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Landslide Susceptibility Zonation of Kolasib District, Mizoram, India Using Remote Sensing And GIS Techniques

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Abstract

Fragile geologic conditions and rugged topography are the main causes of recurring landslide in Mizoram. The present study investigates the Landslide Susceptibility Zones of Kolasib district using Remote Sensing and Geographic Information System (GIS) techniques. Landslide inducing factors within the district were identified and accordingly, five thematic layers viz., slope morphometry, geological structures like faults and lineaments, lithology, relative relief and land use / land cover were generated. These thematic layers were ranked and weighted based on their relative importance in causing landslide. Each class within a thematic layer was assigned an ordinal rating from 1 to 10 as attribute information in the GIS environment. These attribute values were then multiplied by the corresponding rank values to yield the different zones of landslide susceptibility. The ground information on landslide occurences were also considered while classifying the landslide susceptibility zones. The resulting Landslide Susceptibility Zonation map classified the area into five relative susceptibility classes like very high, high, moderate, low, and very low. The final map generated will, therefore, be used by planners and administrators in selecting suitable areas for developments and for implementing appropriate mitigation measures in the landslide prone areas.

Keywords: GIS, Landslide Susceptibility Zonation, Remote Sensing, Kolasib district

Introduction

Landslide is a major natural geologic hazards (Dai et al., 2002) which causes loss of lives, damage to houses, roads and other infrastructures (Sarkar and Kanungo, 2004; Gurugnanam et al., 2012; Sujatha et al., 2012). Rapid increase of man-made stuctures, fast expansion and growth of population in urban areas lead to high vulnerability of human lives and properties. Landslide therefore, become a disaster when it occurs in such human habitations and human settlements which are located on hill slopes are more vulnerable to natural disasters (Chandel et al., 2011; Rawat et al., 2010). Geologically, Mizoram comprises N-S trending ridges with steep slopes, narrow intervening synclinal valleys, dissected ridges with deep gorges, and faulting in many areas has produced steep fault scarps (GSI, 2011).

Several attempts were made to study landslide within the state of Mizoram. These include Geoenvironmental appraisal of Aizawl town and its surroundings (Jaggi, 1988), study of Vaivakawn landslide in Aizawl city with geotechnical laboratory testing of the slide materials (Choubey, 1992), critical study of the causes of South Hlimen landslide in 1992 which claimed the lives of almost 100 people (Tiwari and Kumar, 1997) and Geo-data based Total Estimated Landslide Hazard Zonation in the southern part of the state (Lalnuntluanga 1999). A comprehensive report on Landslide Hazard Zonation of southern part of Mizoram which includes Lunglei, Lawngtlai and Saiha districts (Raju et al., 1999), and Landslide Hazard Zonation Mapping of Serchhip town (Ghosh and Singh, 2001) were also carried out.

Remote Sensing and GIS have wide-range applications in the field of geo-sciences (Jeganathan and Chauniyal, 2002). Therefore, many researchers have utilised these techniques for landslide hazard studies (Vahidnia et al., 2009; Dinachandra Singh et al., 2010). The same techniques had been used to carry out Landslide Hazard Zonation of Uttaranchal and Himachal Pradesh States by National Remote Sensing Agency (NRSA, 2001). Landslide Hazard Zonation of Aizawl city, the state capital of Mizoram using satellite data like IRS LISS III and PAN data had also been done successfully (Lallianthanga and Laltanpuia, 2007).

Remote Sensing and GIS techniques have been proved to be of immense value in landslide hazard zonation, and this had been validated in the study conducted for Aizawl city (MIRSAC, 2007). Similar techniques had also been successfully applied in Landslide Hazard Zonation studies for Serchhip town (Lallianthanga and Lalbiakmawia, 2013), Mamit town (Lallianthanga et al., 2013), Kolasib town (Lallianthanga and Lalbiakmawia, 2013), Saitual town (Lallianthanga and Lalbiakmawia, 2013), entire Aizawl district (Lallianthanga and Lalbiakmawia, 2013) and for Aizawl City (Lallianthanga and Lalbiakmawia, 2013). The present study utilizes IRS(P-6) LISS-III and IRS(P-5) Cartosat-I data to map the different landslide hazard zones of Kolasib district to create database for mitigation measures of landslides, and also to identify suitable areas for future development within the district.

