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GOVERNMENT OF INDIA
भारतीय भूवैज्ञानिक सर्वेक्षण
GEOLOGICAL SURVEY OF INDIA

मेसो-स्केल (1:10,000) हरंगी उप-बेसिन, कोडागु जिला, कर्नाटक के मदापुर होल वाटरशेड के हाडागल होल उप-वाटरशेड में भूस्खलन संवेदनशीलता मानचित्रण

Meso-scale (1:10,000) Landslide Susceptibility Mapping in Hadagal Hole Sub-Watershed of Madapur Hole Watershed of Harangi Sub-Basin, Kodagu District, Karnataka

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द्वारा

एजाज अहमद भट, वरिष्ठ भूवैज्ञानिक
सैथिलकुमार के, भूवैज्ञानिक

सारांश

मेसो-स्केल (1:10,000) भूस्खलन संवेदनशीलता मानचित्रण क्षेत्र सीजन 2021-22 के दौरान कर्नाटक के कोडागु जिले के सोमवरपेट तालुक के कुछ हिस्सों में 16 किमी 2 क्षेत्र में किया गया था। भू-कारक मानचित्रण में स्केल्ड और भूस्खलन विफलता डोमेन-आधारित दृष्टिकोण को अपनाकर प्रबंधन योजना के साथ-साथ अध्ययन क्षेत्र के मेसो-स्केल (1:10,000) भूस्खलन संवेदनशीलता मानचित्र तैयार करने के उद्देश्य से जांच की गई थी। अध्ययन क्षेत्र मदापुर वाटरशेड का एक हिस्सा है जो 102 वर्ग किमी के जलग्रहण क्षेत्र के साथ 7वीं धारा क्रम स्तर का वाटरशेड है। पत्ते की क्षेत्रीय प्रवृत्ति NW-SE (305°-355° से) दिशा में होती है और 24°-88° SW से कोण पर गिरती है। इस क्षेत्र को चार संयुक्त सेटों (J1, J2, J3 & J4) से पार किया जाता है जिन्हें अध्ययन क्षेत्र में दर्ज किया गया था। J1 NE-SW डिपिंग में वर्टिकल से SE तक ट्रेड कर रहा है जबकि J2 NW-SE में ट्रेड कर रहा है, जो मामूली रूप से NE तक डिपिंग कर रहा है। J3 भी NE-SW में उप-ऊर्ध्वाधर रूप से NW में ट्रेड कर रहा है जबकि J4 भी NE-SW में भी ट्रेड कर रहा है, जो क्रमशः SE की ओर मामूली है। इनमें से J1 संयुक्त समूह प्रमुख है और अध्ययन क्षेत्र में अक्सर देखा जाता है। संयुक्त सेट J1 निकट दूरी पर है और क्षेत्र में क्षेत्रीय पत्ते के साथ एक आश्रित संबंध है। यह क्षेत्र में क्षेत्रीय तह का दरार तल होगा। अध्ययन क्षेत्र में स्टीरियो-नेट प्लॉट के माध्यम से विभिन्न संयुक्त हस्तक्षेप पैटर्न का पता चला था, जिनमें से फोलिएशन + J1 + J4 के बीच का हस्तक्षेप रॉक ब्लॉकों / टुकड़ों को विस्थापित करने के लिए क्षेत्र में सबसे अनुकूल स्थिति पाया गया, जो बाद में दक्षिण में नीचे चला गया- पश्चिम दिशा। इस संयुक्त हस्तक्षेप के परिणाम ने क्षेत्र की क्षेत्रीय स्थलाकृति विकसित की है, जिससे एनडब्ल्यू-एसई दिशा में लंबी लकीरें और घाटियां बन रही हैं और एसडब्ल्यू दिशा में खड़ी ढलान हैं। इसके अलावा, अध्ययन क्षेत्र में भूस्खलन की प्रमुख घटनाओं में से एक में, वही संयुक्त हस्तक्षेप प्रमुख कारक कारक के रूप में पाया जाता है। जल निकासी विश्लेषण के गतिज विफलता विश्लेषण और लघुगणक वक्रों के अलावा सुझाव दिया कि संयुक्त सेट J1 और J3 निचले क्रम की जल निकासी प्रणाली (पहली, दूसरी, तीसरी, चौथी और पांचवीं) और धारा खंडों के उन्मुखीकरण और विकास के लिए सबसे जिम्मेदार कारक हैं। उच्च क्रम के (6वें और 7वें) अध्ययन क्षेत्र में क्षेत्रीय फोलिएशन प्लेन का अनुसरण कर रहे हैं। इसके अलावा, धारा लंबाई अनुपात वक्र से पता चलता है कि अध्ययन क्षेत्र में तीसरी और पांचवीं धारा के आदेशों में चैनल क्षरण (स्ट्रीम बेड के साथ-साथ स्ट्रीम

