Assessing Soil Engineering Properties for Landslide Susceptibility in Karo Regency, Indonesia

Muhammad Qarinur[1], Ernesto Maringan Ramot Silitonga[2], Dody Taufik Absor Sibuea[3]

{m.qarinur@unimed.ac.id[1], ernestosilitonga@unimed.ac.id[2], dodytaufikabsor@unimed.ac.id[3]}

Civil Engineering Study Program, Universitas Negeri Medan, Jl. Willem Iskandar Psr.V, Medan, Sumatera Utara, Indonesia, 20221[1,2,3]

Abstract. Landslides are geological phenomena that pose significant threats to communities and infrastructure. Understanding the soil engineering properties of landslide-prone areas is crucial for effective risk assessment and mitigation strategies. This study investigates the soil engineering properties of landslide-prone areas in Karo Regency, focusing on understanding the dominant soil composition after landslide events. In-situ testing, laboratory experiments, and geological surveys are conducted to examine key soil parameters. The research findings reveal that the soil affected by landslides in Karo Regency is predominantly composed of sand. This knowledge can significantly contribute to enhancing disaster preparedness and mitigating future landslide-related risks in Karo Regency and similar landslide-prone regions worldwide.

Keywords: Disaster, Landslides, Soil Investigation.

1 Introduction

Landslide susceptibility refers to the likelihood or vulnerability of a specific area to experience landslides. It involves the assessment of geological, topographical, and environmental factors that can contribute to landslide occurrence [1]–[3]. Understanding the soil engineering properties is crucial for assessing and mitigating this vulnerability [4]–[7]. The research examines the geological conditions, engineering properties, and human interventions that contribute to landslides in the Kutupa- long Rohingya Camp in Cox’s Bazar, Bangladesh [4]. The findings reveal that most slope failures occur in residual soils and weathered silty sandstone units. The study also investigates the mineralogical composition of the slope materials and their influence on landslide occurrence. Factors such as high porosity and permeability of the sandstone layer, loss of root cohesion due to deforestation, and anthropogenic interventions contribute to the reduction of shear strength and trigger landslides during the monsoon season. The study provides valuable information for slope protection and mitigation measures in the camp and its surroundings. Sigdel and Ahikari [5] conducted a comprehensive study on the Taprang landslide in West-central Nepal. The study utilized geological mapping, geophysical surveys, and geotechnical analysis to assess slope stability. The findings indicate that the slope

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is stable under drained conditions but becomes unstable under undrained conditions and seismic loading. The study emphasizes the importance of considering multiple factors in slope stability analysis and provides valuable information for landslide mitigation measures. The presence of weak bedrocks and discontinuities in the slope contributes to its instability. The study recommends the implementation of proper mitigation measures to prevent further slope failure.

The impact of soil engineering properties on the failure mode of shallow landslides was investigated by McKenna et al. [6]. They found that an index based on the initial dry density and fine particle content of the soil could predict the failure mode of landslides with an accuracy of 79%. They also suggest that loose soil can grow from dense soils that expand under shear and that these material properties could be used to identify potential sources of debris flows and slides. The study analyzed different variables such as slope, volume, geomorphic setting, and material properties to determine their influence on landslide failure mode. Olabode et al. [7] evaluated soil water conditions in gravelly sand soil to understand its influence on slope instability. They used Electrical Resistivity Tomography (ERT) to study subsurface geological structures and performed geotechnical tests in the laboratory to obtain soil engineering properties. The results showed three geological zones and identified a potential landslide slip surface at a depth of 3.0 meters. The geotechnical properties of the soil supported the ERT findings and provided important data for assessing and monitoring slope instability in residual soil.

This study endeavors to comprehensively investigate the soil properties that contribute to the susceptibility of the area to landslides. In a region where landslides can result in devastating consequences, from loss of life to damage of vital infrastructure, such research is of crucially importance. The research methodology employed in this study involves a rigorous assessment of soil properties, incorporating techniques such as Triaxial Unconsolidated Undrained (Triaxial UU) testing and the application of the Unified Soil Classification System (USCS) [8], [9]. The results provide a comprehensive insight into the soil's mechanical behavior, shear strength, and classification, all of which are fundamental in understanding the potential triggers and mechanisms of landslides.

