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An Integrated Approach of Statistical, Remote Sensing and GIS techniques for Evaluation of Vulnerable Cut Slopes

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Abstract: Road networks play a vital role in the socio-economic growth throughout the world. Over population in developing countries, such as India, cause destabilisation of hill slopes and movement of mass wasting. Stability of slopes is in hilly terrain is substantial for for proper planning, development, and maintenance of hilly roads. The present study contributes in mitigation processes, through slope stability and qualitative estimation of rock mass classification systems, in between Mettupalayam and Coonoor Ghat sections, Nilgiri District, Tamil Nadu, India. The Coonoor Ghat section (NH-67) plays a significant role in transportation which connects Nilgiri with Karnataka and Kerala. The geo-mechanical classifications of Rock Mass Rating (RMR) and Slope Mass Rating (SMR) provide information about both rock quality and discontinuity associated with the type of the potential failure in each slope. Based on RMR, most of the locations R-2 to R-5 and R-7 to R-8 represent fair rock type (Class II) those of SMR exhibits unstable to stable slopes (Class II to IV). It is clear that RMR values provide better results than SMR values. More attention should be given to the maintenance of these unstable slopes to provide more safety.

Keywords: RMR and SMR Classifications, Slope stability analysis, Slope failure

1 Introduction

Landslides are one of the natural hazards which cause serious damage to life and property. Every year, they cause the death of more than 500 persons and the loss of more than 4 billion $. Compared to other countries, Asian countries, especially the south ones, are strongly affected by them. One of the above-mentioned countries is India where approximately 15% of its area exposes to landslides which cause the death of 500 persons and the loss of more than 300 crores per year. They cover up to 22 states and including 2 union territories. They are highly vulnerable to Himalayan belt, Nilgiri, Eastern Ghats and Western Ghats. Urbanization in the Rock section areas has increased stability-related issues because the environmental factors, i.e. the geological; geomorphological and structural factors, were not taken into account.

Landslide Hazard Zonation atlas of India were, prepared by Building Materials and Technology Promotion Council (BMTPC), as well as the Government of India, identified various Indian areas prone to landslide. Nilgiri District in Tamil Nadu is highly prone to landslide in India [1]. Hence, it is necessary to evaluate the potential zones as well as types of failure in the rocky slopes to assess landslide hazard properly.

Several empirical rocks mass rating techniques are utilized to identify the potential zones and evaluate type of failure in the rocky slopes. The Rock Mass Rating (RMR) and Slope Mass Rating (SMR) have been used to obtain rapidly evaluate slope stability conditions. The hill slopes between Mettupalayam and Coonoor Ghat section is the dynamic phenomenon on the slopes, rainfall and anthropogenic activities which have recently increased. Major and minor landslides are reported in the different places of the ghat sections [2]. Proper investigation of the slope phases should be conducted to improve construction and reduce the slope failure. This present pioneering systematic study comprises of evaluation of rock mass

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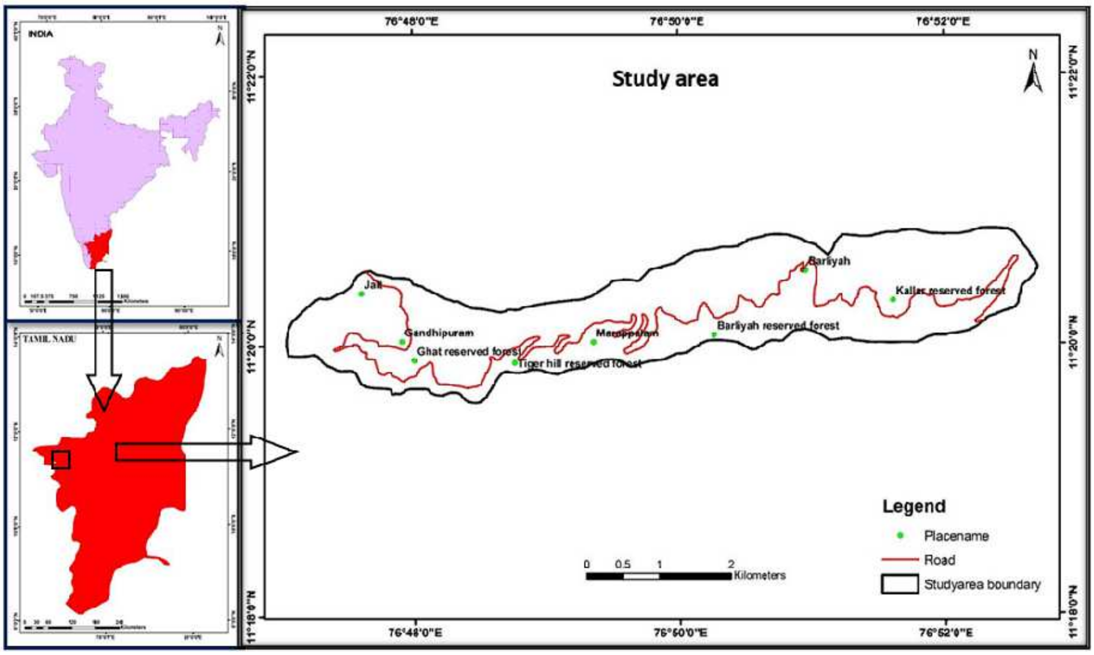

Fig. 1: Location map of the study area

and assessment of stability slopes to identify susceptible zones through field investigation, remote sensing and GIS techniques.

