Journal of Environmental Biology
p-ISSN: 0254-8704 • e-ISSN: 2394-0379 • CODEN: JEBIDP

JEB®

Original Research Paper
Volume 47 Issue 1 January 2026 pp. 11-20
DOI: http://doi.org/10.22438/jeb/47/1/MS-16

J. Environ. Biol., 2026
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Journal website : www.jeb.co.in ★ E-mail : editor@jeb.co.in

Land subsidence in the western part of Aizawl: a case study of Hunthar, Aizawl, India

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Received: 13 June 2025 **Revised:** 20 August 2025 **Accepted:** 05 September 2025

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Abstract

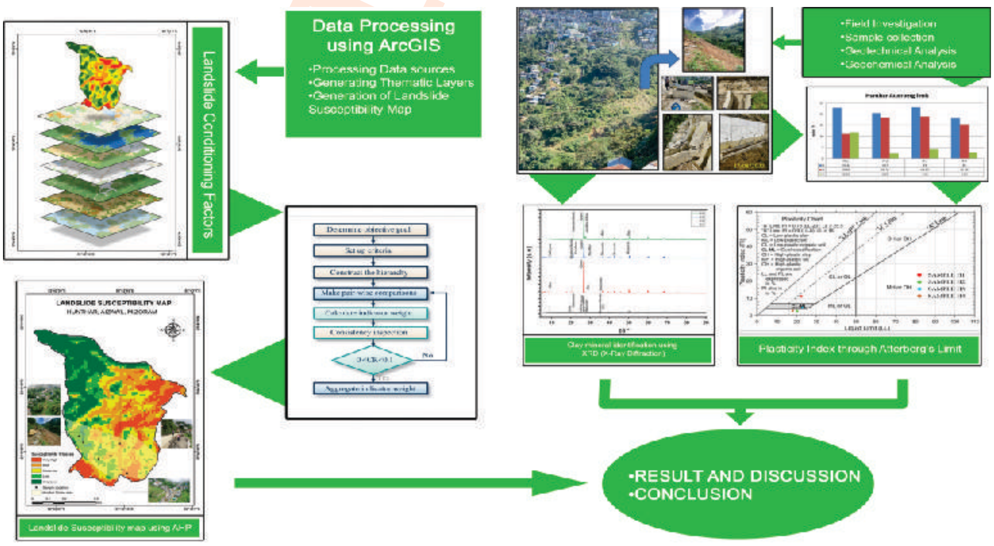
Aim: To generate Landslide Susceptibility Map of Hunthar locality using AHP method, demarcating the study area Hunthar Landslide and interpreted with its physico-chemical properties of soil within the study area.

Methodology: ArcGIS 10.4 was utilized to create Landslide Susceptibility Map through Analytic Hierarchy Process (AHP). Atterberg limit for liquid limit, plastic limit and plasticity index, samples were analyzed to ascertain the geotechnical characteristics of soil. Sieve analysis and hydrometer analysis were performed for soil texture classification. X-Ray Diffraction (XRD) was utilized for clay minerals identification in the soil samples.

Results: Analytic Hierarchy Process (AHP)-based Landslide Susceptibility Consistency Ratio was 0.008. The plasticity chart classified the soil samples ranges to: low-plastic clay to low-plastic silt and clay of intermediate compressibility to low-compressive silt. Loamy soil was indicated by the classification of soil texture. Through X-ray, parent materials such as silica, micas, and feldspars were found alongside clay mineral groups like kaolinite, illite, and smectite. Quartz was the dominant mineral, montmorillonite and illite were common clay minerals.

Interpretation: Physico-chemical characteristics of soils and interpretation of Hunthar landslide susceptibility map showed that the landslide is caused due to erosion of toe area during monsoon. High concentration of clay minerals like monmorillonite (swelling clay) contributes to landslide activity.

Key words: Analytic hierarchy process, Atterberg, Clay minerals, Hunthar, Landslide



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How to cite: Lalthazuala, C., J. Malsawma, C. Zoramthara, C. Lalremruatfela, P. Lalnuntluanga, J. Lalnunmawia, L. Kawilam and G. Rohmingthangi: Land subsidence in the western part of Aizawl: a case study of Hunthar, Aizawl, India. *J. Environ. Biol.*, **47,** 11-20 (2026).

Introduction

A mass movement down a slope influenced by gravity can be termed as a landslide. Landslide, a natural phenomenon both breathtaking and destructive, is a prime example of the Earth's unbridled strength. Landslides, which are the downward movement of soil, rock and/or debris along medium to high angle slope, can vary from gradual, undetectable changes over time to abrupt, catastrophic occurrences that quickly alter landscapes. Intense rainfall, seismic activity, water level change, storm waves or rapid stream erosion, geology, land cover, slope geometry, groundwater saturation, vegetation cover, and human activity can contribute to the occurrence of landslides (El Jazouli *et al.,* 2019a, Althuwaynee *et al.,* 2014; Sangchini *et al.,* 2016). Hunthar landslide is geologically positioned in the western limb of Aizawl anticline. Majority of urbanization and development in Aizawl, the state capital of Mizoram, are confined to hilly terrain. Intense seasonal rainfall triggering numerous landslides not only cause destruction to human life but leads to economic loss disrupting transportation system.