बैंक) की उच्च संभावना है और यही घटना फील्ड मैपिंग में देखी गई है। अध्ययन क्षेत्र में लगभग सभी भूस्खलन की घटनाएं वर्षा से प्रेरित हैं और वर्षा ने एक ट्रिगर के रूप में काम किया। अध्ययन क्षेत्र में भूस्खलन की घटनाओं के लिए प्राकृतिक और मानवजनित दोनों ही कारणों को जिम्मेदार पाया गया। प्राकृतिक कारणों में, डे-लाइटेड (फॉलिएशन प्लेन का डिप> स्लोप एंगल) स्लोप फेस पर पेगमाटाइट वेन्स, शीयर बैंड ट्रेडिंग और डिपिंग प्लेन के समानांतर, इन-सीटू मिट्टी की शीयर स्ट्रेंथ में कमी, स्ट्रीम बैंक मैटेरियल का क्षरण या उच्च जल क्रिया द्वारा प्राकृतिक ढलानों को काटने और चट्टान के टुकड़ों को अलग करने के लिए अनुकूल संयुक्त हस्तक्षेप पैटर्न शामिल हैं। मानवजनित कारणों में, सड़क निर्माण और बंदोबस्त भवनों (घरेलू और वाणिज्यिक दोनों) के लिए प्राकृतिक ढलानों को काटना और खेती के उद्देश्यों के लिए प्राकृतिक ढलानों का संशोधन शामिल है। सोमवरपेट तालुक से वर्षा के आंकड़ों के दैनिक वर्षा विश्लेषण से पता चलता है कि जून-अगस्त 2018 के बीच 100 मिमी से अधिक वर्षा की कई घटनाएं दर्ज की गईं, जिनमें से जुलाई और अगस्त 2018 में 100 मिमी से अधिक बारिश की दो लंबी घटनाएं (5 दिन) हुई होंगी। अध्ययन क्षेत्र में भूस्खलन की घटनाएं 16 वर्ग किमी के अध्ययन क्षेत्र में 15.59 वर्ग किमी क्षेत्र में अधिक भार वाली सामग्री है जबकि चट्टान से ढका क्षेत्र केवल 0.44 वर्ग किमी क्षेत्र है। गुणात्मक रूप से अपनाए गए मॉडल ने उच्च संवेदनशीलता में 45.47 प्रतिशत मानचित्र क्षेत्र और प्रभावकारिता के साथ कम संवेदनशीलता में 26.39 प्रतिशत मानचित्र क्षेत्र की भविष्यवाणी की है और संयुक्त भूस्खलन संवेदनशीलता मानचित्र में 28.14 प्रतिशत मानचित्र क्षेत्र में मध्यम अतिसंवेदनशील वर्ग के संदर्भ में कम से कम अनिश्चितता है। सभी 52 नग संयुक्त भूस्खलन संवेदनशीलता मानचित्र क्षेत्र प्रतिशत के साथ भू-स्खलन की पुष्टि की गई है जिसमें भूस्खलन अनुपात 3 (निम्न): 9 (मध्यम): 40 (उच्च) रहा जो जांच किए गए क्षेत्र के लिए एक संतोषजनक अनुपात है। उपयोगकर्ता के अनुकूल और समझने में आसान दृष्टिकोण को ध्यान में रखते हुए, उच्च संवेदनशीलता क्षेत्र में पड़ने वाले पहाड़ी ढलानों के स्थिरीकरण के लिए भूस्खलन प्रबंधन मानचित्रण और क्षेत्र-विशिष्ट अनुशंसाओं का सुझाव दिया गया है।

Meso-scale (1:10,000) Landslide Susceptibility Mapping in Hadagal Hole Sub-Watershed of Madapur Hole Watershed of Harangi Sub-Basin, Kodagu District, Karnataka

Item no.: M4LSSM/NC/SR/SU-KG/2021/33515

By

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ABSTRACT

The Meso-scale (1:10,000) Landslide Susceptibility Mapping was carried out in a 16 km² area in parts of Somwarpet Taluk of Kodagu district, Karnataka during field season 2021-22. The investigation was carried out with the aim to generate a Meso-scale (1:10,000) landslide susceptibility map of the study area along with a management plan by adopting up scaled and landslide failure domain-based approach in geo-factor mapping. The study area is a part of the Madapur watershed which is a 7th stream order level watershed with a 102 sq.km catchment area. The regional trend of foliation ranges in NW-SE (from 305°-355°) direction and dipping at angle from 24°-88° SW. The area is traversed by four joint sets (J1, J2, J3 & J4) which were recorded in the study area. J1 is trending in NE-SW dipping near vertical to SE whereas J2 is trending in NW-SE dipping moderately to NE. J3 is also trending in NE-SW dipping sub-vertically to NW whereas J4 is also trending in NE-SW dipping moderately to SE respectively. Among these, J1 joint set is dominant and frequently observed in the study area. Joint set J1 is closely spaced and has a dependent relationship with the regional foliation in the area. It would be the cleavage plane of the regional fold in the area. Different joint interference patterns were revealed in the study area through stereo-net plots, among which the interference between foliation+J1+J4 is found the most favorable condition in the area to dislocate the rock blocks/fragments which later moved down in the south-west direction. The result of this joint interference has evolved the regional topography of the area, forming long ridges and valleys trending in the NW-SE direction and steep slopes in the SW direction. Further, in one of the major landslide incidences in the study area, the same joint interference is found as the major causative factor. Besides the kinematic failure analysis and logarithm curves of drainage watershed analysis suggested that the joint sets J1 and J3 are the most responsible factors for the orientation and evolution of lower order drainage system (1st, 2nd, 3rd, 4th & 5th) and the stream segments of higher orders (6th & 7th) are following the regional foliation plane in the study area. Further, the stream length ratio curve shows that there is a high possibility of channel erosion (stream bed as well as stream banks) in the 3rd and 5th stream orders in the study area and the same phenomenon is witnessed in field mapping. Almost all landslide incidences in the study area are rainfall-induced and the rainfall acted as a trigger.

Both natural as well as anthropogenic-related causes were found responsible for landslide occurrences in the study area. In natural causes, the presence of Pegmatite veins, shear bands trending and dipping parallel to foliation plane on day-lighted (dip of foliation plane > slope angle) slope faces, decrease in shear strength of in-situ soil, erosion of stream bank material or toe cut of natural slopes by high water action and favorable joint interference pattern for detaching the rock fragments are included. In anthropogenic causes, cutting of natural slopes for road construction & settlement buildings (both domestic as well as commercial) and modification of natural slopes for cultivation purposes are included. The daily rainfall analysis of rainfall data from Somwarpet taluk shows that there were multiple rainfall events above 100mm rainfall recorded between June-August 2018 among which two longer events (5 days) of rainfall above 100mm in July and August 2018 would have been triggered most of the landslide incidences in the study area. The 16 sq.km study area contains overburden material covering over 15.59 sq.km area whereas the rock-covered area is only 0.44 sq. km area. Qualitatively the adopted model has predicted 45.47 percent map area in high susceptibility and 26.39 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 28.14 percent map area in combined landslide susceptibility map. All 52 nos. of landslides have been validated with the combined landslide susceptibility map area percentage in which the landslide ratio remained 3 (low): 9 (moderate): 40 (high) which is a satisfactory ratio for the investigated area. Keeping the user-friendly and easy to understand approach in consideration, the landslide management mapping and area-specific recommendations have been suggested for the stabilization of hill slopes falling in high susceptibility zone.

