

Identification of landslide vulnerable zones in West Khasi District of Meghalaya

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Abstract. A landslide is a mass of rock, debris, or earth moving down a slope. Landslides are a form of mass waste under the direct influence of gravity, indicating any down-slope movement of rock and soil. Landslide encompasses five forms of slope movement: topples, falls, spreads, slides, and flows. Landslides are the large-scale movement of rock, debris, or earth down a slope. The present study was conducted to identify the landslide-vulnerable zones in the West Khasi District of Meghalaya. In total, nine parameters were chosen to assess the vulnerability, such as geology, geomorphology, lithology, elevation, slope, lineament, rainfall, land use and land cover, and soil. These parameters were classified into five groups and ranked between 1 and 5, in which the value 1 indicates highly vulnerable, and the value 5 indicates less vulnerable. Further, the overall weightage for each parameter was computed using AHP. Then, a weighted overlay analysis was carried out in ArcGIS Pro. The result was classified into five classes: very high to very low vulnerable areas. The result showed that a larger area of the district is covered by moderate vulnerability.

1 Introduction

Landslides are common and potentially catastrophic geohazards, complicated geological phenomena that occur in many geospatial environments and geomaterials [1]. Landslides can cause serious casualties and severe property damage [2, 3]. It is necessary to assess and manage areas skeptically that are vulnerable to landslides to mitigate damages [4] and to decrease the damage [5]. Proper preparation helps identify and predict landslide-susceptible areas and decrease landslide damage [6].

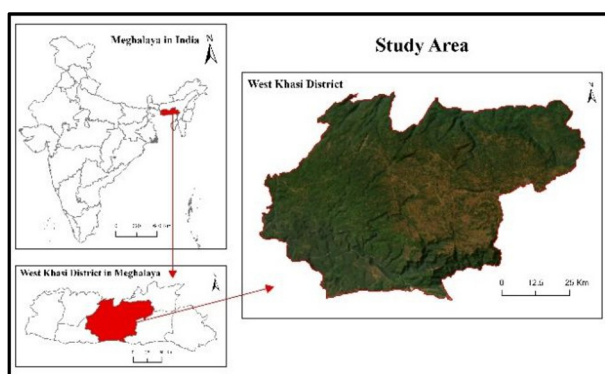


Fig. 1. Study area

West Khasi District is situated in the central part of Meghalaya. It is located between approximately 25 degrees 10' and 25 degrees 51' N latitude and between 90 degrees 44' and 91 degrees 49' E longitude. On the northwest, it shares a border with the Assamese district of Kamrup. On the north-east, with the district of Ri Bhoi; on the east, with the district of East Khasi Hills; on the

south, with Bangladesh and the district of South West Khasi Hills, formerly known as Mawkyrat Civil Subdivision; and on the west, with the districts of East Garo and South Garo Hills, as shown in Fig. 1.

2 Methodology

Several works have been done worldwide for mapping landslide hazard zonation and susceptibility [7], and different techniques or tools have been adopted for determining landslide susceptibility [8, 9]. Different parameters or criteria influence the landslide vulnerability; identifying these parameters is the primary step in the analysis [10]. This study considered nine parameters to assess the vulnerability of landslides, which are i) Geology, ii) Geomorphology, iii) Lithology, iv) Elevation, v) Slope, vi) Lineament, vii) Rainfall, viii) Land Use and Land Cover, and ix) Soil.

The reason for considering these parameters is due to their major influence on the landslides. The chosen parameters were mapped in ArcGIS Pro and classified into different classes further; each class is ranked between 1 and according to the level of vulnerability, such as 1 for very highly vulnerable, 2 for highly vulnerable, 3 for moderate vulnerable, 4 for low vulnerable, and 5 for very low vulnerable.

These parameters were chosen based on their significant impact on the landslides. For example, geology, lithology, and geomorphology impact soil stability. Parameters like slope and elevation influence gravitational triggering landslides. Higher amount of rainfall and denser lineaments increases the possibility of

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landslides. Similarly, changes in land use and land cover by humans or nature will alter the natural drainage system and increase susceptibility.

After the classification, the AHP (Analytical Hierarchical Process), one of the popular methods for calculating weightage [11], was used to compute weightage for each parameter. Further, all the parameters were used in weighted overlay analysis to obtain the result.