As intense rainfall leads to weathering and erosion of the lithologic units, it also alters the slope stability of an area. Therefore, the possibility of landslides is greatly influenced by the characteristics of lithological units. The required geotechnical properties of the unit are determined by the weathered units acting as soil from a mechanical perspective (Yalcin, 2011). Since 1992, this region has experienced frequent landslides mainly in the form of subsidence. However, reactivation of the slide have occurred from 2016 monsoon till date, which has resulted in significant losses to government, commercial and public properties. In the affected region, more than 60 families were forced to evaluate their residences. The Geospar Company has taken up and done mitigation measures to slow down the upper sliding area which they finished on June 2022. They handed over to Department of Disaster Management & Rehabilitation, Government of Mizoram for further monitoring. However, the reactivation of the lanslide starts during the monsoon of 2022, which we intended to study the Middle to Toe of Hunthar landslide that continues till date (Fig. 2). The acceleration of this sliding area usually happens during monsoon seasons. In better understanding of the slide, soils of the area are taken for geotechnical investigation. A key component of landslide prediction is thorough investigation of the units' geotechnical properties (Carrière *et al.,* 2018).

The abundance of clays in soils has been linked to the occurrence of landslides, according to a number of studies based on the physico-chemical properties, mineralogy, and geotechnical properties of soil clays (Daoudi *et al.,* 2015; Diko *et al.,* 2014; Ekosse *et al.,* 2005) and (Fall and Sarr, 2007; Ngole *et al.,* 2007; Yalcin, 2007, 2011). In areas that are vulnerable to landslides, this study can help local authorities to create safe construction zones, safeguarding property as well as individuals. Therefore, the whole Hunthar municipality was selected for preparing landslide susceptibility mapping and demarcating of the area of interest that is Hunthar landslide. Apart of Landslide susceptibility map, ground-based data collection was also carried out by means of soils physico-chemical and geo-mechanical properties within the landslide. The objective of the study was to create a susceptibility map for the Hunthar locality using AHP method, which includes the Hunthar Landslide, an area of interest. Additionally, the physical characteristics of the soils from the Hunthar landslide were assessed through a rigorous laboratory testing program that included quantitative analyses using X-ray diffraction (XRD) to determine the minerals found in clay. The outcomes are then compared to determine how they all contributed to the Hunthar landslide.

Materials and Methods

Study area: The study area is located within Aizawl city, Mizoram, Northeast India. Being in high sedimentary basin, Aizawl is the state Capital of Mizoram and settled in the central northern part of the State (Fig. 1). It is situated at just north Tropic of Cancer at 23º39'N to 23º50'N latitudes and 92º39'E to 92º47'E longitudes and falls within the Survey of India topographical map no. 84A/10, 13 and 9. The study area Hunthar lies in latitude 23º44.706'N and longitude 92º44.472'E. The landslide area covers approximately 158,903 m² with elevation ranged from 781 to 1001 m. For better understanding of the area of interest, the whole Hunthar locality susceptibility map was prepared (Fig. 2). From this, Hunthar landslide falls on high -moderate risk zone which is then proved by geophysical-chemical and mechanical properties of the soils of the area. Owing to the collision between Indian and Burmese plates, the study area's topography rises sharply. The bed rocks have folded as a result of this impact, creating hill ranges that trend from north to south. The basin was also cut by a number of transverse faults and thrusts that ran parallel to sub-parallel. This is often utilized as a key to landslide studies and is closely linked to the formation of many landslides.

Preparation of thematic layers: The sources of data area are as follows : Resourcesat-2A LISS-4 (5.8 m Resolution) from Bhoonidhi, ALOS PALSAR DEM (12.5 m Resolution) from Alaska Satellite Facility, Lithology was downloaded from GSI (Geological Survey of India), Slope, Aspect, Elevation, Profile Curvature and Drainage density was derived from DEM 12.5m ALOS PALSAR DEM 12.5m. LULC Derived from LISS-4 (5.8 m Resolution) and field observation LISS 4 (5.8m Resolution), Distance to Road Extracted using buffering through Google Earth, Rainfall was Downloaded from the State Meteorological Center, Directorate of Science and Technology, Government of Mizoram. Thematic maps was generated using ArcGIS software. The coordinates of projected WGS 1984 UTM zone 46N was used for generating thematic maps.