2 Study Area

The study area (Fig. 1) is situated in the eastern part of Nilgiri District, located in the western part of Tamil Nadu. The present study area, Mettupalaym to Coonoor Ghat section (NH-181) is coming under the Coonoor Block and falling in the middle of Coimbatore–Pykara National Highways. It covers 35 km and the entire catchment area is taken into account to evaluate the natural condition and type of failure in the area. It lies between latitudes 11°18′ 00″ N and 11°22′ 00″ N and longitudes of 76°47′ 00″ E and 76°53′ 00″ E and approximately covers 12.38 Km^2. It is included in the survey of India toposheets (1:25000) 58 A/15 SE and 58 A/15 SW.

From the mean sea level, relative relief of the study area gradually increases from 327 m. to 2091 m. from south-east to north-west direction. The area is also called as “Kallar Ghat Section” which follows the valley of Kallar and Coonoor River. It receives an average rainfall of 1435.73 mm during Southwest Monsoon and 2934.07 mm during Northeast Monsoon. The average annual rainfall recorded in the study area is 2184.90 mm. Rainfall pattern is seasonal and extensively expected in the months from October to December.

3 Methodology

In India, several researches are carried out using the quantitative, statistical, and geotechnical methods as well as artificial neural network algorithm to evaluate the Landslide Hazard Zonation (LHZ) [3–6]. Several empirical rock mass rating techniques are utilized to identify the potential zones and to evaluate type of failure in the rocky slopes. The Rock Mass Rating (RMR) and Slope Mass Rating (SMR) have been used to rapidly evaluate the slope stability of the terrain. Bieniawski introduced and developed Rock Mass Rating (RMR) [7]. Later in India, this method was adopted in the various parts of Mountain terrains [8–14]. The RMR classification has become a standard method to evaluate any rock mass in tunnels. Many researchers illustrated different relationships between slope and RMR values [15–17]. However, later Romana [18] proposed an approach to RMR concepts and is mostly suitable for all types of rocky slopes. Five parameters are adopted to evaluate the RMR: (a) strength of intact rock, (b) Rock Quality Designation (RQD), (c) spacing between discontinuities, (d) orientation of discontinuities and (e) groundwater condition.

3.1 Rock Mass Rating & Slope Mass Rating Techniques

In between Mettupalayam and Coonoor Ghat section, (8) major vulnerable rock slopes (R-1 to R-8) were identified

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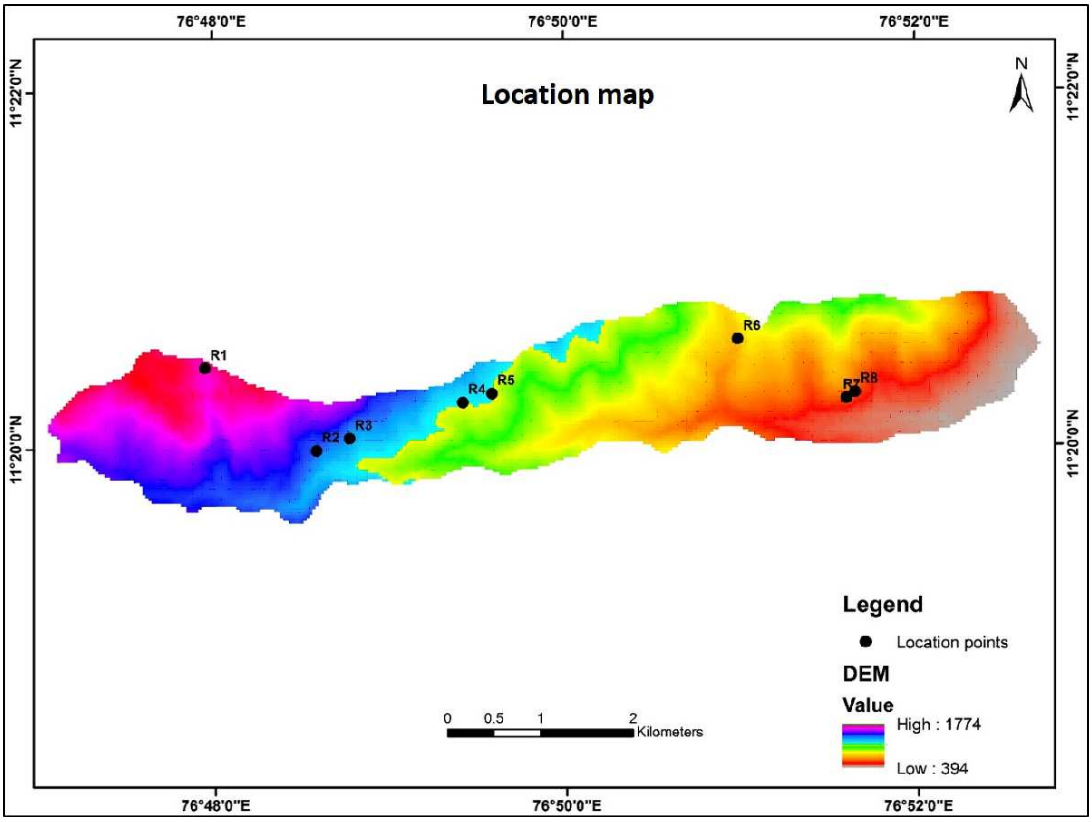