Study Area

Kolasib district is located in the northern part of Mizoram, in north-east India. With a total area of 1382.00 sq km., the district is located between 92o 31′ 55" to 92o 54′ 08" E longitudes and 23o 51′ 17" to 24o 31′ 14" N latitudes. It falls under Survey of India topo sheet No. 83D/11, 83D/12, 83D/14, 83D/15, 83D/16, 84A/9 and 84A/13. Location map of the study area is shown in Fig. 1. The climate of the study area ranges from moist tropical to moist sub-tropical. The entire district is under the direct influence of south west monsoon, with average annual rainfall of 2819.90 mm (MIRSAC 2012).

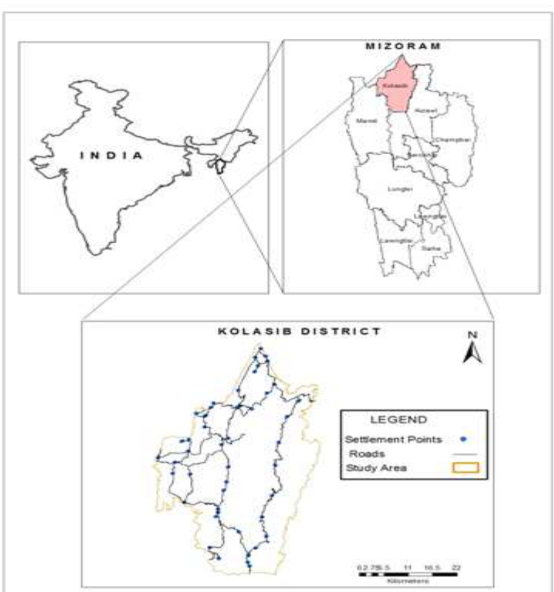

Figure 1: Location map of study area district

Materials and Methods

Data used

Indian Remote Sensing Satellite (IRS-P6) LISS III data having spatial resolution of 23.5m and Cartosat-I stereo-paired data having spatial resolution of 2.5m were used as the main data. SOI topographical maps and various ancillary data were also referred in the study.

Thematic layers

For the preparation of landslide susceptibility map, a detailed knowledge of the processes which influence the landslide activities in an area is required (Dutta and Sarma, 2013). There are several geo-environmental factors which are known to induce landslide (Bijukchhen *et al.*, 2009). Selection and preparation of these factors as thematic data layers are highly crucial for landslide susceptibility mapping (Sarkar and Kanungo, 2004). Integration of multi-sources of information is a major goal to attain more reasonable results in the assessment of many environmental issues (Archana and Kausik, 2013). The present study utilised five thematic layers for Landslide Susceptibility Zonation which were prepared from satellite data and field work. The different layers are as follows-

Land use / Land cover

Land use / land cover pattern is one of the most important parameters governing slope stability as it controls the rate of weathering and erosion (Anbalagan *et al.*, 2008). The study area was divided into four classes, viz., Dense Vegetation, Sparse Vegetation, Scrubland and Built-up areas. Built-up areas were more prone to landslide than all the other classes (Pandey *et al.*, 2008) and were given high weightage, while Dense vegetation class was assigned low weightage value as the areas covered by dense vegetation were considered less prone to the occurrence of landslides (Mohammad Onargh *et al.*, 2012). The different land use / land cover classes in the study area are shown in Table 1 and Figure 2.

Table 1: Land use/land cover type and area covered

Land use Class	Area (Sq.Km)	Percentage
Dense Vegetation	254.56	18.42
Sparse	999.25	72.30
Scrubland	106.91	7.74
Built up	12.26	0.89
Water body	9.02	0.65
Total	**1382.00**	**100.00**