Susceptibility mapping: In the current study, the landslide susceptibility triggering elements were arranged in a matrix with a hierarchical structure. A numerical number was assigned to each factor according to its relative relevance using the Prioritized Factors Rating number (PFRV) technique (Saaty, 1980).Weights and rating value/eigenvalue were calculated using the average of

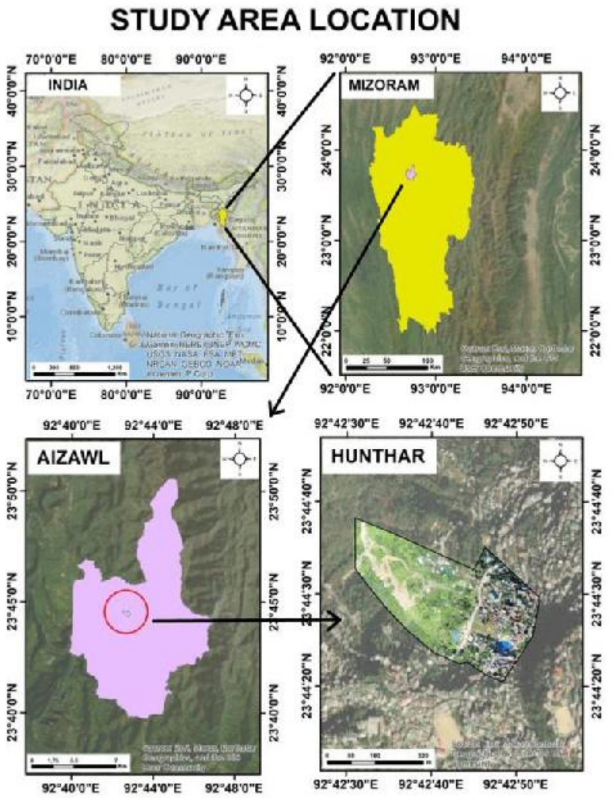

Fig. 1: Location of the Hunthar Landslide, Aizawl, Mizoram.

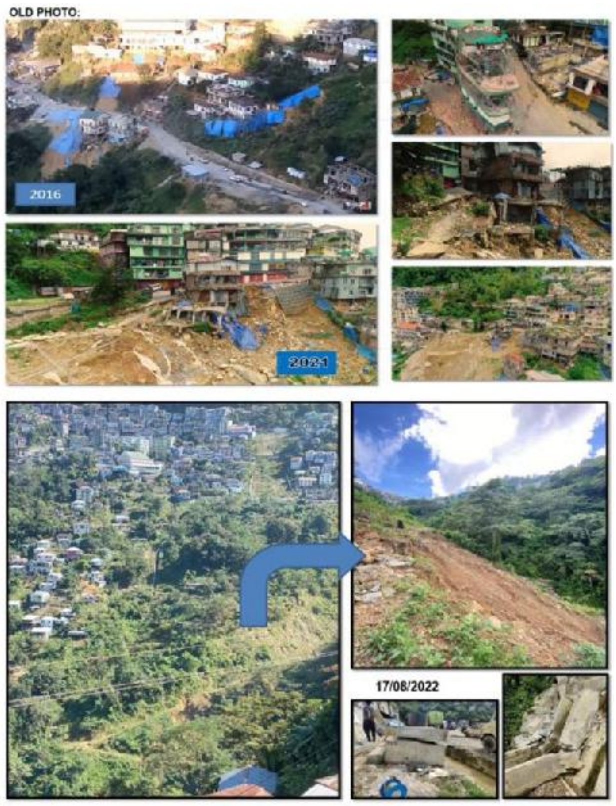

Fig. 2: Hunthar landslide showing destruction within the scarp and the toe.

hierarchically arranged factors, along with Consistency Ration (CR), based on the propositions of (1980). The consistency of the pairwise comparisons was assessed using the consistency ratio (CR) (Kolat *et al.,* 2012). The two methods used to map landslide susceptibility were qualitative (knowledge-driven) and quantitative (statistical) approaches (Kaur *et al.,* 2017). Fieldwork as well as theoretical understanding of the physical processes were combined to provide expert information. As with the Analytic Hierarchy Process (AHP) (Saaty and Vargas, 1980; Barredo *et al.,* 2000; Yalcin, 2008; Kamp *et al.,* 2010), certain qualitative techniques turn semi-quantitative by adding ranking and weighting (Ayalew *et al.,* 2005). AHP breaks down a complex choice problem into several levels of hierarchy. Opinions can be quantified and converted into a logical decision model using this method (Saaty, 1990). For LSZ, it was extensively utilized by numerous writers across the globe (Kayastha *et al.,* 2013; Shahabi *et al.,* 2015; Pal and Chowdhuri, 2019; Basu and Pal, 2020) One advantage of the AHP method is that it permits inconsistent associations while offering a CR as a measure of the degree of consistency or inconsistency (Chen *et al.,* 2010; Feizizadeh and Blaschke, 2013). The class weights can be recognized with a substantial level of consistency if the CR is <0.10.:

$$\textit{Consistency Ratio (CR)} = \frac{\textit{Consistency Index (CI)}}{\textit{Random Consistency Index (RI)}}$$

$$CI = \frac{\lambda max - n}{n - 1} \qquad (1)$$

where, λ_{max} is the principal eigenvalue and "n" is the number of components $\lambda_{max}=\Sigma$ of the sum between each component of the priority vector and column totals. Random consistency index (RI) was calculated from a sample of randomly produced reciprocal matrices (Saaty, 1980) (Table 1). This study had a consistency ratio (CR) of 0.008, suggesting that the weight age in Table 2 was appropriate for the zonation model of landslide hazards and that the attribute comparisons were highly consistent.