Fig. 2: SRTM elevation data illustrating the vulnerable cut slopes in the study area

and taken into account for further geo-mechanical classification of RMR and SMR studies to evaluate nature of slope and type of failures (Fig. 2 & Table. 1). Site investigation, including slope angle, slope height, cut slope angle, cut slope height, volumetric joints, spacing and orientation between discontinuities and ground water conditions [19]. Rock samples were collected to be examined in the laboratory and identify point load index that helps evaluate the intact strength of rock. RMR classification from the potential zones the proper investigation of the site and the laboratory results provides an average condition for each and every parameter which is plotted against after Bieniawski RMR chart. Parallel to Rock Mass Rating (RMR), Slope Mass Rating (SMR) parameters, such as slope–dip amount and dip direction, joint–dip amount and direction, thickness of soil cover, height of slope, cut slope angle and characteristics of materials were also collected in the field.

The present study is an integrated statistical approach (Geomechanical–RMR & SMR classification), Remote Sensing and GIS to evaluate the vulnerable cut slopes. t serves as a future scope for the management and planning of land as well as risk mitigation.

3.1.1 Intact Strength of Rock Mass

In general, rock mass strength is depending upon the strength of the rock and discontinuities in the rock mass. It also depends upon the volume of rock under consideration. To define intact strength of rock mass, samples were collected from each rock section taken into measurement of point load test. Before testing of samples, a care was taken for measurement of length and width of the rock specimen. According to BIS 8764: 1988, the minimum thickness of specimen should be 5 cm, mean compressive strength of the rock specimen, was calculated (Eq. (2)) and the results were shown. Minimum width of the rock specimen (W) was calculated in perpendicular to the direction of load applied from Eq. (1).

$$W = \frac{W_1 + W_2 + W_3}{3} \tag{1}$$

Point load values were calculated for lump specimen was adopted as per IS 8764:1998. Mean depth (D) in cm, Mean Width (W) in cm and Peak load failure (P) in kg.f. were calculated for each specimen and point load failure was calculated from the (2) and presented in Fig. 3(a).

$$I_L = \frac{P}{(DW)^{0.75}\sqrt{D}} \tag{2}$$

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Table 1: Location of vulnerable rock slopes

Rock slopes	Location	Discontinuous direction and dip amount	Slope direction and slope amount	Land mark
R-1	N 11°20′27″ E 76°47′51″	N–320 / 80 N–120 / 50 N–175 / 65	N–50/40 Cut slope height 4 m	Near to Coonoor town Near to railway line
R-2	N 11°19′59″ E 76°48′35″	N–220 / 65 N–150 / 70 N–065 / 60	N–160/25 Cut slope height 5 m	400 m away from 13/14 hair pin bend
R-3	N 11°20′05″ E 76°49′00″	N–220 / 55 N–120 / 70 N–175 / 85	N–160/42 Cut slope height 80 m	Marapalam village, exactly 12/14 hair pin bend
R-4	N 11°20′15″ E 76°49′25″	N–285 / 60 N–165 / 85 N–120 / 60	N–170/25 Cut slope height 10 m	Near to 8/14 hair pin bend
R-5	N 11°20′18″ E 76°49′35″	N–245 / 60 N–185 / 80 N–085 / 60	N–170/25 Cut slope height 10 m	4/14 hair pin bend, rock fall board is placed
R-6	N 11°20′36″ E 76°50′59″	N–050 / 75 N–110 / 30 N–295 / 65	N–143/45 Cut slope height 5 m	After Buraliyar drainage system, near to 2/14 hair pin bend
R-7	N 11°20′16″ E 76°51′36″	N–230 / 65 N–195 / 70 N–075 /40	N–143/50 Cut slope height 15 m	Kallar reserve forest area, near to culvert
R-8	N 11°20′18″ E 76°51′39″	N–210 / 45 N–165 / 65 N–190 / 85	N–180/25 Cut slope height 5 m	Kallar reserve forest area, near to R-7 location