CHAPTER-1

INTRODUCTION

1.1 General

The landslide investigation titled “Meso-scale (1:10,000) Landslide Susceptibility Mapping in Hadagal Hole Sub-Watershed of Madapur Hole Watershed of Harangi Sub-Basin, Kodagu District, Karnataka” has been carried out in a 16 km² area in Somvarpet taluk, Kodagu district Karnataka during field season 2021-22. This investigation was taken up in the landslide-prone area in accordance with the implementation of the Ministry of Mines approved Landslide Vision and Strategy Document 2020-2030. This investigation has been done through a domain-specific approach as per the Standard Operating Procedure (SOP) of the Meso-scale (10,000) Landslide Susceptibility Mapping project, in which the following things were brought to achieve quality product; (1) demarcation of landslide failure domains such as rock slide/rock fall domain, debris slide/debris flow domain, earth slide/earth flow domain and cut-slope domain in both rock and overburden covered slopes; (2) the field data density is higher; (3) the validation of geo-factor maps is upscaled with higher accuracy; (4) the landslide susceptibility has modeled as per the types of slope failures; (5) the final landslide susceptibility map is user-friendly and contains additional value-added information for comprehensive landslide risk assessment and management so that the same can be utilized for detailed infrastructure planning and mitigation strategies. Earlier in Macro-scale (1:50,000) landslide susceptibility mapping the landslide failure domain-specific approach has not been adopted. However, in the present investigation, different types of data sets including remote sensing and field data were collected and analysed separately in each landslide failure domain, the subsequently landslide susceptibility map for each landslide failure domain has been generated independently. The earlier geological map (1:50,000) of the study area has been updated on a 1:10,000 scale with due care. In rock slide/rock fall domains the kinematic failure analysis has been done for each rock outcrop to find out different rock failure types and to prepare their kinematic failure maps which were later used in modelling for landslide susceptibility in rock slide/rock fall domains. The work of preparation of kinematic failure maps and modelling for landslide susceptibility in rock slide/rock fall domains is in progress. In overburden failure domains the classification of the material (debris or earth) has been done in field mapping and 32 nos. of undisturbed samples in each classified material at different elevations were collected to analyse their geotechnical properties. On the bases of analyzed geotechnical properties, the interpolation-based geotechnical themes were prepared which were used in modelling indirectly in several corrections made in the geotechnical map based on cohesion and angle of internal friction matrix. The cut-slope domain has been identified and demarcated in field mapping both in rock and overburden-covered slopes. The cut-slope height, relief, and upslope angle in each cut-slope were

analysed to prepare the cut-slope failure tendency map which was used in modelling the landslide susceptibility in the cut-slope domain. Subsequently, based on field-based observations, the landslide management mapping will be done and it will give additional value-added information for comprehensive landslide risk assessment and management for detailed infrastructure planning and mitigation strategies.

1.2 Location, Physiography and Communication

The study area of 16 km² is situated in the Somwarpet taluk Kodagu/Coorg district of Karnataka (see fig. 1.1) and it lies in SOI toposheets no. 48P/14. The study area is bound between latitudes 12°31'30" N and 12°34'45" N and longitudes 75°46'00" E and 75°49'30" E respectively. The localities situated in the study area are; Kirdale, Biligeri, Garwale, Sherangalli, Kalladi, and parts of Thakeri villages.

The study area lies in the vicinity of the Western Ghats which runs for about 1600 km as an unbroken relief along the western border of Deccan from the river Tapti Valley in Gujarat to Kanyakumari in Tamil Nadu, of the Indian Peninsula. The Western Ghats represent the hilly terrain with steep escarpments parallel to the west coast of India. On the western side, the Western Ghats appear abruptly rising from the Arabian Sea whereas they merge through a series of hills with the Deccan plateau in the east. Due to the unique type of topography and climate in parts of Kodagu district among southern states, it is known to be quite a pleasant and healthy place in south India. The study area is having lowly to moderately dissected hill slopes. The study area is a part of the Madapur watershed which is a 7th-order level watershed with a 102 sq. km catchment area. The elevation range in the study area varies from 1230m to 797m and the slope angle ranges from 0°-56°. Kodagu is famous for the hilly tourist destinations in India. Some of the most popular tourist destinations in Kodagu are Talakaveri, Bhagamandala, Nisargadhama, Abbey Falls, Dubare, Nagarhole National Park, Iruppu Falls, and the Tibetan Buddhist Golden Temple.

The Kodagu district is bordered by the Dakshina Kannada district of Karnataka in the north, the Mysore district of Karnataka in the east, and the Kasargod district of Kerala state in the west and south. The study area has a fairly good network of roads that connects the area to the district headquarters stationed at Madikeri. The study area is about 28 km away from Madikeri town, 244 km away from Bangalore (Karnataka State Capital), 121 km from Mysore, and 165 km from Mangalore, respectively. The nearest railway stations to the study area are Hassan (83 km), Mysore (119 km) and Mangalore (162 km). The nearest airport stations to the study area are Mysore (134 km) and Mangalore (167 km).

the Kodagu district, the average annual normal rainfall of 2192 mm and average annual actual rainfall of 2028 mm has been recorded for the period 2015-2020 (KSNDMC). The southwest monsoon reaches usually during early June. Generally, June-September is the period of heavy rainfall (*see fig. 1.3*) and the precipitation in July remains incessant and very heavy in the Kodagu district. The analysis of rainfall data (*from KSNDMC*) shows a continuous increasing trend in the annual actual rainfall pattern from the year 2015 to 2018 in Kodagu district and then decreasing onwards (*see fig. 1.2*). The highest average actual rainfall has been recorded in the year 2018 in Somvarpet taluk during the June-September period (*see fig. 1.3*). Further detailed analysis of rainfall data of June, July and August months of the year 2018 has been done for recording rainfall stations at Garwale, Harangi, Shirangali, Somwarpet and Madapur rainfall stations. These recording rainfall stations are nearest to the study area. As per the information collected in the study area during field mapping, most of the landslide incidences occurred during July-August 2018 period in which maximum rainfall was recorded in the area (*see figure-1.4 b&c*). The daily rainfall data recorded during July-August 2018 at Garwale, Harangi, Shirangali, Somwarpet and Madapur rainfall stations show considerable variations. The Garwale station is nearest to the study area which is why its rainfall data has been specifically analysed in correlation with the rainfall data of other nearest stations. The daily rainfall analysis shows that there were multiple rainfall events above 100mm rainfall recorded (*figure-1.4a,b&c*)