Soil sampling and analysis methods: Sampling was done during monsoon season in June 2022. Global Positioning System (GPS) was used to record coordinates for four samples of soil that were taken, namely (Sample H1from top to H4 bottom) of the Hunthar landslide location down to a depth of three to four feet. Randomly selected samples were placed in labeled polythene bags, which were subsequently allowed to air dry in a laboratory before being sealed in sterile bags for further analysis.

Geotechnical properties: Atterberg Limits define the consistency states of fine-grained soils based on the moisture content—Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). Liquid Limit of the soil sample was determined by the casagrande apparatus as per IS:2720 Part 5 – 1985. The soil sample was sieved through 425 micron sieve and tested. Plastic Limit of the soil was conducted by standard method (IS:2720 Part

5 – 1985). In order to assess their contribution to increasing landslide susceptibility, Atterberg limits were utilised in this study to quantify the swell potential of each soil sample and were later categorised appropriately.

- LL: Water content at which soil changes from plastic to liquid.
- PL: Water content at which soil changes from semi-solid to plastic.

The range of water concentrations at which soil exhibits plastic qualities is shown by the plasticity index (PI), which is a measure of soil plasticity (Wroth and Wood, 1978). Calculations are made using the numerical difference between the liquid and plastic limits.

$$PI = LL - PL \quad (2)$$

Soils are classified based on PI values from non-plastic to very highly plastic. A fundamental indicator of soil plasticity as a result of moisture fluctuation is the Atterberg limits. Clay mineral swelling is the cause of soil plasticity. Soils that do not swell are referred to as non-plastic in clay minerals (Gourley *et al.,* 1993; Mitchell, 1993 Thomas *et al.,* 2000). The point at which the soil transfarms from a semi-solid to a plastic condition as a result of an increase in water content is known as the plastic limit (PL). The point at which a soil transfarms from a plastic to a liquid form when its water content rises is known as its Liquid Limit (LL) (Das, 2002). In this study, Atterberg limits were used to estimate swell potential and classify soils by their landslide susceptibility.

Analysis of grain size: Grain size distribution affects the soil strength and landslide behavior. It was determined using sieve analysis for coarse particles and by hydrometer method for fine particles that could pass through a 75 µm sieve (IS:2720 Part 4 – 1985). The frequency and speed of landslides were significantly influenced by the distribution of particle sizes (Yalcin, 2007), which helped in the classification of soil texture and assessing its role in landslide-prone areas.

Mineral identification using X-ray diffraction: X-ray diffractometer is used in identification of clay minerals present in each sample and what type of clay could possibly contribute the slide within the study area. It was necessary to further grind the samples into particle size smaller than 75 µm to a preferred fraction smaller than 10 µm in order to perform XRD analysis (El Jazouli *et al.,* 2020). PAN alytical Empyrean XRD, Software: PAN alytical Data Collector and High Score Plus with PDF4 database of ICDD. Tested in Sophisticated Analytical Instrument Facility (SAIF), Guwahati University, Department of Instrumentation & USIC, Guwahati – 781014, India were used for analyses.

Results and Discussion

An AHP approach based on GIS was applied in this work to better understand the Hunthar Locality and identify possible landslide risk zones. This is then preceded with our study area, an area of interest Hunthar landslide where subsidence occurred. For this, nine landslide contributing factors *i.e,* Lithology, slope, elevation, rainfall, Land Use Land Cover (LULC), drainage density, distance to road, aspect and profile Curvature (Fig. 3), were combined for susceptibility analysis (Liu *et al.,* 2024). The Cumulative Index (CI) showed 0.012 and the Random Consistency Index showed 1.45 in the AHP calculation. The dependability of the landslide susceptibility map created using the Analytic Hierarchy Process (AHP) was confirmed by the

Table 1: Random index value. Random Consistency Index (R.I)

No. of criteria	1	2	3	4	5	6	7	8	9	10
R.I	0.0	0.0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Source: Saaty (1980).

Table 2: Data layers used for Pairwise comparison matrix, weights and consistency ratio Relative Weightage Values

Factors	Lithology	Slope	Elevation	Rainfall	LULC	Drainage Density	Distance to Road	Aspect	Profile curvature	Weightage
Lithology	1									0.27
Slope	0.50	1								0.21
Elevation	0.40	0.50	1							0.14
Rainfall	0.33	0.40	0.67	1						0.11
LULC	0.29	0.33	0.50	0.67	1					0.08
Drainage Density	0.25	0.29	0.40	0.40	0.67	1				0.07
Distance to Road	0.22	0.25	0.33	0.40	0.50	0.67	1			0.05
Aspect	0.20	0.22	0.29	0.33	0.40	0.50	0.67	1		0.04
Profile Curvature	0.18	0.20	0.25	0.29	0.33	0.33	0.50	0.50	1	0.03

Consistency Ratio (CR) - 0.008

consistency ratio of final calculation, which was determined to be 0.008, far below the acceptable level of 0.10 (Alamrew *et al.,* 2024; Gulbet and Getahun, 2024). (Fig. 4).