3 Discussion

3.1 Geology

Geology data is downloaded from <https://bhukosh.gsi.gov.in/Bhukosh/Public> portal, which is a gateway to all geoscientific data of the Geological Survey of India (Fig. 2). The geological structure of the study area is classified into five classes and ranked between 1 and 5 based on the landslide vulnerability (Table. 1), then ranked raster data was prepared (Fig.3).

Table 1. Rank assigned for geology category

Category	Rank
Garo Gp. (Baghmara/Chengapara Fm.), Miocene - Pliocene	1
Garo Gp. (Simsang Fm.), Eocene - Oligocene	2
Jaintia Gp., Palaeocene - Eocene	2
Khasi Gp. (Mahadek Fm.), Cretaceous	3
Sylhet Traps, Jurassic- Cretaceous	3
Kyrdem, Nongpoh, Myllem Granite., S.Khasi Batholiths & Equivalent Granites, Neoproterozoic - Earl	3
Umsning Schist Belt Gr., Proterozoic	3
Supracrustal, Proterozoic	3
Assam - Meghalaya Gneissic Complex Sgp., Proterozoic	4
Shillong Gp., Palaeoproterozoic - Mesoproterozoic	5

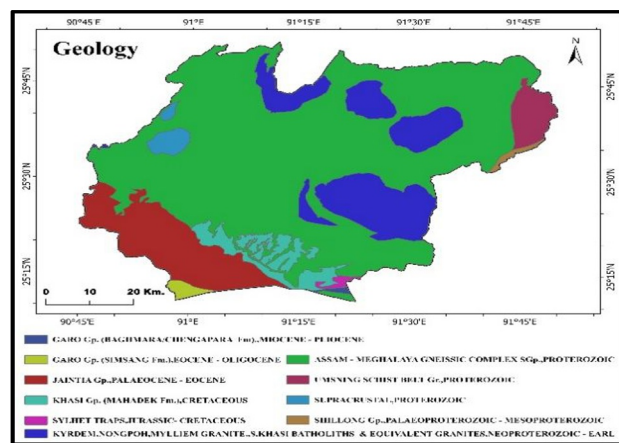


Fig. 2. Geology map of West Khasi district of Meghalaya

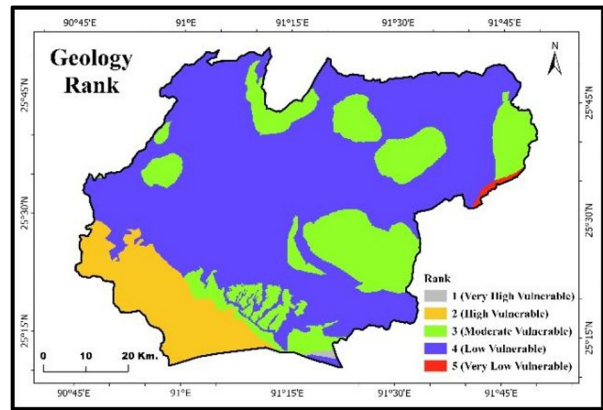


Fig. 3. Classified geology map of West Khasi district of Meghalaya

3.2 Geomorphology

Geomorphology data is downloaded from <https://bhukosh.gsi.gov.in/Bhukosh/Public> portal. The downloaded data was mapped in ArcGIS Pro. It was found that 24 different geomorphological categories were present in the study area (Fig. 4). These 24 types were classified into five categories and ranked between 1 and 5 based on their influence in the landslide (Table 2), then ranked raster data was prepared (Fig. 5).