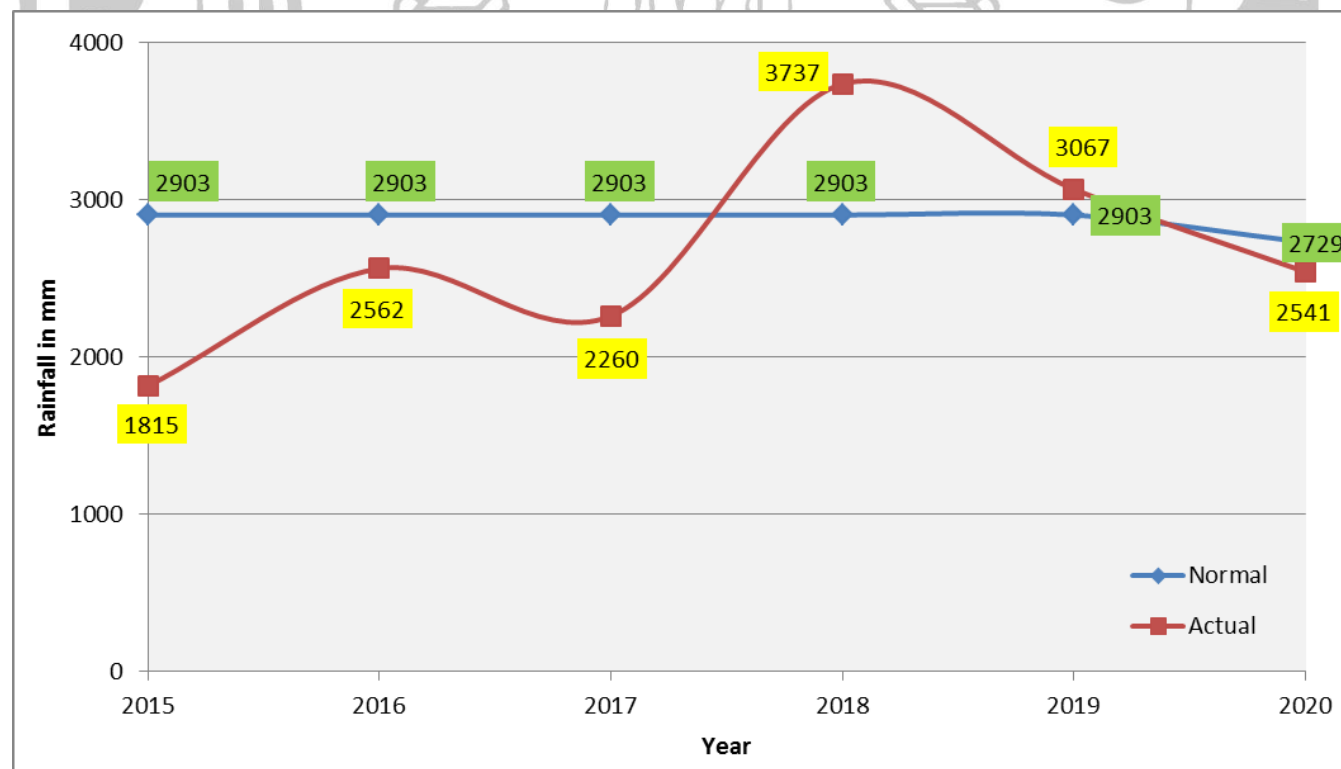


Figure-1.2: Trend of average annual normal and actual rainfall pattern in Kodagu district from 2015-2020 period. (Source: KSNDMC)