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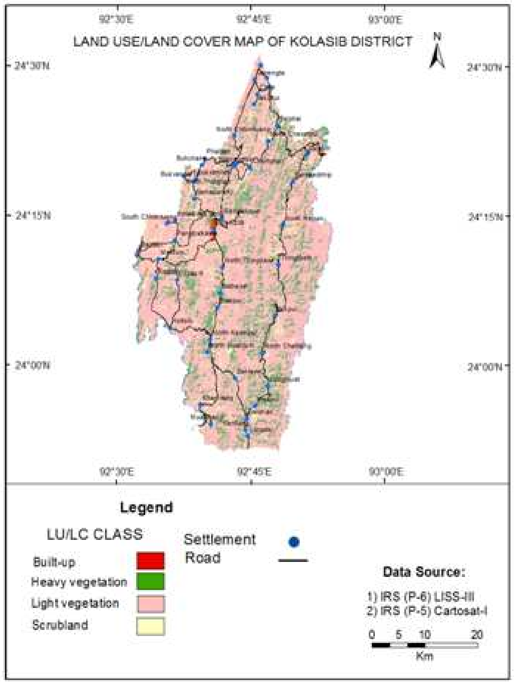

Figure 2: LU/LC map of Kolasib district

Slope

Landslides are more prevalent in the steep slope areas than in moderate and gentle slope areas (Sharma *et al.*, 2011; Das *et al.*, 2011). This is due to the fact that the shear stress in soil or other unconsolidated material increases as the slope angle increases. Therefore, slope is one of the most important parameter for stability consideration (Lee *et al.*, 2004; Nithya and Prasanna, 2010). Slope map was generated from Digital Elevation Model (DEM) which is prepared utilising the Cartosat-I stereo-paired data in a GIS environment. The slopes of the area are represented in terms of degrees, and are divided into eight slope classes, viz., 0-15, 15-25, 25-30, 30-35, 35-40, 40-45, 45-60 and above 60 degrees. Weightage values are assigned in accordance with the steepness of the slope. Slope classes and area covered are given in Table 2, and the slope map is shown in Figure 3.

Table 2: Slope classes and area covered

Degree of Slope	**Area (Sq.Km.)**	**Percentage**
0-15	263.39	16.43
15-25	4.54	0.33
25-30	81.27	5.88
30-35	182.53	13.21
35-40	509.05	36.83
40-45	251.12	18.17
45-60	76.20	5.51
>60	13.90	1.01
Total	**1382.00**	**100**

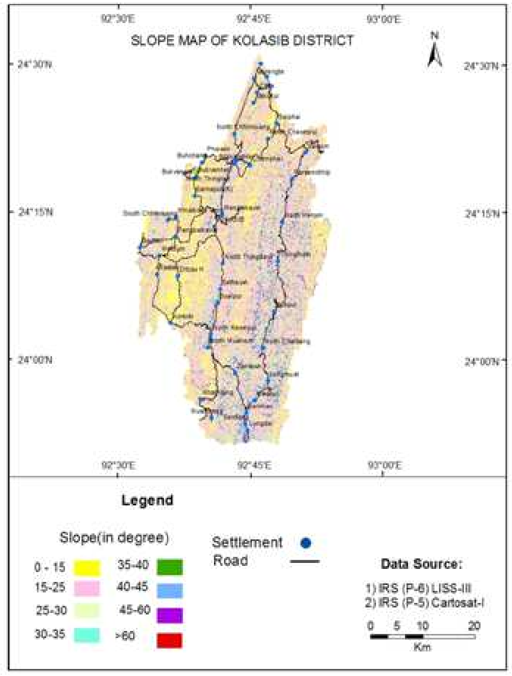

Figure 3: Slope map of Kolasib

Relative Relief

Relative relief plays a crucial role in the vulnerability of settlements, transport network and land. Hence, it is an important factor in landslide susceptibility zonation (Chandel et al., 2011). The study area possesses high relative or local relief and was divided into High, Moderate and Low classes with elevation ranging from more than 1000m, 500-1000m and less than 500m from msl respectively. High elevated areas are more susceptible to landslide than areas with lower elevation (Lee et al., 2004) and following this pattern, weightage values were given to each of the relative relief classes. The area coverage of different relative relief classes is given in Table 3 and relative relief map of the study area is shown in Fig. 4.