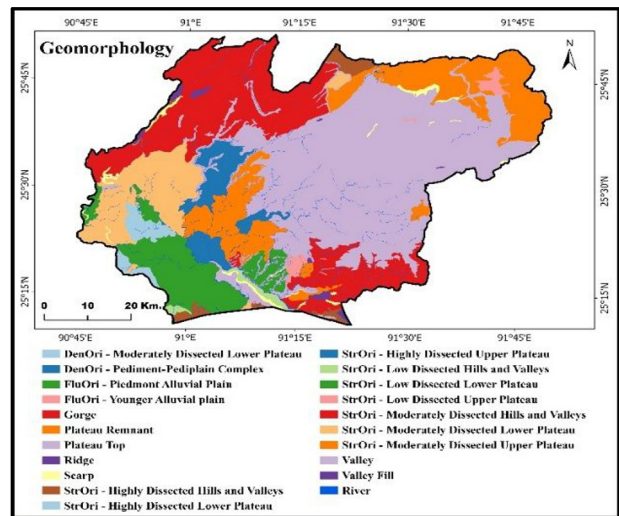


Fig. 4. Geomorphology map of West Khasi district of Meghalaya

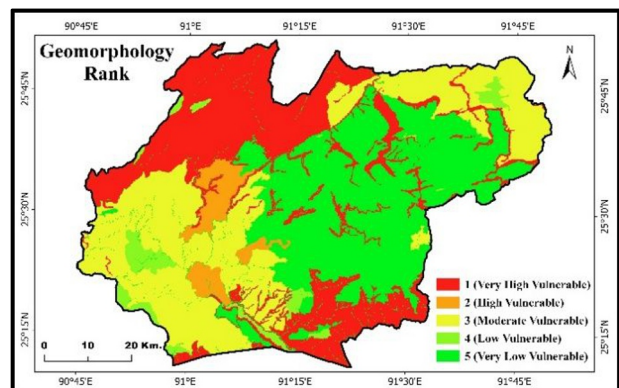


Fig. 5. Classified geomorphology map of West Khasi district of Meghalaya

Table 2. Rank assigned for geomorphology category

Category	Rank
DenOri - Moderately Dissected Lower Plateau	3
DenOri - Pediment-Pediplain Complex	4
FluOri - Piedmont Alluvial Plain	3
FluOri - Younger Alluvial plain	3
Gorge	1
Plateau Remnant	5
Plateau Top	5
Ridge	4
River	5
Scarp	1
StrOri - Highly Dissected Hills and Valleys	1
StrOri - Highly Dissected Lower Plateau	4
StrOri - Highly Dissected Upper Plateau	2
StrOri - Low Dissected Hills and Valleys	4
StrOri - Low Dissected Lower Plateau	3
StrOri - Low Dissected Upper Plateau	4
StrOri - Moderately Dissected Hills and Valleys	1
StrOri - Moderately Dissected Lower Plateau	3
StrOri - Moderately Dissected Upper Plateau	3
Valley	1
Valley Fill	1

Table 3. Rank assigned for lithology category

Category	Rank
Cenozoic (Unclassified)	2
Cretaceous	4
Eocene - Oligocene	2
Holocene	1
Jurassic- Cretaceous	3
Meghalayan	1
Middle - Late Pleistocene	1
Miocene - Pliocene	4
Neoproterozoic - Early Palaeozoic	3
Palaeocene - Eocene	2
Palaeoproterozoic - Mesoproterozoic	5
Pleistocene - Holocene	5
Proterozoic	3

3.3 Lithology

The lithology data was also downloaded from <https://bhukosh.gsi.gov.in/Bhukosh/Public> portal. The downloaded data was mapped, and thirteen types of lithology were found (Fig 6). These thirteen classes were ranked between 1 and 5 based on the influence of landslide (Table 3 and Fig. 7).