This research not only contributes to the scientific understanding of landslide susceptibility but also holds practical implications for local authorities, engineers, and policymakers. By identifying key soil engineering properties that influence landslide occurrences, it aims to facilitate informed decision-making in land use planning, construction, and disaster risk reduction strategies in Karo Regency. In the following sections, we delve into the methodology, results, and discussions surrounding the assessment of soil engineering properties and their significance in the context of landslide susceptibility in Karo Regency, Indonesia.

2 Methodology

Karo Regency is located in North Sumatra, Indonesia, and is known for its mountainous terrain, including the presence of active volcanoes like Mount Sinabung. The region is susceptible to various geological hazards, including landslides, due to its steep slopes, heavy rainfall, and geological conditions. Landslides in Karo Regency have been a recurring issue, causing damage to infrastructure, loss of life, and displacement of communities.

2.1 Field tests

Field testing is carried out to gather data on slope geometry and soil characteristics. Field soil testing is conducted to obtain crucial data on the index properties and mechanical characteristics of the soil at the landslide-prone location. The field soil testing encompasses measurements of slope geometry, and soil bulk density tests. In total, seven landslide-prone sites have been identified, with three of these sites undergoing in-depth investigation. This in-depth analysis takes into account the post-landslide slope morphology and the level of disaster risk severity. Additionally, disturbed and undisturbed soil samples from both the bedrock and landslide materials are collected for laboratory testing. The locations and coordinates of these soil testing points can be found in Fig. 1 and Table 1. Measurement of slope geometry at landslide sites can be accomplished using a distance-measuring tool known as a hypsometer or range finder, as outlined by Qarinur in 2015 [10]. This hypsometer is capable of measuring both horizontal distances and the height from the user's eye to the target object.

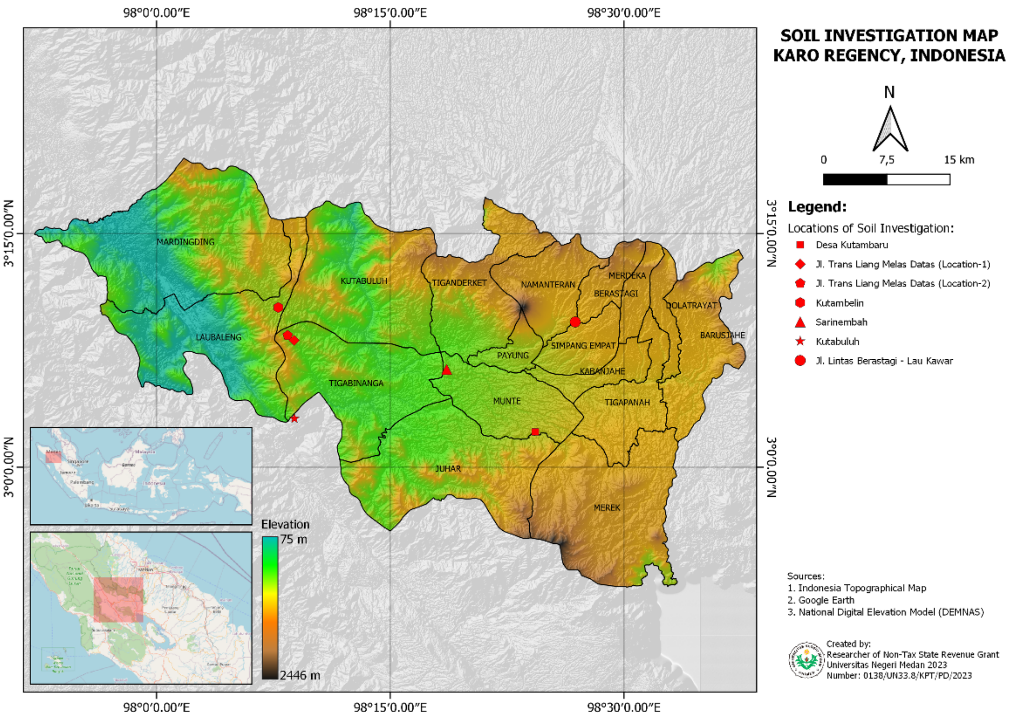

Fig. 1. Soil investigation map.