3.1.2 Rock Quality Designation (RQD)

Rock Quality Designation provides a quantitative estimation in the rock mass through visible discontinuity on rock surfaces estimated by volumetric joints (joints per cubic metre) for all joint sets [20]. RQD of the rock mass can be calculated as per (3) from the volumetric joints. Results were tabulated and represented in Fig. 3(b).

$$RQD = 115 - 3.3J_v \tag{3}$$

3.1.3 Spacing of Discontinuity

Discontinuity spacing is an important parameter for RMR classification. The average discontinuity spacing of each joint set was measured through the distance between adjacent discontinuities. The average discontinuity spacing of each individual joint set was measured and the rating can be defined with respect to RMR classification and tabulated and as illustrated in Fig. 3(c).

3.1.4 Condition of Discontinuity

Discontinuity condition is measured for each Rock section such as length, aperture, roughness, and infilling. Weathering conditions in the field were investigated and the rating can be defined according to RMR classification and tabulated as illustrated in Fig. 3(d).

3.1.5 Groundwater Condition

Groundwater condition in the field was measured in the form of nature of condition (dry, damp, wet, dripping, flowing) and tabulated. Different groundwater conditions are observed in each Rock section and rating can be recorded according to the nature of surface condition and RMR classification illustrated in Fig. 3(e).

3.1.6 Orientation of Discontinuities

Discontinuities direction refers to the dip amount with respect to horizontal plane, dip direction of discontinuities in the slope face, slope direction, cut slope amount, cut lope direction, direction of road, with respect to north direction using Brunton Compass. These parameters are beneficial to slope stability analysis of Rock sections.

3.1.7 Remote Sensing and GIS

The fundamental database is derived from Survey of India (SOI) toposheets (1:25000 scale), aerial photographs, and IRS LISS–III satellite imagery. In the meantime, extensive field work is carried out in the entire study area to identify various aspects, such as landslide locations, slope characteristics, geometrical analysis of each individual landslides and thickness of soil cover. The entire spatial database constructed by using GIS

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Table 2: Rock Mass Rating (RMR) of all geo-mechanical parameters for the different cut slopes

Rock slope	Location	Mean Point load values (M. Pa)	Rating	RQD (%)	Rating	Spacing of Discon-tinuities (mm)	Rating	Discontinuity length, aperture, roughness, infilling, weathering	Rating	Ground water condition	Rating	Total RMR
R-1	N 11°20′27″ E 76°47′51″	7.90	12	72.1	13	150	8	15 m, 6 mm, smooth, soft filling, < 5 mm, moderately weathered	7	wet	7	47
R-2	N 11°19′59″ E 76°48′35″	11.97	15	91.9	20	450	10	20 m, 1 mm, rough, none, slightly weathered	21	wet	7	73
R-3	N 11°20′05″ E 76°49′00″	17.80	15	95.2	20	800	15	> 20 m, 1 mm, rough, none, slightly weathered	20	flowing	0	70
R-4	N 11°20′15″ E 76°49′25″	12.85	15	75.4	17	450	10	15 m, 5 mm, smooth, soft filling, < 5 mm, moderately weathered	8	dripping	4	54
R-5	N 11°20′18″ E 76°49′35″	8.71	12	65.4	13	250	10	18 m, > 5 mm, smooth, soft filling, < 5 mm, highly weathered	5	wet	7	47
R-6	N 11°20′36″ E 76°50′59″	7.72	12	52.3	13	100	8	15 m, > 5 mm, smooth, soft filling, < 5 mm/ highly weathered	5	dripping	4	42
R-7	N 11°20′16″ E 76°51′36″	7.87	12	68.8	13	350	10	18 m, 2 mm, slightly rough, hard filling, < 5 mm/ moderately weathered	12	wet	7	54
R-8	N 11°20′18″ E 76°51′39″	13.84	15	75.4	17	225	10	> 20 m, 2 mm, smooth, soft filling, < 5 mm, slightly weathered	5	wet	7	54