This Landslide Susceptibility shows that the area of interest Hunthar Slide falls within Very High- low risk zone. Based on the analysis, very low, low and moderately susceptible occurrences make up 23.33%, 17.04% and 22.43% of the entire Hunthar Locality region according to the analysis results displayed in Table 3. Of the total research area, 21.67% and 15.37% were high and very high susceptible zones. In order to support XRD soil categorization and assess the swell potential of soils, Atterberg limit tests were performed. Validating the XRD-based soil categorisation required making sure that soils classified as swelling or non-swelling showed proper plasticity, or swelling potential (Barbosa *et al.,* 2023). The Atterberg limit test (Fig. 5) shows the results for liquid limit and plastic limit of the soils which were employed to determine the soil's plasticity index, a

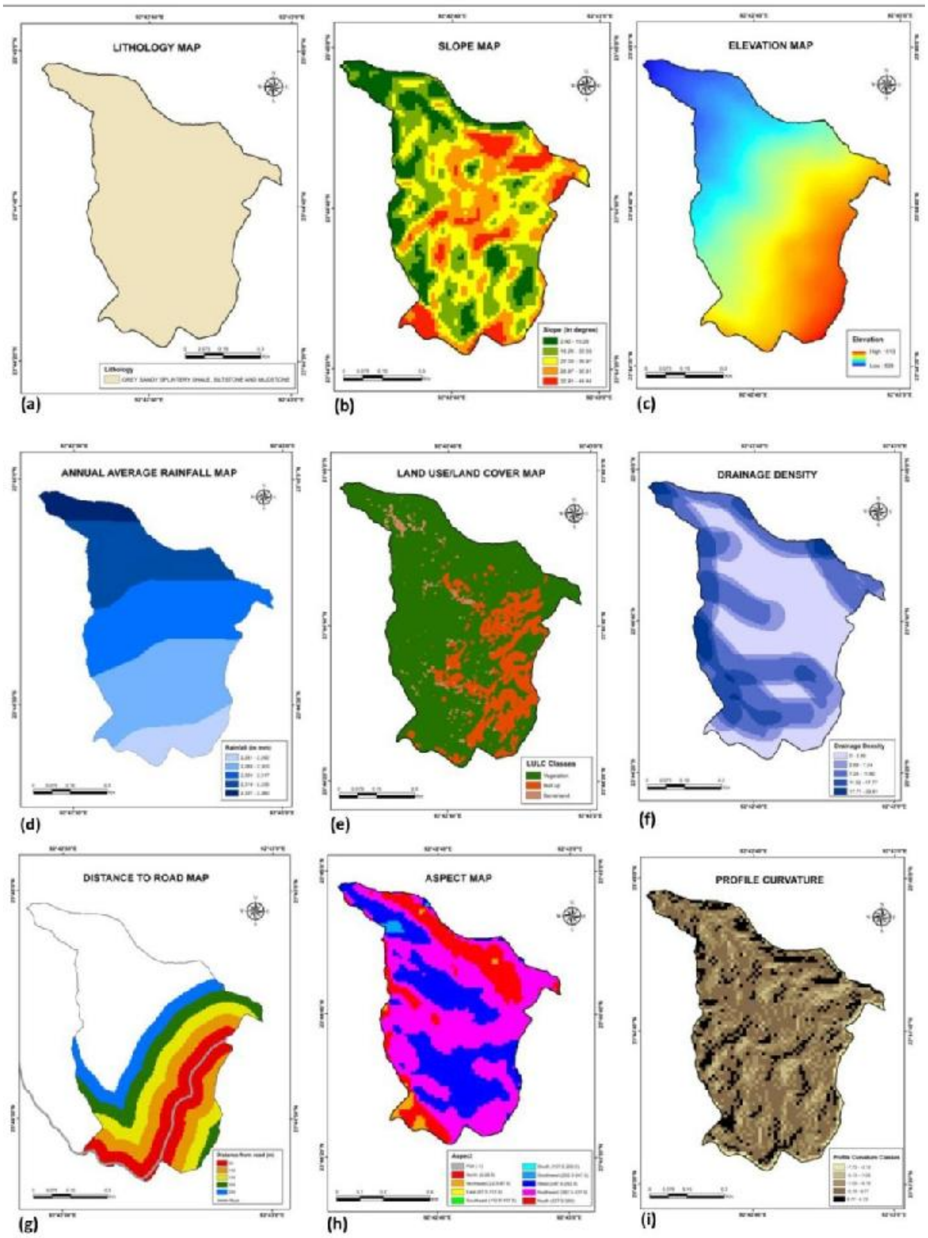

Fig. 3: Triggering factors for landslides (a) Lithology, (b) Slope, (c) Elevation, (d) Rainfall, (e) LULC, (f) Drainage density, (g) Distance to road, (h) Aspect and (i) Profile curvature.

numerical variation between them (Equation 2). Thus, the result of the Plasticity index shows a range from low plasticity to intermediate plasticity of soils.