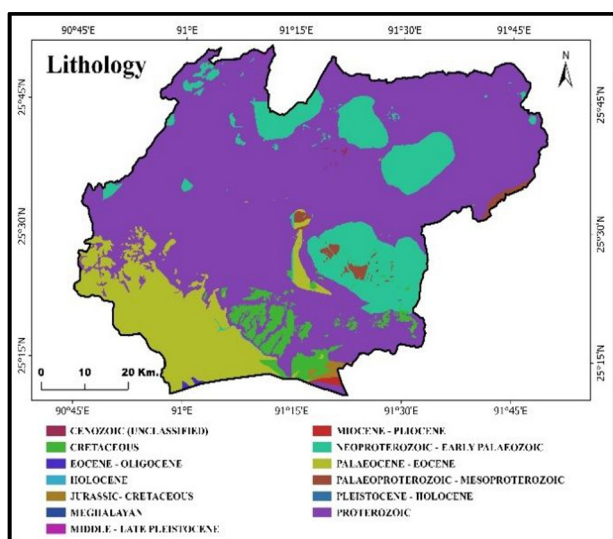


Fig. 6. Lithology map of West Khasi district of Meghalaya

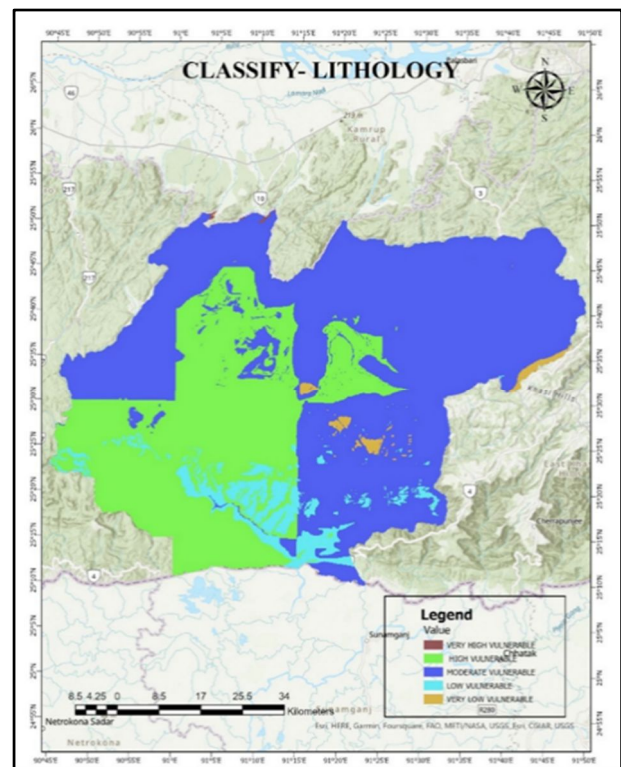


Fig. 7. Classified lithology map of West Khasi district of Meghalaya

3.4 DEM (3D)

The Digital Elevation Model (DEM) of West Khasi District in Meghalaya digitally represents its terrain, providing elevation data in a grid format. It depicts the varying heights and contours of the landscape, aiding in topographic analysis, land planning, and assessing geographical features within the district.

The extracted DEM map is reclassified into five classes. The elevation of the study area rank is given based on the importance from 1 to 5. After giving the rank-based classification, the extracted map is reclassified as a DEM map (Figs. 8 and 9).

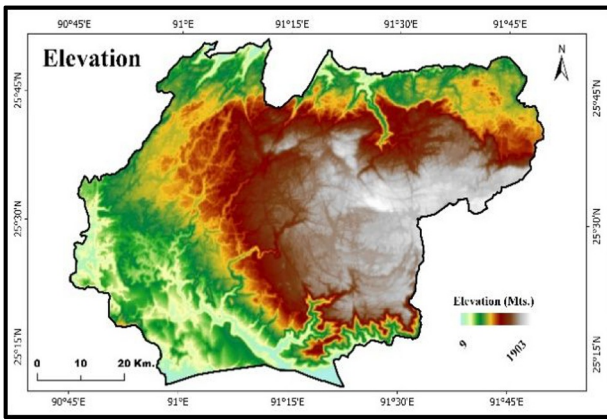


Fig. 8. DEM map of West Khasi district of Meghalaya

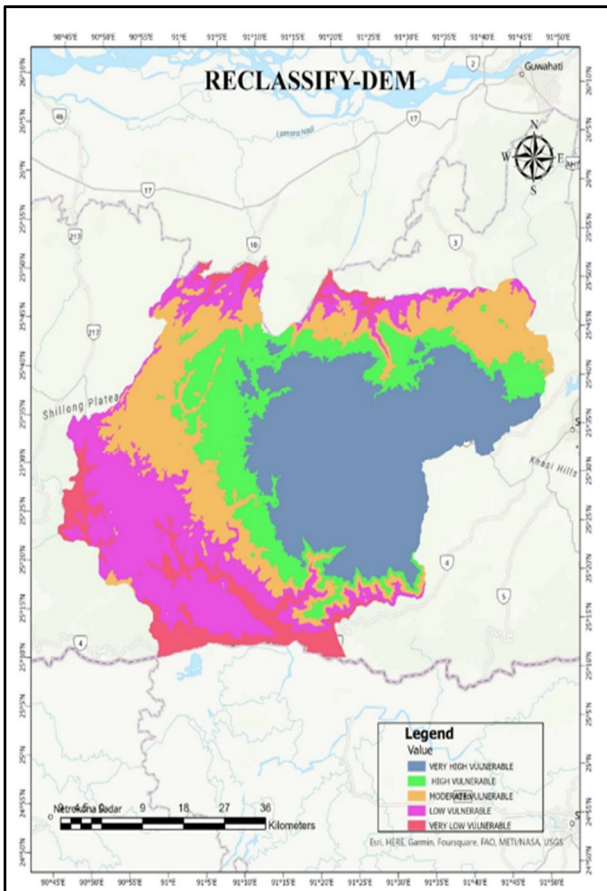


Fig. 9. Re-classified DEM map of West Khasi district of Meghalaya

3.5 Slope

The West Khasi District in Meghalaya features diverse terrain with varying slopes. Its landscape includes steep hills, plateaus, and valleys. Slopes in this region significantly shape the local geography and influence factors such as agriculture, land use, and the potential for landslides.