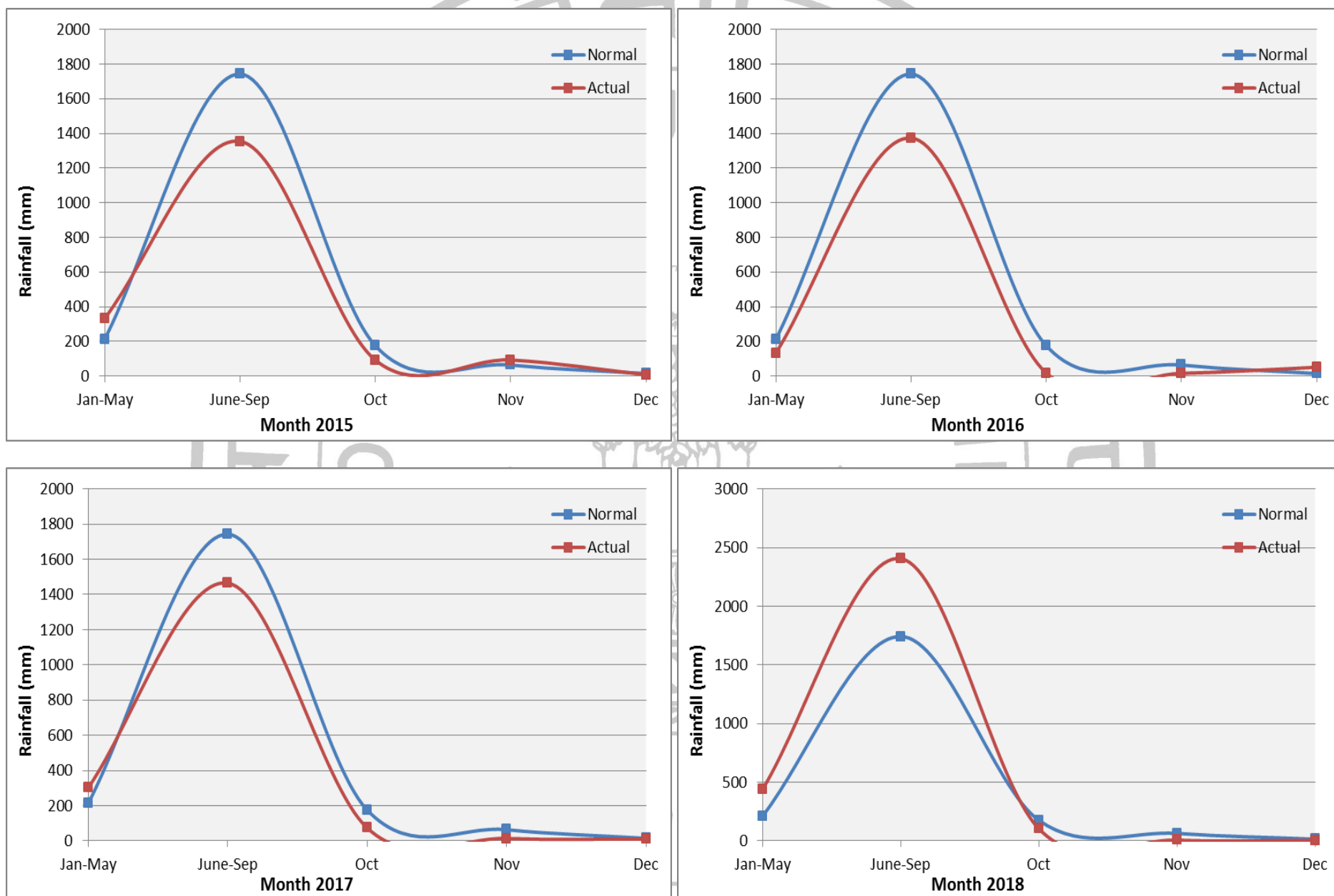


Figure-1.3 (a): Trend of monthly average normal and actual rainfall pattern in Somvarpet taluk, Kodagu from 2015-2018 (Data source: KSNDMC)

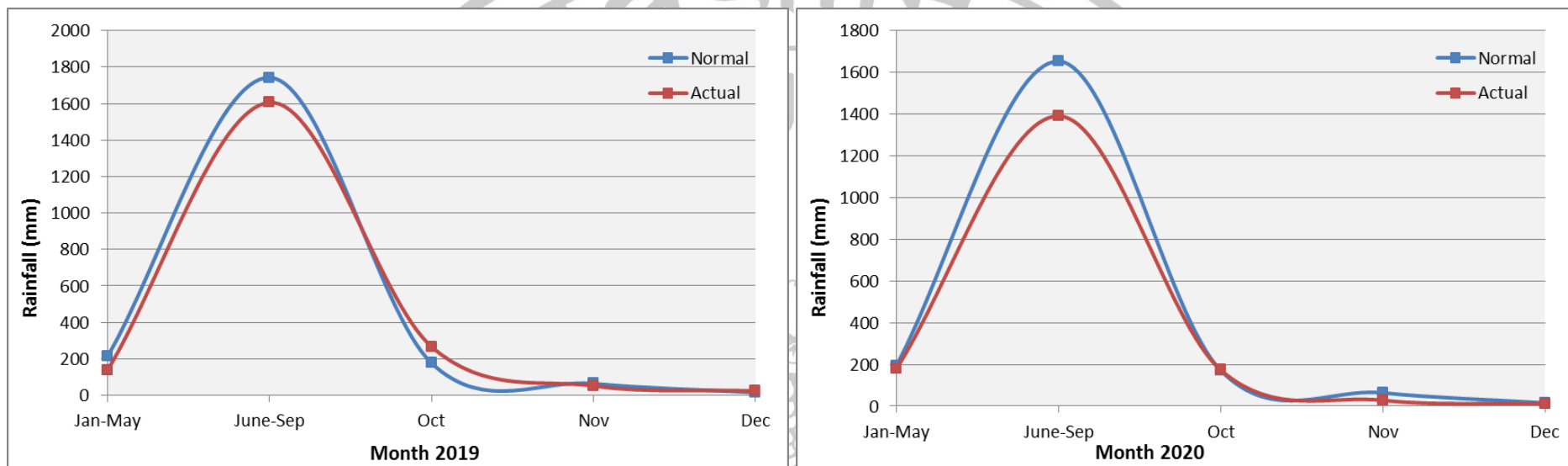


Figure-1.3 (b): Trend of monthly average normal and actual rainfall pattern in Somvarpet taluk, Kodagu from 2019-2020 (Data source: KSNDMC)

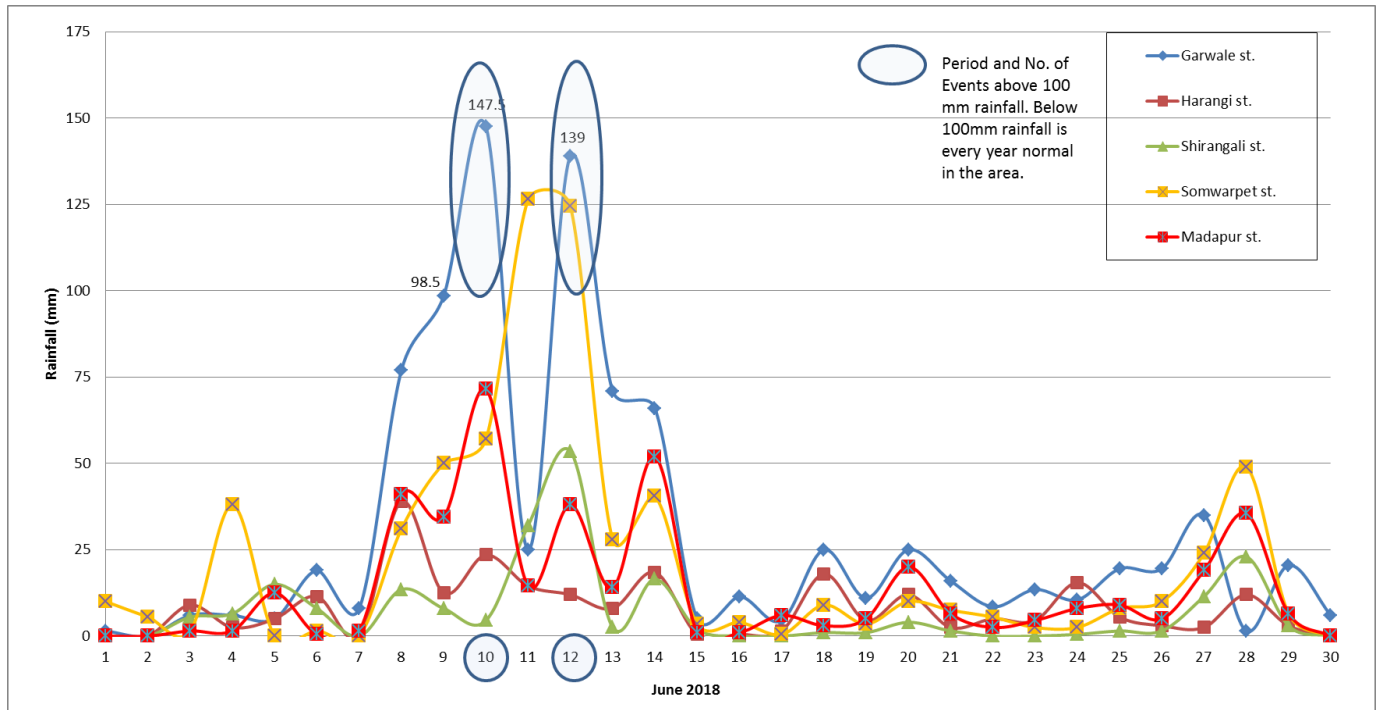


Figure-1.4 (a) Trend of daily rainfall data in June 2018 at Garwale, Harangi, Shirangali, Somwarpet and Madapur rainfall stations. (Data source: KSNDMC)