The categories, range, and percentage of each soil texture are shown Fig. 6 in along with the number of samples in each of the categories. The soil samples of H2 and H-4 were classified as clay of intermediate compressibility – silt of low compressibility, H-1 of Clay of low compressibility – Organic soil of low compressibility and H-3 of CL-ML (dual classification) Low-Plastic Clay to Low-Plastic Silt through plasticity chart (IS: 1498-1970). Accordingly, the Plasticity Index (PI) is recognised as a crucial factor in regulating the soil's ability to retain water and, consequently, its propensity for swelling (Reddy *et al.,* 2020). Casagrande (1948) developed a plasticity chart (Fig. 6) to make comparison different soils posible. The empirical A-line on the plasticity chart distinguishes clay and silty soils, and soils of same geological origin generally follow straight, fairly parallel trends to that line, indicating their constant plasticity behaviour. The volume change will increase as the plasticity index rises. Debris flows are likely to occur when materials are close to liquid limit (Hungr and Picarelli, 2014). The study shows that the sample collected are constitute of finer grains. Through grain size analysis the results showed that the area was having high silt and clay concentration (Table 4) and soil textural classification was done on the basis of sand, silt and clay. The result (Fig. 7) shows that the samples fall within loam in the soil triangular texture classification (Dewangan *et al.,* 2023).

Along with their parent elements, which include quartz, micas, and feldspars, clay mineral groups like kaolinite, smectite, and illite were discovered in the study area. Halloysite and other minerals were also identified. The most common mineral found was quartz; among clay minerals, montmorillonite and illite minerals predominated, and quartz, feldspar and smectite made up the majority of alluvium materials. Quartz, Plagioclase feldspar, illite, and trace amounts of glauconite and Halloysite were the most common clays found in the formations, as determined by the results of X-ray diffractometry study of the clays (Fig. 8). Montemorillonite, a clay mineral noted for its considerable swelling potential due to water absorption between its layers, was present in all of the samples under study. Since the swelling and shrinking behaviour of montmorillonite alters the cohesion and strength of soil, its abundance implies a significant role in slope instability. Similar findings were published by Hossain *et al.* (2025), who emphasised the role of weathered rocks rich in montmorillonite in causing landslides, and Suryadi *et al.* (2024), who emphasized that the expansive nature of montmorillonite in tropical soils increases susceptibility to failure under rainfall conditions. Thus, even though some areas on the landslide susceptibility map are classified as low hazard zones, they contributed to the Hunthar landslide.

As intense rainfall contributes the main factor of landslide within and around Aizawl. Reactivation of paleo-slides are frequently seen during monsoon season, when heavy seasonal rainfall penetrates pre-weakened slip zones, decreasing shear strength and mobilizing slopes. Landslides primarily occur during this time (Ren *et al.,* 2023). The study area is a reactivation of paleo-slide, where these factors contribute to landslide apart from rainfall are its lithology, slope, elevation, land use drainage density, distance to road, aspect and profile curvature. The susceptibility map shows that the upper part of Hunthar landslide extension falls under Very-high to high zone, while the lower portion of the area (bellow NH-54) falls under moderate to low. Despite this, the lower portion of the Hunthar landslide, experiences over saturation of the soil during monsoon that exceed its liquid limit causing toe erosion to the area covered with thick paleo-slide with high silt and clay content soils (Thounaojam and Soibam, 2024).

With highly distorted topography, the lithology of the study area was highly fractured and folded, making it proneness to weathering. This weathered rock of grey, sandy, splintery shale, siltstone and mudstone, which falls on the lower Bhuban formation (Geological Society of India), contributes to clay mineralogy of soils of the study area. The mechanical deformation of slope materials has been greatly influenced by the quantity of smectite (montmorillonite), kaolinite and illite clays as well as their high propensity for absorbing water. Wetting and drying cycles cause these clay minerals to swell and contract, changing the pore-water pressure, decreasing shear strength, and ultimately speeding up slope instability (Hossain *et al.,* 2025). The cause of the landslide impact is also related to the Atterberg limit of soil plasticity index (PI) being close to its liquid limit (Hungr and Picarelli, 2014), indicating that the current slumping and debris flow activity within the Hunthar landslide during monsoon is relevant to these results. However, additional research will be conducted to determine the Angle of Internal Friction (ϕ) and

Table 3: Classes for Areas of Susceptibility map

Susceptibility Classes	Area (ha)	Area (%)
Very Low	12.6	23.33
Low	9.2	17.04
Moderate	12.1	22.43
High	11.7	21.67
Very High	8.3	15.37
Total	54.0	100.00