Table 3: Relative relief classes and area covered

Relative Relief Classes	**Area (Sq.Km)**	**Percentage**
High	10.78	0.78
Medium	229.67	16.62
Low	1141.55	82.60
Total	**1382.00**	**100.00**

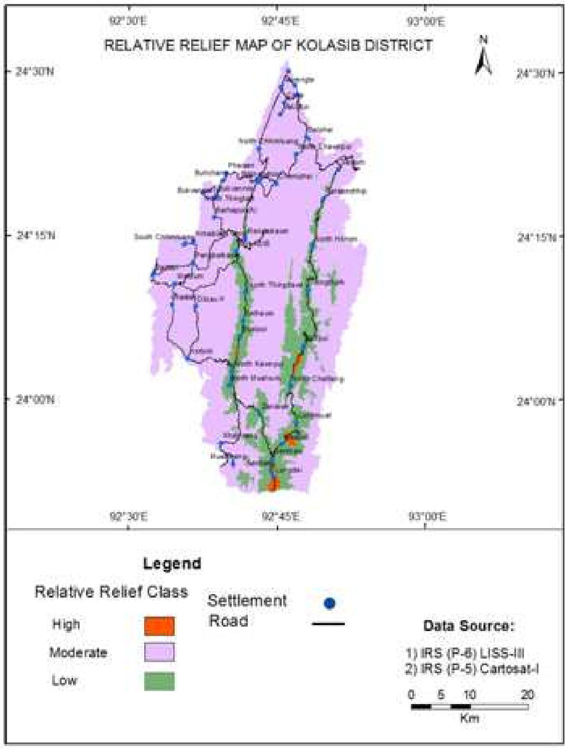

Figure 4: Relative relief map of Kolasib District

Lithology

Lithology is one of the major parameters for landslide hazard zonation (Sharma et al., 2011). The geology of Mizoram consists of great flysch facies of rocks comprising monotonous sequences of shale and sandstone (La Touche, 1891). The study area lies over Middle Bhuban, Upper Bhuban and Bokabil formations of Surma Group of Tertiary age (GSI, 2011). Middle Bhuban and Bokabil formations consist mainly of argillaceous rocks while Upper Bhuban formation compirses mainly of arenaceous rocks. Four litho-units have been established for the study area purely based on the exposed rock types. These are named as Sandstone unit, Shale-siltstone unit, Clayey unit and Gravel, sand & silt unit. Soft rock units comprising of shale and siltstone erode faster and are easily weathered (Anbalagan et al., 2008), and are therefore considered more susceptible to landslide than the hard and compact sandstone units. In accordance with this, weightage values are assigned for analysis. The different lithological units and area covered is given in Table 4 and the geological map showing the lithology of the area is given in Figure 5.

Geological Structure

Remote sensing data can be utilised to delineate and analyse the geological structures like faults, fractures, joints, etc. (Kanungo *et al.*, 1995). These geological structures are among the most important parameters for Landslide Hazard Zonation (Saha *et al.*, 2002). It was observed that the rocks exposed within the study area were traversed by several faults and fractures of varying magnitude and length (MIRSAC, 2006). Areas located within the vicinity of faults zones and other geological structures are considered more vulnerable to landslides. For analysis, areas with 50 m on both sides of all the lineaments including faults were buffered. The geological map of the study area is given in Fig. 5.

Table 4: Lithological units and area covered

Rock Types	**Area (Sq. Km)**	**Percentage**
Sandstone	267.00	19.32
Shale & Siltstone	1077.84	77.99
Clayey Sand	22.40	1.62
Gravel, Sand & Silt	14.75	1.07
Grand Total	**1382.00**	**100.00**