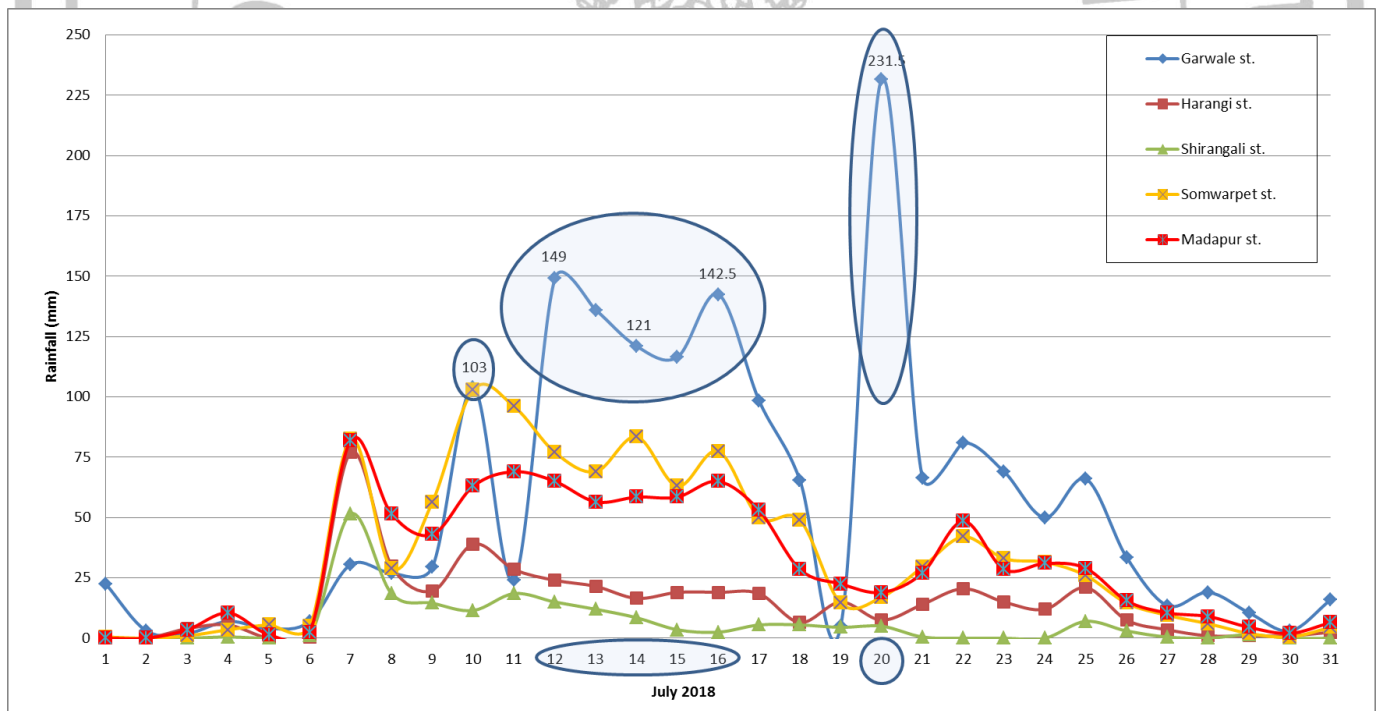


Figure-1.4 (b) Trend of daily rainfall data in July 2018 at Garwale, Harangi, Shirangali, Somwarpet and Madapur rainfall stations. (Data source: KSNDMC)