Table 4: Grain size analysis

Sample	Sieve analysis %			Total percentage
	Sand	Silt	Clay	
H1	47.46	31.05	21.48	100
H2	45.04	30.31	24.65	100
H3	44.00	37.09	18.91	100
H4	44.33	39.00	16.67	100

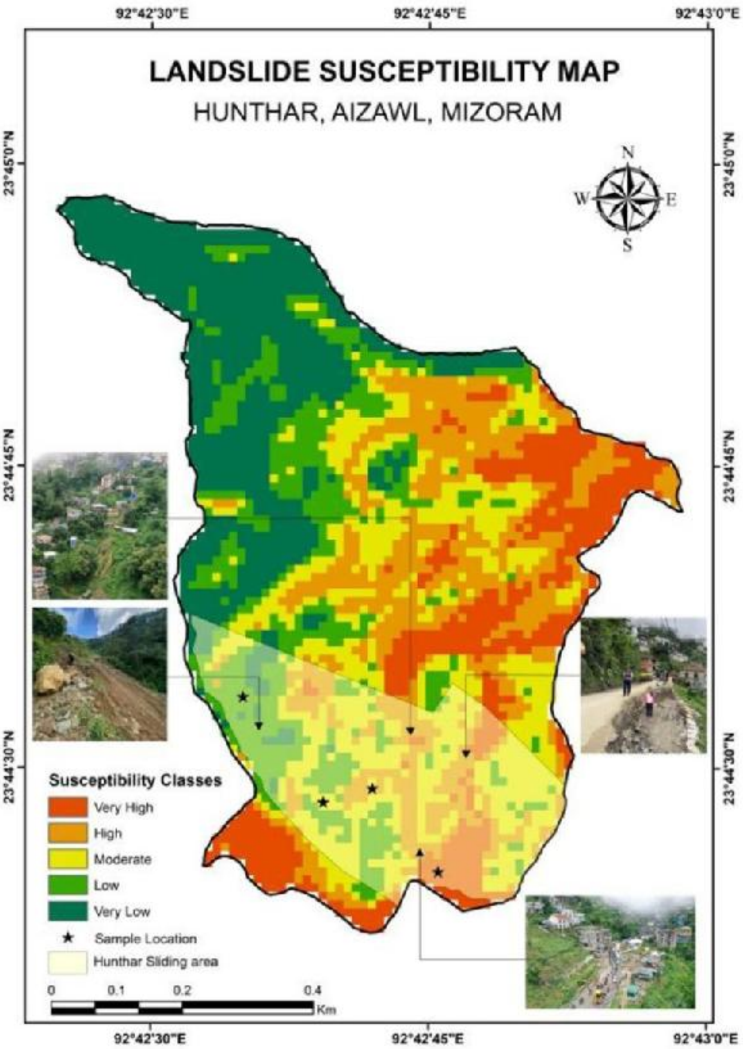

Fig. 4: AHP based Landslide susceptibility map model along with the study area Hunthar sliding area and its effect.

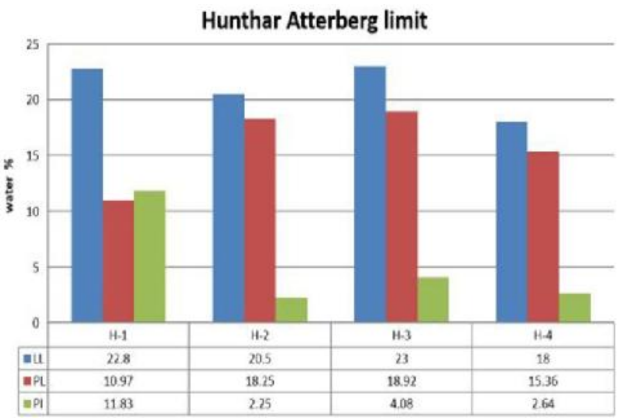

Fig. 5: Atterberg limit results showing Plastic limit, Liquid limit and Plasticity Index.

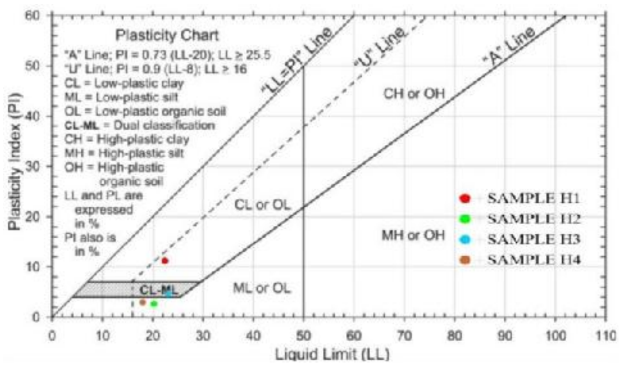

Fig. 6: Distributions of samples on the plasticity chart showing soil samples of H2 and H4 classified as clay of intermediate compressibility – silt of low compressibility, H1 Clay of low compressibilty – Organic soil of low compressibilty and H3 CL-ML (dual classification) Low-Plastic Clay to Low-Plastic Silt through plasticity chart (IS: 1498-1970).