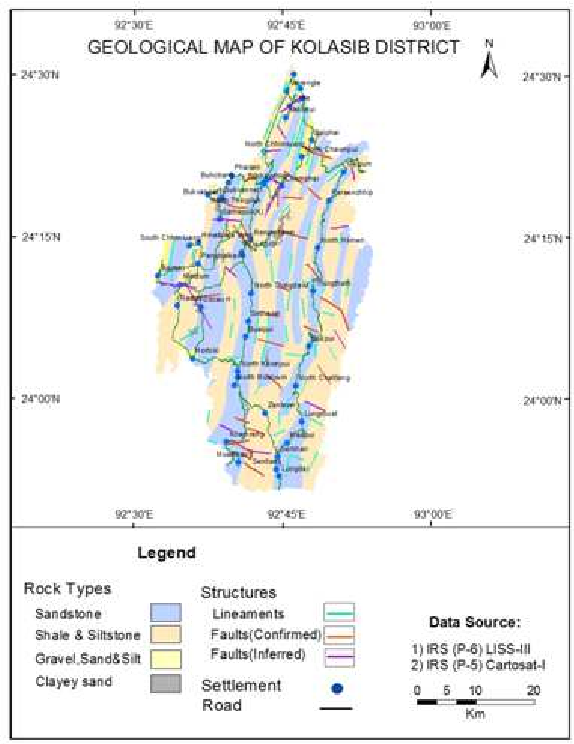

Figure 5: Geological map of Kolasib district

Data Analysis

The geo-environmental factors like slope morphometry, land use/land cover, relative relief, lithology and geological structure are found to be playing significant roles in causing landslides in the study area. These five themes form the major parameters for landslide susceptibility zonation and are individually divided into appropriate classes. Individual classes in each parameter are carefully analysed so as to establish their relation to landslide susceptibility. Weightage value is assigned for each class based on their susceptibility to landslide in such a manner that less weightage represents the least influence towards landslide occurrence, and more weightage, the highest. The assignment of weightage value for the different categories within a parameter is done in accordance to their assumed or expected importance in inducing landslide based on the apriori knowledge of the experts. In addition, ground information regarding landslide occurences within the study area were also considered. All the thematic layers were integrated and analysed in a GIS environment using ARCINFO (9.3 version) to derive a Landslide Susceptibility Zonation map. The scheme of giving weightages by National Remote Sensing Agency (NRSA, 2001) and stability rating as devised by Joyce and Evans (Joyce and Evans1976) were adopted in the study as shown in Table 5.

Table 5: Ratings for Parameters on a scale of 1-10

Parameter	Rank (%)	Category	Weight
Lithology	25	Sandstone	4
		Shale & Siltstone	8
		Clayey Sand	6
		Gravel, Sand &	5
Land Use / Land Cover	15	Dense Vegetation	3
		Sparse Vegetation	5
		Scrubland	6
		Built-up	8
		Barren land	5
Slope in degrees	35	0 - 15	1
		15-25	3
		25-30	4
		30-35	5
		35-40	6
		40-45	7
		45-60	8
		>60	5
Structure: Faults and Lineament	15	Distance Buffered	8
Relative relief	10	High	5
		Medium	4
		Low	3

Results and Discussion

Combining all the controlling parameters by giving different weightage value for all the themes, the final Landslide Susceptibility Zonation map is prepared and categorised into 'Very High', 'High', 'Moderate', 'Low' and 'Very Low' susceptible zones. The output map is generated on a scale of 1: 50,000. Various susceptible classes are described below:

Very High Susceptibility Zone

This zone is highly unstable and is at a constant threat from landslides. The area forms steep slopes with loose and unconsolidated materials, and include areas where evidence of active or past landslips were observed (Plate 1). Besides, it also includes those areas which are located near faults and tectonically weak zones. This zone is manifested on the surface by subsidence of the land as noticed in some parts of the district. It further includes areas where road cutting and other human activities are actively undertaken (Plate 2). Therefore, the Very High Susceptibility Zone is found pre-dominantly in settlement areas. This zone constitutes an area of about 44.06 sq. km and forms 3.19% of the total study area. Since the Very High Susceptibility Zone is considered highly prone to landslides, it is recommended that no human induced activity be undertaken in this zone. Such areas have to be entirely avoided for settlement or other developmental purposes.

Plate 1 : Massive landslide near Serkhan village, Kolasib district, causing disruption of transport network.

Plate 2 : Road cutting without considering slope stability causes rock fall near Kolasib town, Kolasib distict.

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High Susceptibility Zone

It mainly includes areas where the probability of sliding debris is at a high risk. It covers an area of steep slopes which when disturbed are prone to landslides. Most of the pre-existing landslides fall within this category. Besides, this zone comprises areas where the dip of the rocks and slope of the area, which are usually very steep, [about 45 degrees or more] are in the same direction. This rendered them susceptible to slide along the slope. Several lineaments, fractured zones and fault planes also traverse the high susceptible zone. Areas which experience constant erosion by streams because of the soft nature of the lithology and loose overlying burden, fall under this class. The High Susceptibility Zone is well distributed over the entire study area. It is commonly found to surround the Very High Susceptibility Zone as seen in many of the villages and Kolasib town. This zone occupies 161.35sq. km which is 11.68% of the total area. The High Susceptibility Zone is also geologically unstable, and slope failure of any kind may be triggered particularly after heavy rain. As such, allocation and execution of major housing structures and other projects within this zone should be discouraged. Afforestation scheme should be implemented in this zone.