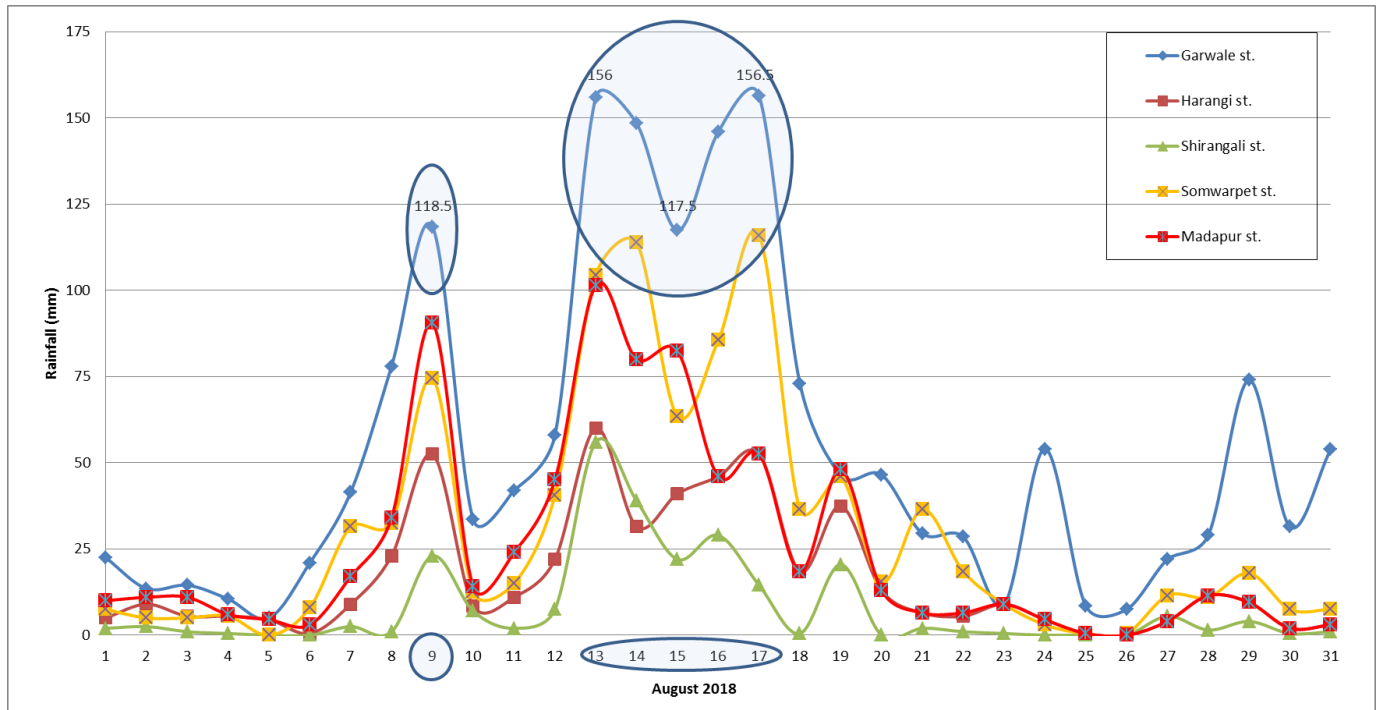


Figure-1.4 (c) Trend of daily rainfall data in August 2018 at Garwale, Harangi, Shirangali, Somwarpet and Madapur rainfall stations. (Data source: KSNDMC)

between June-August 2018 among which two longer events (5 days) of rainfall above 100mm in July and August 2018 would have triggered most of the landslide incidences in the study area. Therefore indirectly it may be concluded that the slopes having moderate to high slope gradients are vulnerable to failures above 100mm rainfall in the study area and its surroundings.

1.4 Previous and Present Work

In Karnataka, the geotechnical study was initiated during 2002-2003 for unstable slopes of Cabo hills by R.Panduranga et al., and later the feasibility stage investigation was carried out for the construction of the shore-based test facilities for LCA (Navy) at Dabolim Airfield, Goa by R.Dharuman. In Kodagu district, the pioneered works of the Geological Survey of India A. K. Mishra et al., 2008; K.V. Maruthi et al., 2012, 2013, 2010, 2014; and A.K. Srivastava et al., 2016 & 2018 have carried out landslide investigations since 2007. Among these A. K. Mishra et al., K.V. Maruthi et al., have done landslide inventory, landslide hazard zonation and post-disaster landslide studies while A.K. Srivastava et al. 2016, have done Macro-scale (1:50,000) landslide susceptibility mapping (NLSM) which was a national programme launched by GSI in the year 2014 with an aim to generate a seamless landslide susceptibility map of landslide vulnerable areas in the country. The areas which have been classified as a high and

moderate zone of landslide susceptibility by A.K. Srivastava *et al.*, 2016 & 2018 were severely affected by landslides during the 2018 monsoon period.

The earlier workers of GSI have carried out landslide investigations in the area wherein the study area lies, on different mapping scales. A detailed site-specific study in Billigeri village, Somwarpet was carried out by A.K.Mishra *et. al*, during 2006-2007. This study was taken up to investigate the behaviour of the creep movement in the S10°W facing slope of the ENE-WSW trending hill near Basavaneswar temple. Detailed mapping on the 1:1000 scale was carried out to delineate the unstable zones. Mishra *et al.* in the year 2010 carried out landslide susceptibility mapping of Madikeri town and its surroundings, Coorg district, Karnataka along road corridors with a 1 km buffer on both sides. This work has been carried out on a macro-scale (1:25,000) level in an 85 sq. km area. In this work, the majority of slides have been classified as debris slumps and earth slumps mainly due to toe-cutting of the slope during road construction. The area was classified as low, moderate, and highly susceptible. The recommendations include the construction of a drainage system on the slopes to reduce the pore pressure, the construction of a retaining wall, stone pitching and gabions, biotechnical measure of slope protection and geometrical modification of slope by grading and benching.

K.V. Maruthi and K.V.Chandran in the year 2013 carried out landslide susceptibility mapping along Virajpet – Madikere – Sulya road corridor, Coorg district, Karnataka. They carried out this work according to the methodology prescribed by Bureau of India Standards IS 14496 (Part 2): 1998, later modified by the Geological Survey of India. They have recommended geometrical modification of the slope by grading and benching, bio-technical measures of slope protection and proper drainage arrangements. However, these works have not recorded any landslide incidence in the present study area. In field season 2013-14, K. V. Maruthi carried out landslide inventory along NH & SH of Ghat roads in Coorg and Uttar Kannada districts, Karnataka and they have investigated the present study area also. However, in this investigation, no landslide incidence has been recorded in the present study area.

Ankur Kumar Srivastava and Rahul Kumar Chaurasia in the year 2017-18 carried out macro-scale (1:50,000) landslide susceptibility mapping in parts of toposheet no. 48O/16, 48P/13 & 14, Kodagu district, Karnataka in 1317 sq. km area in which the present study area of 16 sq. km has also been taken into account. Although they have not recorded any landslide incidence in the present study area, they have classified the area into low, moderate, and high landslide-susceptible zones on the bases of the Analytical Hierarchy Process (AHP) method which would be advantageous for either Govt. or private organisations in land conversion, land planning or constructional works at the preliminary level of investigation. This work was part of the NLSM national programme for generating a seamless landslide susceptibility map. The workers in this study have prepared various thematic factor maps by utilizing remote sensing datasets

and field inputs. These factor maps include a geomorphology map, land use/landcover map, slope forming material map, slope map, slope aspect map, slope curvature map and regolith thickness map. The workers in this study have generated a landslide susceptibility map using the AHP model by integrating all thematic factor maps in ArcGIS software. A subset of this landslide susceptibility map has been created for the present study area. It has been worked out from this subset that 1.3 sq. km area (8.12%) falls under the high landslide susceptible zone, 4.32 sq. km area (27%) falls under the moderate landslide susceptible zone and 10.69 sq. km area (66.81%) falls under low landslide susceptible zone (*see figure-3*). The workers have found that most landslides occurred on slopes ranging from 15°-35° angle and on slopes that have been modified by anthropogenic activities. They have observed that old landslides reactivated by water saturation and an increase in pore water pressure. The workers in this study have recommended slope terracing and the construction of retaining walls as preventive measures. Besides post landslide hazard studies have been carried out from time to time as per necessity in the area by GSI.

