.

Susetyo, J.A., Astutik, S., & Kurnianto, A, (2023) Pemetaan Daerah Rawan Bencana Tanah Longsor di Wilayah Kecamatan Silo Kabupaten Jember, Jurnal Ilmu Lingkungan, 21(4), 861–869. 1829-8907.

Widagdo, A. Iswahyudi, S. Setijadi, R. Permanajati, I. & Tilaksono, A., (2021). Kontrol struktur geologi terhadap gerakan tanah dan batuan pada batuan formasi halang di daerah Sirau, Kecamatan Karang Moncol-Purbalingga, Propinsi Jawa Tengah. Prosiding the 12th Industrial Research Workshop and National Seminar, Bandung.