The extracted Slope map is reclassified into five classes. For the slope of the study area, rank is given based on the importance from 1 to 5. After giving the rank-based classification, the extracted map is reclassified as a Slope map (Figs. 10 and 11).

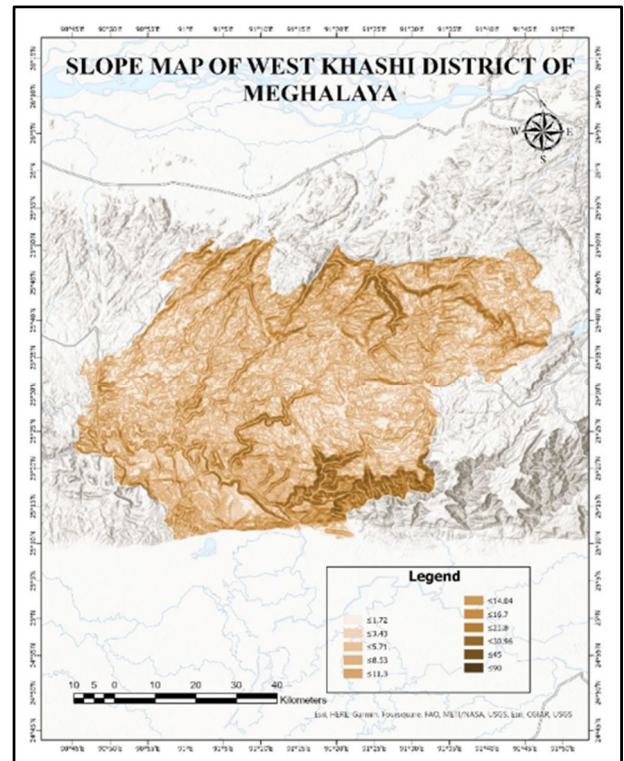


Fig. 10. Slope map of West Khasi district of Meghalaya

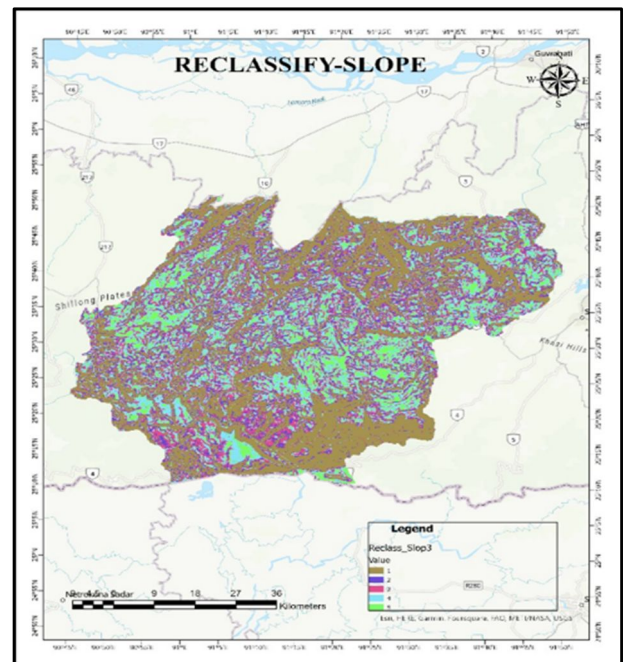


Fig. 11. Re-classified slope map of West Khasi district of Meghalaya

3.6 Lineament

The West Khasi district of Meghalaya exhibits prominent lineaments, linear geological features, or fault lines, often associated with the region's rugged topography. These lineaments are crucial in controlling drainage patterns, groundwater flow, and potential geological hazards like landslides, making them significant for geological and environmental assessments. Here is the Lineament Map of the study area.

The extracted Lineament Map is reclassified into five classes, and the lineament of the study area rank is given based on importance from 1 to 5. After giving the rank-based classification, the extracted map is reclassified as a Lineament map (Table 4, Figs. 12 and 13).