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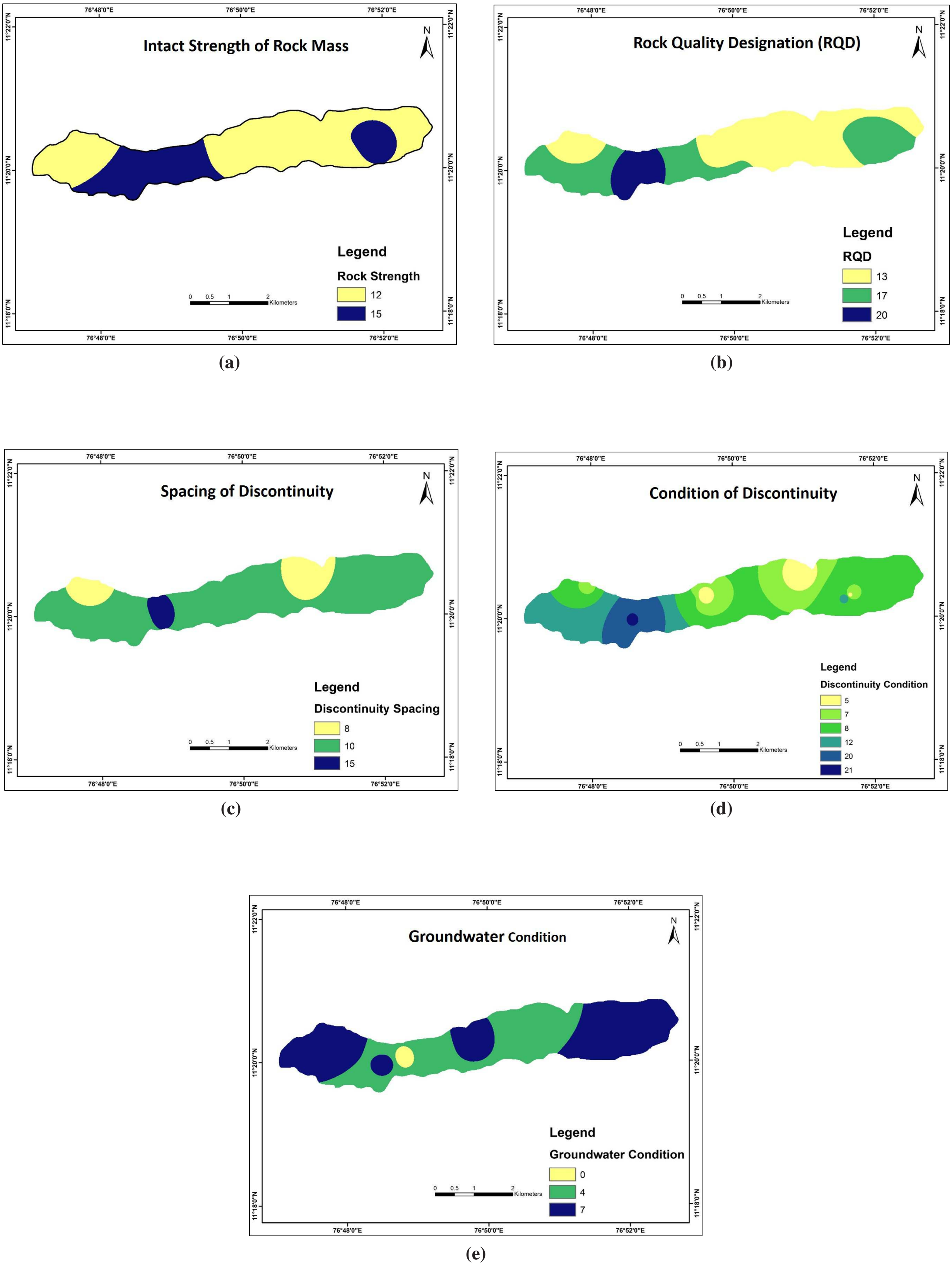

Fig. 3: Spatial distribution of geo-mechanical parameters from various vulnerable cut slopes

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Table 3: Estimated RMR for different rock slopes

Rock Slope	Rock type	RMR Value	Description	Class	Cohesion of Rock mass (K. Pa)	Friction angle of rock mass(°)
R-1	Charnockite	47	Fair Rock	III	235	28.5
R-2	Charnockite	73	Good Rock	II	365	41.5
R-3	Charnockite	70	Good Rock	II	350	40
R-4	Charnockite	54	Fair Rock	III	270	32
R-5	Charnockite	47	Fair Rock	III	235	28.5
R-6	Charnockite	42	Fair Rock	III	210	26
R-7	Charnockite	54	Fair Rock	III	270	32
R-8	Charnockite	54	Fair Rock	III	270	32

Table 4: Estimated SMR for different rock slopes

Rock Slope	Critical sections	SMR values	Class No	Description	Stability	Probable type of failure	Support
R-1	J_1 & J_2	38	IV	Bad	Unstable	Planar / Big wedges	Important corrective measures
R-2	J_1 & J_3	59	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-2	J_2	73	II	Good	Stable	Blocks	Occasional supports
R-3	J_1 & J_2	46	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-4	J_1 & J_3	52.65	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-4	J_2	54	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-5	J_1 & J_3	41.75	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-5	J_2	47	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-6	J_1 & J_2	25.2	IV	Bad	Unstable	Planar / Big wedges	Important corrective measures
R-7	J_1 & J_2	54	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-7	J_2	54	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-8	J_1 & J_2	54	III	Normal	Partially stable	Planar / many wedges	Systematic supports
R-8	J_3	54	III	Normal	Partially stable	Planar / many wedges	Systematic supports

techniques (IDW interpolation method), where different layer maps are prepared by using nature of failure (Discontinuities nature, condition and ground water condition), slope nature (Discontinuity and slope direction and dip).