Table 1. Soil investigation coordinate.

No.	Location	Coordinate	
		Latitude	Longitude
1	Kutabuluh	3.052152	98.147402
2	Sarinembah	3.104831	98.310258
3	Kutambelin	3.170918	98.130179
4	Jl. Trans Liang Melas Datas (location 1)	3.141114	98.140148
5	Jl. Trans Liang Melas Datas (location 2)	3.135760	98.147099
6	Berastagi-Lau Kawar	3.155472	98.447694
7	Kutambaru	3.038028	98.405306

2.2 Laboratory experiments

Laboratory testing is conducted to acquire a comprehensive understanding of the soil characteristics at the research site. The specific types of tests performed and the standards adhered to are detailed in Table 2. These laboratory tests serve as a crucial foundation for our further analysis and planning within the scope of our research.

Table 2. Laboratory experiments standard.

No.	Test	Standard
1	Water Content	SNI 1965:2008 [11]
2	Bulk Density	SNI 03-3637-1994 [12]
3	Specific Gravity	SNI 1964:2008 [13]
4	Liquid Limit	SNI 1967:2008 [14]
5	Plastic Limit	SNI 1966:2008 [15]
6	Sieve Analysis	SNI 3423:2008 [16]
7	Hydrometer Analysis	SNI 3423: 2008 [16]
8	Triaxial Unconsolidated-Undrained	SNI 4813: 2015 [8]

3 Results and Discussion

3.1 Measurement of slope

The measurement of slope geometry was conducted using a laser distance meter telescope, as depicted in Fig. 2, which illustrates the conditions of the measured slope. From the measurements of the slope geometry, it was determined that the mass movement classification is predominantly characterized by translational mass movement of soil/rock, with materials consisting of debris and soil in the landslide. Furthermore, the type of landslide at the Sarinembah location exhibits a distinct classification compared to other sites, characterized as lateral spreading, specifically soil creep. Detailed classifications of mass movements of soil or rock can be found in Table 3.