Table 4. Classification of lineament

Lineament	Rank
0-1000	5
1000-2000	4
2000-4000	3
4000-6000	2
6000-13207.667963	1

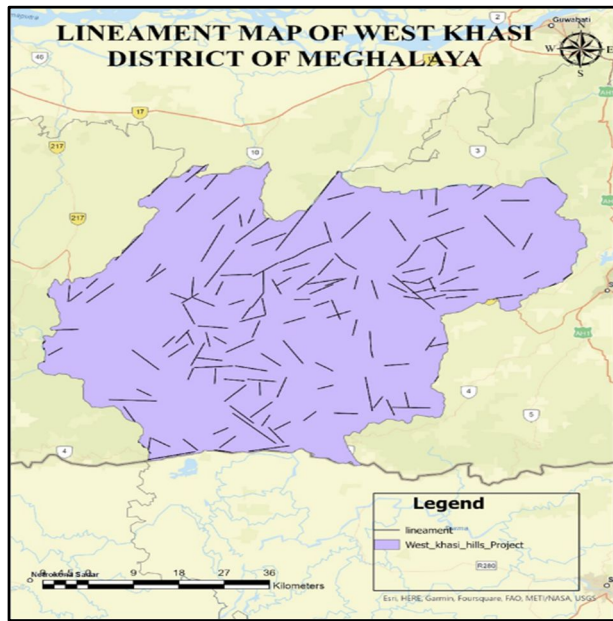


Fig. 12. Lineament map of West Khasi district of Meghalaya

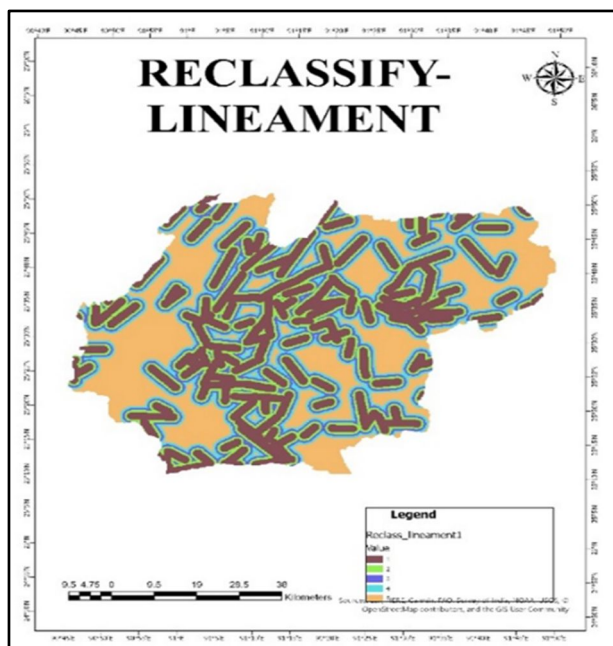


Fig. 13. Re-classified lineament Map of West Khasi district of Meghalaya

3.7 Rainfall

West Khasi District in Meghalaya experiences heavy rainfall, with an annual average of 1,500 mm to 2,500 mm. This high rainfall is primarily due to its location in the northeastern region of India, characterized by a subtropical climate and the influence of the southwest monsoon, leading to lush vegetation and potential landslide risks.

The extracted Rainfall Map is reclassified into five classes; for the rainfall of the study area, the rank is given based on the importance from 1 to 5. After giving the rank-based classes, a reclassified Rainfall map is generated (Table 5 and Fig. 14).

Table 5. Classification of rainfall data

Rainfall in mm	Rank
1069.71-1100	5
1100-1200	4
1200-1300	3
1300-1400	2
1400-2148.57	1