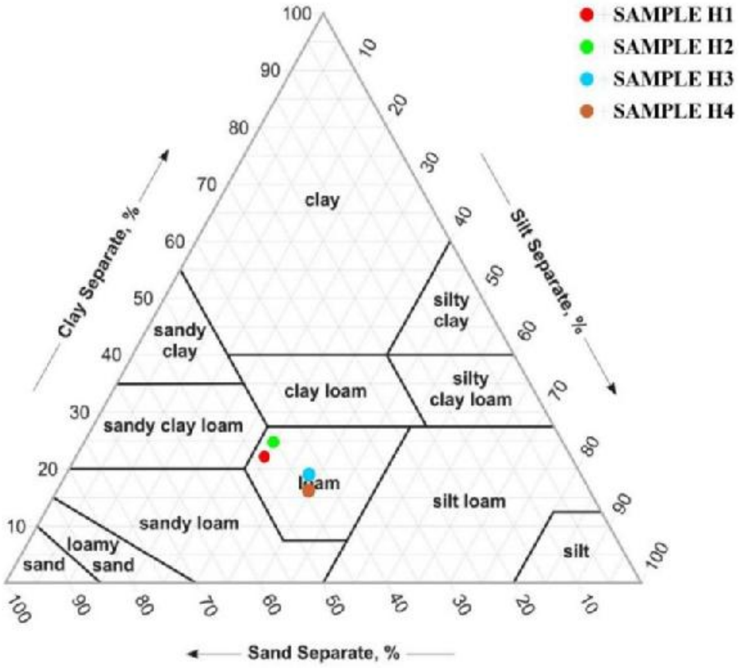

Fig. 7: Soil textural classification triangle from sieve analysis.

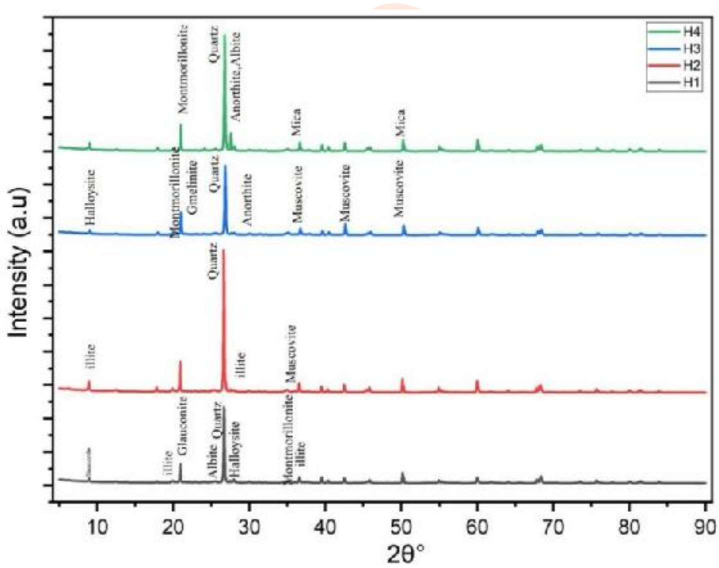

Fig. 8: X-ray diffractogram of the studied samples.

Cohesion © employing direct shear and triaxial. The resultant data will be incorporated to analyse the slope stability and calculation of factor of safety using LEM.

Acknowledgments

The Directorate of Geology and Mining, Government of Mizoram, is duly acknowledged by the first author for providing geotechnical laboratory for the analyses soil samples. The authors express sincere thanks to the Ministry of Tribal Affairs for funding research under the National Fellowship for Schedule Tribes. The authors express gratitude towards the organizers and Dr. K. C Das convener, publication committee of International Conference on Environmental Hazards in Mountainous Regions: Problems and Prospects (ICEHMRPP 2024) for publishing this article in a special issue of JEB.

Authors' contribution: C. Lalthazuala: Field investigation, sample collection, data analysis- geotechnical and GIS, manuscript writing; **J. Malsawma:** Supervision and editing of the manuscript; **C. Zoramthara:** Field investigation, data analysis- geotechnical and GIS, manuscript writing; **C. Lalremruatfela:** Field investigation, assisted in statistical data analysis and interpretation; **P. Lalnuntluanga:** Editing of the manuscript; **L. Kawilam:** Field investigation, data analysis and manuscript writing; **G. Rohmingthangi:** Assisted in statistical data analysis and interpretation; **J. Lalnunmawia:** Editing of the manuscript.

Funding: National Fellowship for Schedule Tribe Students under Ministry of Tribal Affairs. Award No - 201920-NFST-MIZ-03624.

Research content: The research content of manuscript is original and has not been published elsewhere.

Ethical approval: Not applicable.

Conflict of interest: There are no conflicts of interest according to the authors.

Data availability: No information from other sources is used; it is available from the respective author and will be supplied upon request.

Consent to publish: All authors consent to the article being published in the *Journal of Environmental Biology.*

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