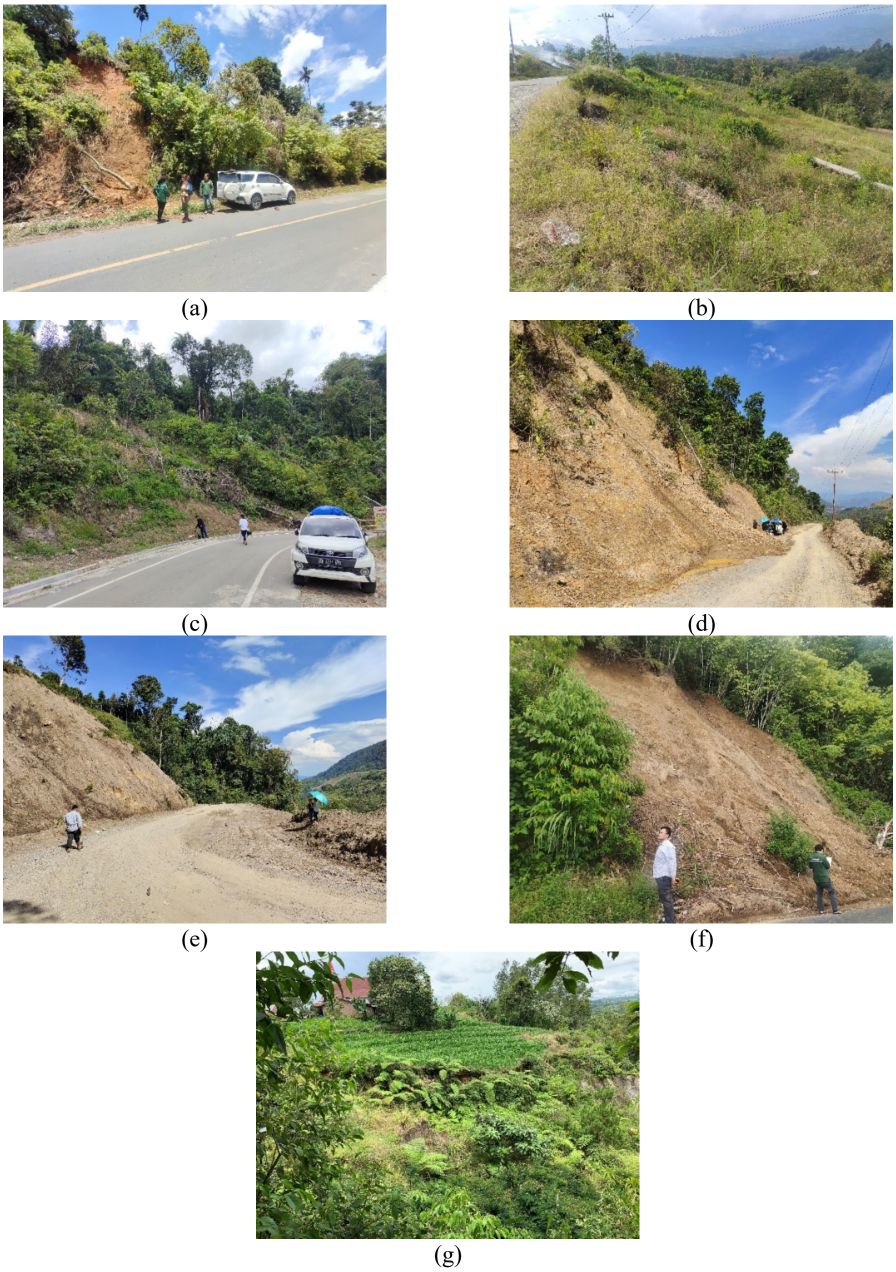

Fig. 2. Condition of soil testing points in the field: (a) Kutabuluh; (b) Sarinembah; (c) Kutambelin; (d) Jl. Trans Liang Melas Datas (location 1); (e) Jl. Trans Liang Melas Datas (location 2); (f) Jalan Lintas Berastagi-Lau Kawar; (g) Kutambaru.

Table 3. The results of the classification of soil/rock mass movements.

No.	Location	Movement	Material
1	Kutabuluh	Translational	Predominantly coarse
2	Sarinembah	Lateral Spread	Predominantly fine
3	Kutambelin	Rotational	Predominantly coarse
4	Jl. Trans Liang Melas Datas (location 1)	Translational	Predominantly coarse
5	Jl. Trans Liang Melas Datas (location 2)	Translational	Predominantly coarse
6	Berastagi-Lau Kawar	Translational	Predominantly coarse
7	Kutambaru	Rotational	Predominantly fine

3.2 In situ bulk density

The results of soil bulk density testing are essential for determining the natural soil density in the field. These values are subsequently employed in the process of creating soil mechanical testing samples in the laboratory, such as Triaxial tests. A steel core barrel with internal dimensions of 36 mm in diameter and 72 mm in height serves as the tool for obtaining soil bulk density values in the field (Fig. 3a). Sampling is carried out on the surface of the natural soil around the landslide and the landslide slip surface (Fig. 3b). Table 4 provides a summary of the soil bulk density test results from the three research-focused locations. These results reveal that the landslide soil characteristics in Kutambelin are denser compared to the other locations. The landslides in this area are primarily attributed to steep slope cutting for the road without adequate reinforcement or erosion control measures (Fig. 2c).

(a) (b)

Fig. 3. In situ bulk density: (a) steel core barrel; (b) sampling process.

Table 4. Summary of soil bulk density test results.

No.	Location	Bulk density (γ_b, gr/cm^3)	Dry density (γ_d, gr/cm^3)
1	Kutabuluh	1,87	1,45
2	Kutabuluh (slip surface)	1,83	1,35
3	Sarinembah	1,72	1,29
4	Kutambelin	1,70	1,34
5	Kutambelin (slip surface)	1,95	1,69

3.1 Soil properties

Soil index properties testing comprises evaluations of moisture content, Atterberg limits, specific gravity, and grain analysis. A summary of the test results obtained is presented in Table 5.

Table 5. Summary of soil index properties.