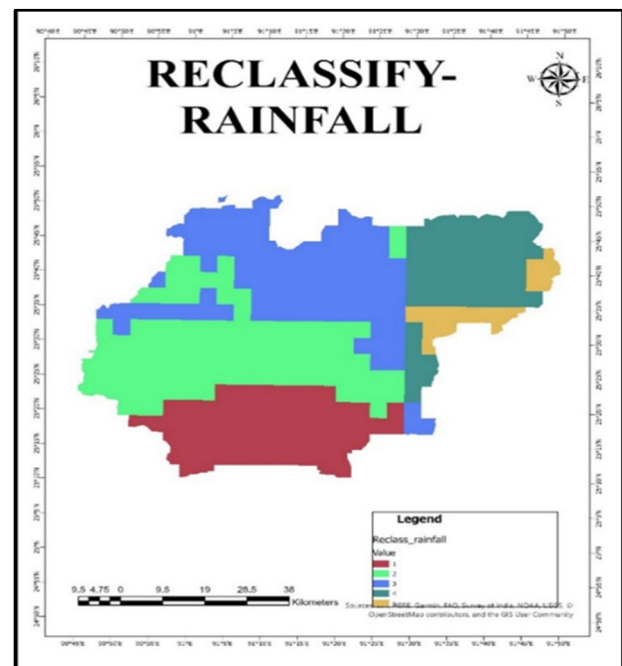


Fig. 14. Re-classified rainfall Map of West Khasi district of Meghalaya

3.8 LULC

In the West Khasi District of Meghalaya, Land Use and Land Cover (LULC) typically consists of a mix of dense forests, agricultural lands, grasslands, and scattered settlements. The region's topography, characterized by steep hills and valleys, influences land use patterns, with forests dominating the landscape and agriculture practiced in terraced fields on slopes.

This LULC Map is reclassified into five classes; for the LULC of the study area, rank is given based on the importance from 1 to 5. After giving the rank-based

classes, a reclassified LULC map is generated, as shown in Fig. 15.

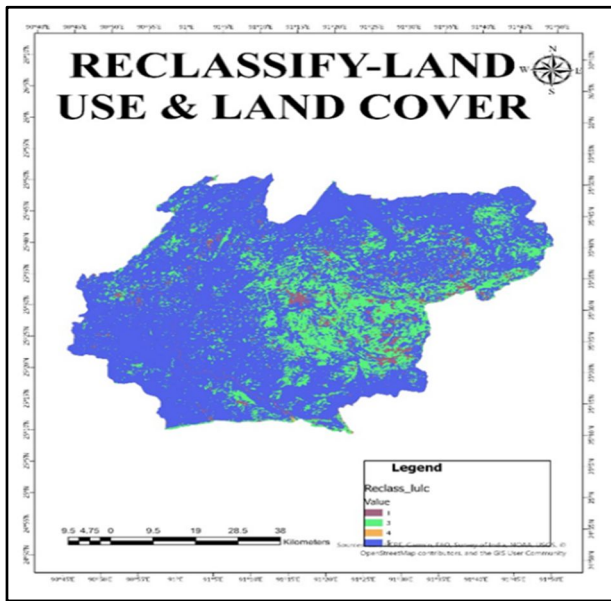


Fig. 15. Re-classified LULC map of West Khasi district of Meghalaya

3.9 Soil

In the West Khasi District of Meghalaya, soil composition primarily consists of red and lateritic soils, often rich in iron and aluminium oxides. These well-drained soils are suitable for agriculture, supporting crops like rice and ginger. However, the hilly terrain can lead to erosion and landslides, requiring proper soil management practices.

This Soil Map is reclassified into five classes. For the Soil of the study area, rank is given based on the importance from 1 to 5. After giving the rank-based classification, the extracted map is reclassified as a Soil map, as shown in Figs. 16 and 17.