3.2 Slope Mass Rating (SMR)

The Slope Mass Rating (SMR) is a system of classification developed by Romana and utilized by many researchers in India for stability analysis [21–23]. The extension of Factorial adjustments is depending upon the joint–slope relationship and adding additional factor depending upon the methods of excavation. The factorial adjustments for SMR rating for the joints are the product of three parameters such as (i) F_1-depends on the parallelism between joints and strike of the slope face (ii) F_2- refers to joint dip angle in the planar mode of failure (iii) F_3- refers to the relationship between slope and dip of the joints and (iv) F_4-is the adjustment factor the method of excavation has been fixed empirically. In general F1, F2 and F3 can be calculated from the following equations (Eqs. (4)–(6))

$$F_1 = \frac{16}{25} - \frac{3}{500}\arctan\left[\frac{1}{10}(IAI - 17)\right] \tag{4}$$

$$F_2 = \frac{9}{16} + \frac{1}{195}\arctan\left[\frac{17}{100}(B-5)\right] \tag{5}$$

$$F_3 = -30 + \frac{1}{3}\arctan C \tag{6}$$

$$SMR = RMR + (F_1 \times F_2 \times F_3) + F_4 \tag{7}$$

The total slope mass classification through different adjustment ratings and various stability classes were derived from these parameters, such as rock mass rating values and different factorial adjustment values (F_1, F_2, F_3 and F_4) which were plotted against standard Slope mass Rating classification and tabulated.

3.3 Slope Stability Analysis

Slope stability analyses were conducted in (8) major vulnerable rock slopes through the strereonet plotting for the orientation of unfavourable discontinuities to evaluate the potential mode of rock failure, such as Planar, Wedge, Toppling. Planar failure occurs when discontinuity dips in the same direction with an angle less than 20°towards the slope face and dip angle should be less than slope angle and greater than friction angle along the failure plane. Wedge shape of failure may be possible when the line of intersection of the two discontinuities should be in the same slope face forming wedge shaped block plunge and the plunge angle should be less than the slope angle and

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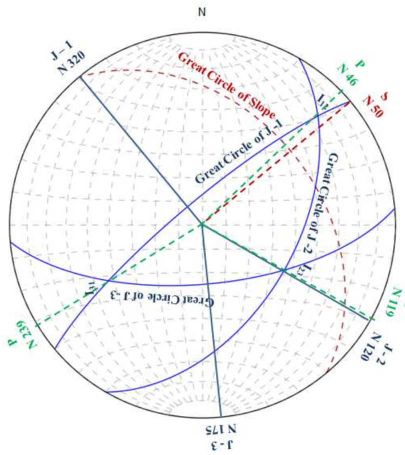
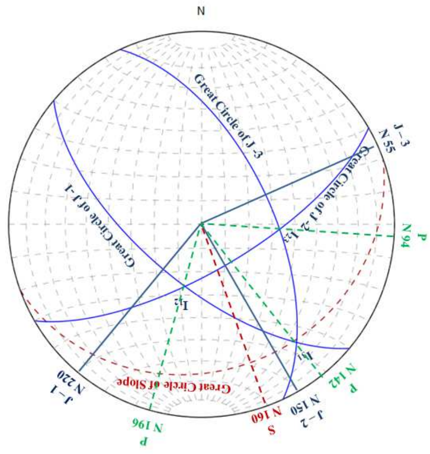
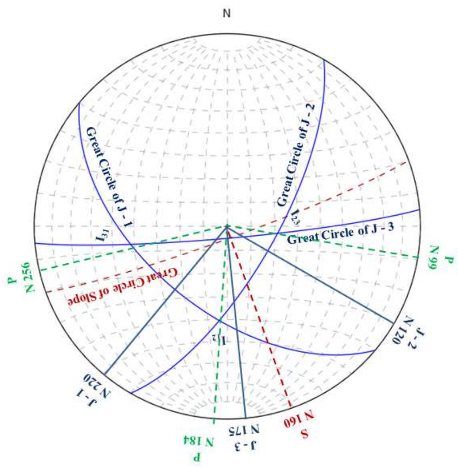