Moderate Susceptibility Zone

This zone comprises the areas that have moderately dense vegetation, moderate slope angle and relatively compact and hard rocks. It is generally considered stable, as long as its present status is maintained. Although this zone may include areas that have steep slopes, the orientation of the rock bed and absence of overlying loose debris and human activity make them less hazardous. The Moderate Susceptibility Zone is well distributed within the study area. Several parts of the human settlement also come under this zone. It may be noted that as seismic activity and continuous heavy rainfall can reduce the slope stability. It is recomended not to disturb the natural drainage, and at the same time, slope modification should be avoided as far as possible. Further, future land use activity has to be properly planned so as to maintain its present status. This zone covers 669.42 km. which is 48.44% of the total study area.

Low Susceptibility Zone

This zone includes areas where the combination of various controlling parameters is generally unlikely to adversely influence the slope stability. Vegetation is relatively dense, the slope angles are generally low, about 30 degrees or below. Large part of this zone prominantly lies over hard and compact rock type. This zone is mainly confined to areas where anthropogenic activities are less or absent. No evidence of instability is observed within this zone, and mass movement is not expected unless major site changes occur. Therefore, this zone is suitable for carrying out developmental schemes. It spreads over an area of about 395.70sq. km. and occupies 28.63% of the total study area.

Very Low Susceptibility Zone

This zone generally includes valley fill and other flat lands where the slope angles of the rocks are fairly low. As such, it is assumed to be free from present and future landslide hazard. Although the lithology may comprises of soft rocks and overlying soil debris in some areas, the chance of slope failure is minimized by low slope angle. This zone extends over an area of about 105.84sq. km. and forms 7.66% of the total area.

The area coverage of the landslide susceptibility zones are given in Table 6 and the Landslide Susceptibility Zonation map is shown in Fig. 6.

Table 6: Landslide susceptibility zones with area occupied

LSZ Code	Susceptibility Class	Area (Sq.km)	Percent
1	Very High	44.06	3.19
2	High	161.35	11.68
3	Moderate	669.42	48.44
4	Low	395.70	28.63
5	Very Low	105.84	7.66
Other			
1	Water body	5.63	0.41
TOTAL		**1382.00**	**100.00**

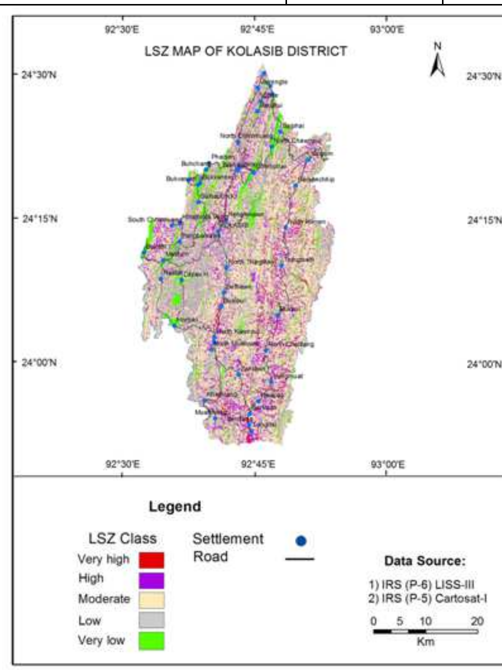

Figure 6: Landslide susceptibility zonation map

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of Kolasib district

Conclusion

The present study has proven that terrain factors like land use/ land cover, lithology, slope, geological structure and relative relief are directly associated with the occurrence of landslides. The study further indicates that landslide occurrences are mostly confined in the inhabited areas. This shows that proper planning with landslide mitigation measures is required for expansion of settlement and construction of road communications.

Landslide Susceptibility Zonation map prepared through the present study, therefore, forms an important database for developmental activities, and also for identifying critical areas for implementing suitable mitigation measures.

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