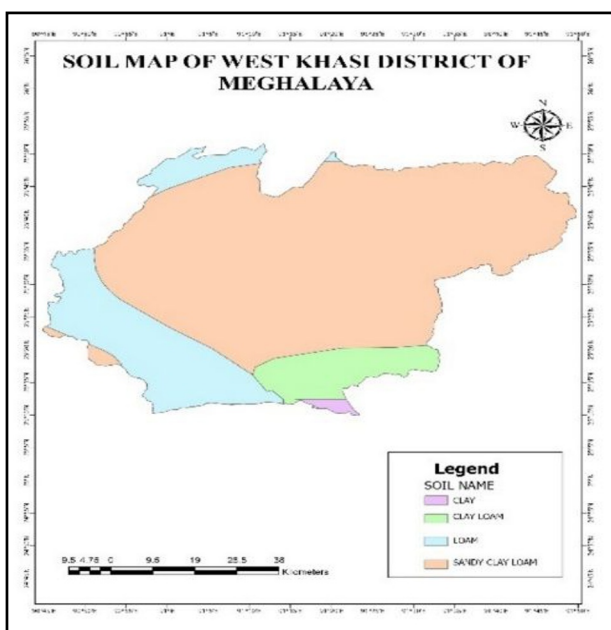


Fig. 16. Soil map of West Khasi district of Meghalaya

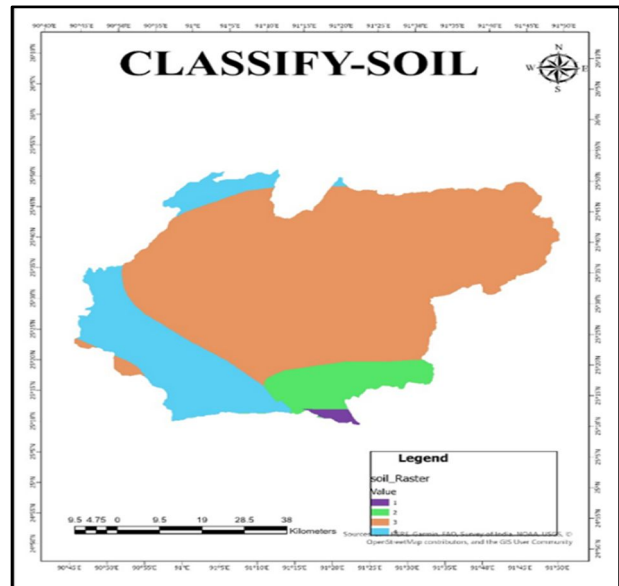


Fig. 17. Classified soil map of West Khasi district of Meghalaya

4 Overlay method

In order to find patterns, links, or areas of interest, the "overlay method" is a geographic information system (GIS) technique that combines and analyses many layers of spatial data, generally in the form of maps or datasets. It entails superimposing thematic layers (such as land use, elevation, vegetation, and population) to create a composite map illustrating where these levels cross or combine. The overlay approach makes it possible to identify spatial linkages, such as the locations where two or more elements overlap or coincide, which aids in making well-informed decisions in areas like resource management, environmental assessment, and urban planning.

For this exercise the resulted parameters are processed by Weighted Overlay Method, the weightage is given based on the AHP (Analytical Hierarchical Process) calculation (Tables 6 and 7).

Table 6. Criteria weight calculation

Criteria	Criteria Weights
DEM	0.17
Slope	0.13
Lineament	0.24
Soil	0.08
Lithology	0.04
Geology	0.03
Geomorphology	0.06
Rainfall	0.08

Table 7. Criteria weight calculation

Criteria	Criteria Weights	Ratio
DEM	0.17	10.64706
Slope	0.13	10.73586
Lineament	0.24	8.958333
Soil	0.08	10.6201
Lithology	0.04	10.32745
Geology	0.03	10.20548
Geomorphology	0.06	9.35274
Rain	0.08	10.375
Lulc	0.13	11.15385
Average Value		9.2375873
Consistency Index		0.0408

5 Result

The result of the weighted overlay analysis revealed values from 1 to 5, in which value one represented highly vulnerable areas and value five represented less vulnerable areas. Accordingly, other values are classified as shown in Fig. 18. It is identified that a small portion of the study area falls under very highly vulnerable, and highly vulnerable areas are located in the central and southern parts of the district surrounded by moderate vulnerability. It is also clear that the areas with steep slopes with a high density of lineaments result in highly vulnerable areas combining other factor's influence. Low and very low vulnerable areas are located in the west and east parts of the district. Overall, the larger area of the district is covered by moderate, followed by low and highly vulnerable, as shown in Fig. 18.

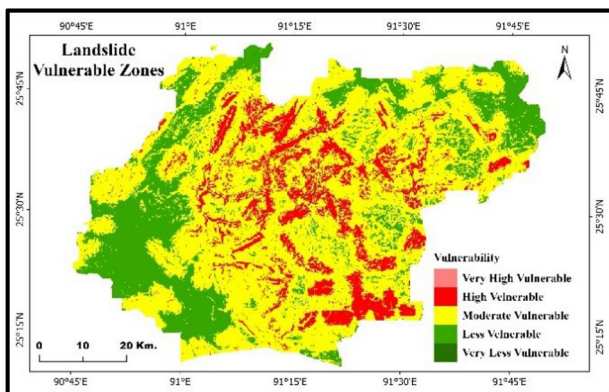


Fig. 18. Result shown in the map after the overlay analysis with 5 classes

6 Conclusion

This study of identifying landslide-prone zones highlights the importance of conducting landslide analysis and familiarizes us with practical techniques such as AHP (Analytical Hierarchy Process) and Weighted Overlay. Such analyses can be extremely useful for government

agencies and the public to assess the likelihood of landslides and develop effective mitigation strategies.

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