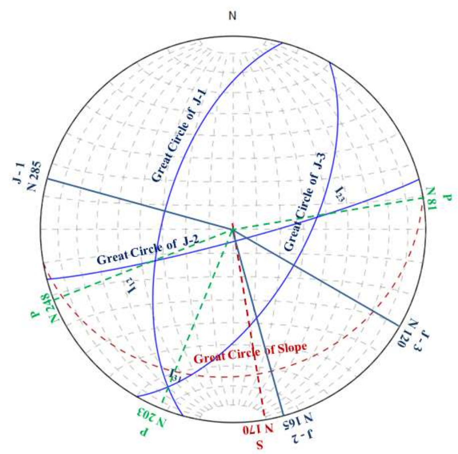
(a) R-1



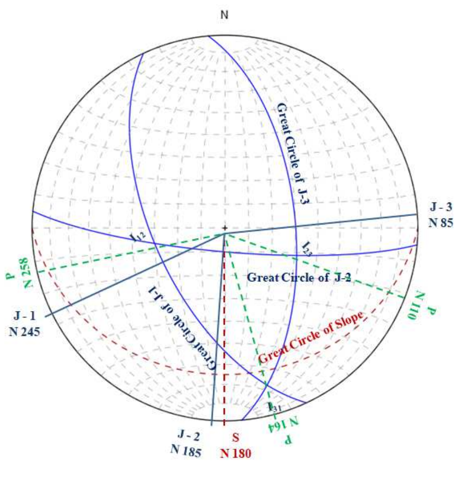
(b) R-2



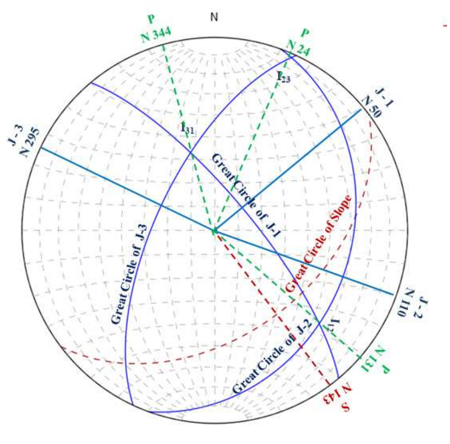
(c) R-3



(d) R-4



(e) R-5



(f) R-6

Fig. 4: Continued . . .

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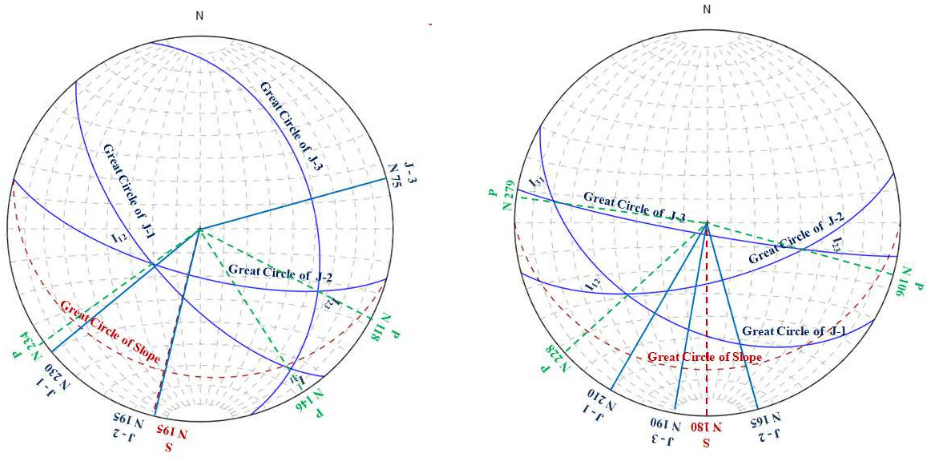