No	Location	Water Content (%)	Specific Gravity (-)	Atterberg Limits			Grain Size		
				Liquid Limit (LL) (%)	Plastic Limit (PL) (%)	Plasticity Index (PI) (%)	Gravel (%)	Sand (%)	Silt/ Clay (%)
1	Kutabuluh	21,23	2,61	32,55	25,13	7,41	16,02	82,29	1,69
2	Kutabuluh (slip surface)	29,58	2,61	0,00	0,00	NP	4,99	94,59	0,41
3	Sarinembah	37,49	2,60	57,61	30,81	26,80	0,00	95,99	4,01
4	Kutambelin	21,88	2,48	0,00	0,00	NP	19,49	76,14	4,37
5	Kutambelin (slip surface)	16,32	2,65	0,00	0,00	NP	5,22	91,31	3,47

3.2 Soil classification

The classification of soil can be determined based on the results of soil properties index testing. According to the Unified Soil Classification System (USCS), the prevalent soil type responsible for landslide occurrences in Karo Regency is sandy soil. For a detailed breakdown of the soil classification results refer to Table 6, which provides comprehensive information regarding the specific characteristics of the soil types identified. This information is crucial for understanding and addressing the factors contributing to landslides in the region, aiding in the development of effective mitigation strategies and land use planning in Karo Regency.

Table 6. Summary of soil classification USCS system.

No	Location	Group Symbols	Typical Names
1	Kutabuluh	SW-SM	Well-graded sands, gravelly sands, and silty sands.
2	Kutabuluh (slip surface)	SP	Poorly graded sands and gravelly sands, little fines.
3	Sarinembah	SW	Well-graded sands and gravelly sands, little fines.
4	Kutambelin	SP	Poorly graded sands and gravelly sands, little fines.
5	Kutambelin (slip surface)	SP	Poorly graded sands and gravelly sands, little fines.

3.3 Triaxial

Triaxial testing was conducted with the objective of obtaining soil shear strength values, specifically employing the Triaxial Unconsolidated Undrained (Triaxial UU) testing method. A comprehensive breakdown of the test results is available for reference in Table 7, offering detailed insights into the soil's shear strength characteristics. This data is essential for assessing the stability of soil structures, determining their load-bearing capacities, and facilitating informed engineering decisions in various applications, from civil engineering projects to geotechnical assessments.

The data presented in Table 7 reveals that the Sarinembah location possesses the smallest angle of internal friction. This implies that the site is predominantly characterized by fine-grained soil with no presence of sandy or gravelly soil. Field observations further confirm that the ground movement in the Sarinembah location exhibits lateral spreading (as depicted in Fig. 2b). This fine-grained soil that contributes to the gradual nature of the ground movement, making it challenging to halt the movement. This highlights the importance of considering soil characteristics in the design and implementation of infrastructure and stabilization measures to effectively manage and mitigate the effects of ground movement in such areas.

The location of Kutabuluh stands out with the highest angle of internal friction among the two other locations, coupled with cohesive properties. These findings suggest that the soil in this area is a combination of coarse and fine-grained material, likely resulting from the weathering of rock formations due to the steep slopes of the road cut and the additional load imposed by the surrounding vegetation, as illustrated in Fig. 2a. The rock weathering process has given rise to the soil, which is prone to shallow landslides characterized by translational movement. In contrast, Kutambelin exhibits relatively lower values for both the angle of internal friction and cohesion. Consequently, this location is susceptible to deeper landslides with larger deposit volumes, typically involving rotational movement, as depicted in Fig. 2c. These observations underscore the critical role of soil properties in influencing the type and depth of landslides, contributing valuable insights for geotechnical assessments and disaster risk management in the area.

Table 7. Summary of Triaxial UU test results.

No	Location	Angle of internal friction (φ) °	Cohesion (c) kN/m^2
1	Kutabuluh	40,00	10,00
2	Kutabuluh (slip surface)	18,00	32,00
3	Sarinembah	0,00	84,00
4	Kutambelin	19,00	15,00
5	Kutambelin (slip surface)	24,00	25,00

4 Conclusions

The soil characteristics of landslide areas in Karo Regency are predominantly characterized by sandy soil. Visually, the regions at risk of landslide disasters within Karo Regency are identifiable along roadsides lacking slope reinforcement and within forested areas that have been converted into plantations. These areas stand out as vulnerable zones, particularly when subjected of intense rainfall and seismic events. To mitigate the risk and enhance disaster preparedness, there is an urgent need for the revision and enhancement of landslide vulnerability maps in Karo Regency. These updated maps should incorporate the soil characteristic data generated in this study. Such proactive measures are essential for safeguarding the region against future landslide events, providing valuable insights for land use planning, infrastructure development, and disaster management strategies.

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References

[1] R. Pacheco Quevedo, A. Velastegui-Montoya, N. Montalván-Burbano, F. Morante-Carballo, O. Korup, and C. Daleles Rennó, “Land use and land cover as a conditioning factor in landslide susceptibility: a literature review,” Landslides, vol. 20, no. 5, pp. 967–982, 2023, doi: 10.1007/s10346-022-02020-4.

[2] P. Reichenbach, M. Rossi, B. D. Malamud, M. Mihir, and F. Guzzetti, “A review of statistically-based landslide susceptibility models,” Earth-Science Rev., vol. 180, no. November 2017, pp. 60–91, 2018, doi: 10.1016/j.earscirev.2018.03.001.

[3] U. Ozturk, M. Pittore, R. Behling, S. Roessner, L. Andreani, and O. Korup, “How robust are landslide susceptibility estimates?,” Landslides, vol. 18, no. 2, pp. 681–695, 2021, doi: 10.1007/s10346-020-01485-5.

[4] A. S. M. M. Kamal, F. Hossain, M. Z. Rahman, B. Ahmed, and P. Sammonds, “Geological and soil engineering properties of shallow landslides occurring in the Kutupalong Rohingya Camp in Cox’s Bazar, Bangladesh,” Landslides, vol. 19, no. 2, pp. 465–478, 2022, doi: 10.1007/s10346-021-01810-6.

[5] A. Sigdel and R. K. Adhikari, “Engineering Geological and Geotechnical studies of Taprang landslide, west-central Nepal: An approach for slope stability analysis,” J. Geol. Res., vol. 2, no. 4, pp. 22–35, 2020, doi: 10.30564/jgr.v2i4.2302.

[6] J. P. McKenna, P. M. Santi, X. Amblard, and J. Negri, “Effects of soil-engineering properties on the failure mode of shallow landslides,” Landslides, vol. 9, no. 2, pp. 215–228, 2012, doi: 10.1007/s10346-011-0295-3.

[7] O. P. Olabode, H. S. Lim, and M. H. Ramli, “Geophysical and Geotechnical Evaluation of Landslide Slip Surface in a Residual Soil for Monitoring of Slope Instability,” Earth Sp. Sci., vol. 9, no. 12, 2022, doi: 10.1029/2022EA002248.

[8] Badan Standardisasi Nasional, Cara uji triaksial untuk tanah kohesif dalam keadaan tidak terkonsolidasi dan tidak terdrainase (UU). SNI 4813:2015. Jakarta, 2015.

[9] A. K. Howard, “Unified Soil Classification System - Test Procedures,” Denver, Colorado, 1988.

[10] M. Qarinur, “LANDSLIDE RUNOUT DISTANCE PREDICTION BASED ON MECHANISM AND CAUSE OF SOIL OR ROCK MASS MOVEMENT,” J. Civ. Eng. Forum, vol. 1, no. 1, Jan. 2015, doi: 10.22146/jcef.22728.

[11] Badan Standardisasi Nasional, Cara uji penentuan kadar air untuk tanah dan batuan di laboratorium. SNI 1965:2008. Jakarta, 2008.

[12] Badan Standardisasi Nasional, Metode Pengujian Berat Isi Tanah Berbutir Halus Dengan Cetakan Benda Uji. SNI 03-3637-1994. Jakarta, 1994.

[13] Badan Standardisasi Nasional, Cara uji berat jenis tanah. SNI 1964: 2008. Jakarta, 2008.

[14] Badan Standardisasi Nasional, Cara uji penentuan batas cair tanah. SNI 1967 :2008. Jakarta, 2008.

[15] Badan Standardisasi Nasional, Cara uji penentuan batas plastis dan indeks plastisitas tanah. SNI 1966:2008. Jakarta, 2008.

[16] Badan Standardisasi Nasional, Cara uji analisis ukuran butir tanah. SNI 3423:2008. Jakarta, 2008.