(g) R-7 (h) R-8

Fig. 4: (a)–(h): Kinematic analysis of the vulnerable cut slopes of R-1 to R-8

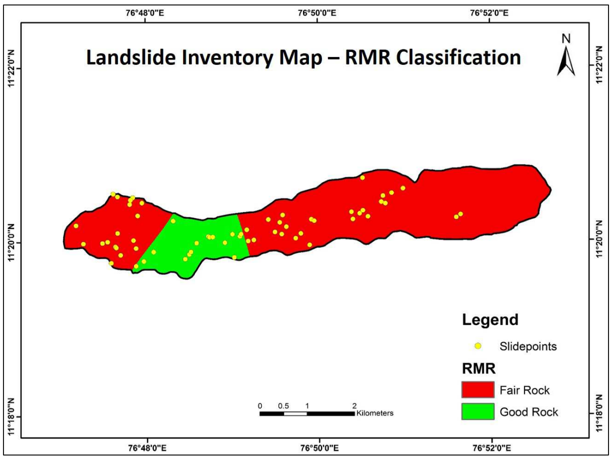

Fig. 5: Inventory map of the landslide locations with RMR value

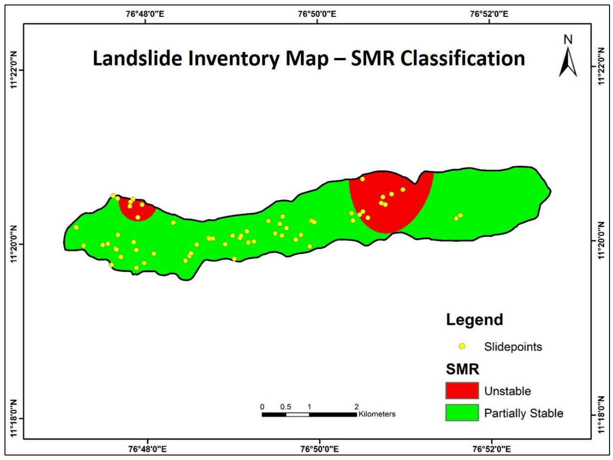

Fig. 6: Inventory map of the landslide locations with SMR values

more than the friction angle along the failure plane. Toppling may occur when the discontinuity dips in the slope face with in 30° and dips in the same direction.

4 Result and Discussion

4.1 Estimation of Rock Mass Rating (RMR)

The Total Rock mass classification and engineering properties were derived from these various parameters: as point load test (intact strength of rock), Rock Quality Designation (RQD), spacing of discontinuity, condition of discontinuity and ground water condition which were plotted against standard Rock mass classification and illustrated in Tables 2 and 3 and presented in Fig. 5.

4.2 Slope Stability Analysis & Estimation of Slope Mass Rating (SMR)

Discontinuity orientation, represented in dip and dip direction, slope amount and direction and cut slope, was measured in the field and tabulated. These parameters are very important for SMR as well as slope stability analysis of each rock section. Discontinuities orientation and slope were plotted in the stereo net, to find out the type of failure and plunge of discontinuities of each rock section (Fig. 4(a)–(h) and Table 4). Stereo plots indicated the possibility of planner and wedge failure in these rock slopes. Planner failure was identified in the sections of R-2, R-4, R-5, R-7 & R-8 and wedge failure was identified in the entire rock slopes R-1 to R-8. The Slope stability analysis exhibits that all the slopes occur in case

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of unfavourable conditions. The relationship between discontinuities and slope face is thoroughly explored to identify the factorial adjustments such as F_1, F_2 and F_3 and F_4. Slope mass rating (SMR) were evaluated when RMR_basic added with summation of all adjustment factors: F_1, F_2, F_3 and F_4 (Eqs. (7)) as indicated in Fig. 6.

4.3 Validation of Vulnerable Cut Slope (RMR & SMR Rating)

Vulnerable map was prepared according to the values of RMR and SMR obtained in the field investigation. In keeping with RMR classification, the map was divided into 2 major zones based upon the nature of rocks such as Good Rock and Fair Rock. In consonance with field investigation, out of 61 landslide points, 45 points are falling in the Fair rock type zones and remaining 16 landslide points are falling in the Good rock type zones. It is clearly depicts that 73.8% landslides occurred in the fair rock type zones and 26.2% occurred in the good rock type zones.

According to SMR classification, the map was divided into 2 major zones based upon the stability of rocks such as partially stable and unstable conditions. The field investigation demonstrates that (47) out of (61) landslide points are existent in the partially stable conditions and (14) are in the unstable conditions. It is clear that 77.1% landslides occurred in the partially stable conditions and 22.9% occurred in the unstable conditions.

5 Conclusion

The present pioneering study is an application of RMR and SMR classification system to evaluate landslide hazard zones with natural type of failure using the interpolation method. The point load index of any rock slopes designates the strength of the rock and R-1 to R-8 point load values varies between 7.72 and 17.82. The RQD values expose durability of any rock mass and R-1 to R-8 values varies between 65.4% and 95.5% indicating moderate to high durability. According to RMR values, R-2 and R-3 show good rock type, while remaining R-1 and R-4 to R-8 fair rock types. The analysis made from stereonet plots shows that R-2, R-4, R-5, R-7 and R-8 rock slopes demonstrate planar failure and R-1 to R-8 rocks slopes are wedge failure. The estimated SMR values demonstrate that R-1 and R-6 slopes are classified into very bad category, wedge type of failure is involved in class II and the other rock slopes R-2 to R-5 and R-7 to R-8 which exhibit partially stable condition are included in class III. These slopes are supported by shotcrete, dental concrete, ribs or beams and toe walls bolts which provide systematic support to avoid slope failure in this study area.

The present study reveals that RMR values present better result than those of SMR and nature of rocks causes landslides more than slope and directions of discontinuities in the study area.

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