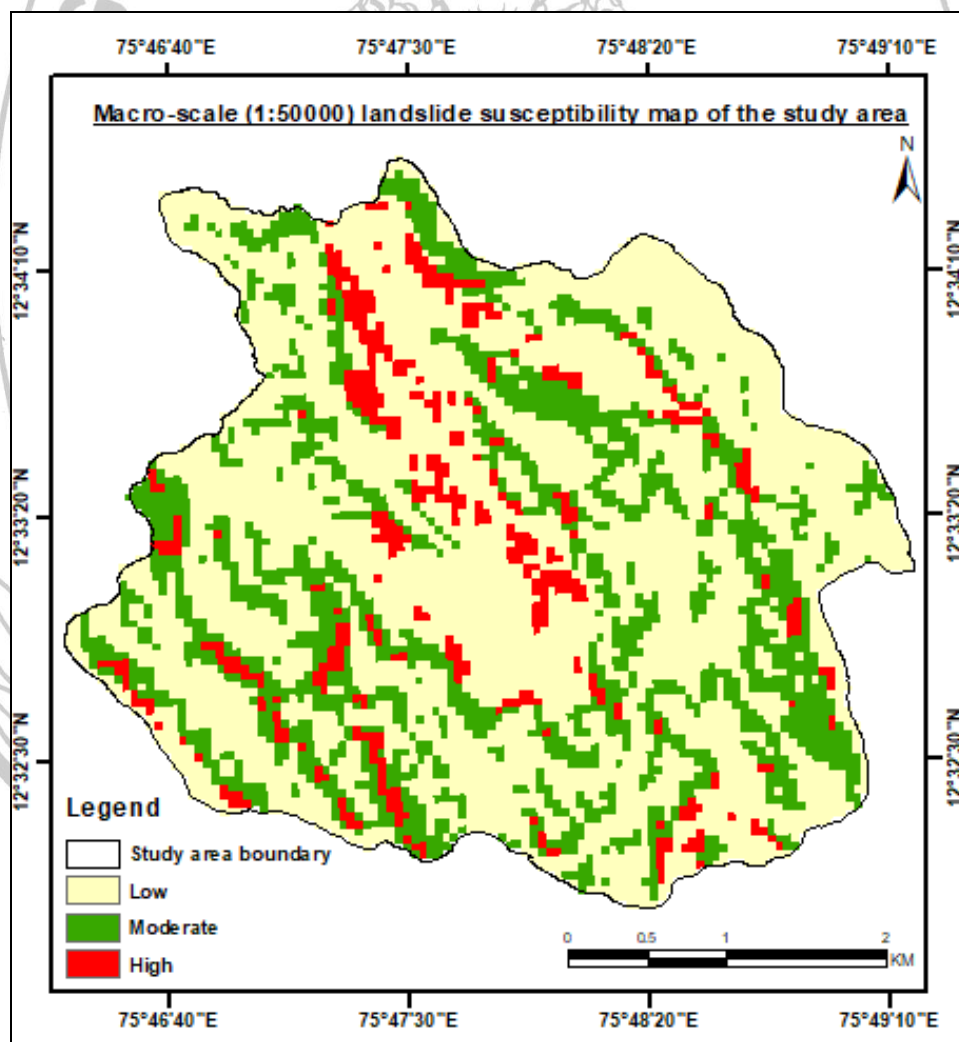


Figure-1.5: Extract of 1:50000 scale Landslide Susceptibility map (NLSM) of the present study area
High=8.12%; Moderate=27%; Low=66.81%

The present study was taken up in pursuance to implement the Ministry of Mines approved Landslide Vision and Strategy Document 2020-2030. The investigation was carried out to generate Meso-scale (1:10,000) landslide susceptibility map for the study area, to find out the major causative factors of past landslide incidences that occurred in the study area and to suggest generic mitigation/remedial measures so that the risk factor would be minimized. An up-scaled and domain-specific approach was adopted to achieve a quality product. Domain-specific field mapping was carried out to observe and assess the geo-themes of rock-covered and overburden-covered areas separately so that the failure mechanism, landslide material involved, causative factors, and prevailing geological conditions would be understood. The present assignment was one year programme with given nature, quantum, and target (NQT) details as shown in *table-1.1*. The concerned field officers have successfully achieved all assigned targets and spent the mandatory field days (*see table-1.2*).

Table-1.1: Nature, Quantum and Target of Work Component

Nature of Work	Target (km ²)	Achievement (km ²)
1. Detailed pre-field landslide inventory map including ground deformation, creeps, etc., and identification of failure domains.	16	16
2. Preparation of pre-field thematic geo-factor maps on 10k based on failure domains.		
a. Land use/Land cover map	16	16
b. Drainage map		
c. Geomorphology map / Landform map		
d. Slope Morphometry (Slope Angle, Slope Aspect, Slope Curvature, and Relative Relief)		
e. Slope forming material map (Geological)		
f. Stream Power Index map		
g. Landslide domain map		
h. Overburden thickness map		
i. Slope facet map		
3. Field-based studies		
a. Validation and updation of all thematic maps	16	16
b. Data collection for preparation of the Geotechnical map		
c. Geotechnical field sample collection for determination of geotechnical parameters**	32 nos.	32 nos.
4. Post-field studies and modelling		
a. Updation and finalization of thematic maps and landslide inventory in the GIS platform.	16	16
b. Preparation of Geotechnical map		
5. Preparation of landslide susceptibility map in GIS platform.	16	16
6. Collection of rainfall data	As per availability	Collected from the year 2015-2020

Table-1.2: Total field days spent as per NQT by the officers

Name of the officer	Field days mandatory	Total field days spent
Aijaz Ahmad Bhat, Sr. Geologist	90 days	93 days
Senthilkumar K, Geologist	90 days	100 days
R. Sajeew, Director (G)	-	07 days

1.5 Objectives of Work

The objectives were:

1. To identify slope-failure domains and to prepare domain-specific geo-factor maps in GIS.
2. To rate and weigh relevant geo-factor maps for different failure domains.
3. To integrate the rated and weighted geo-factor maps per identified failure domain in a GIS.
4. To combine the domain-specific landslide susceptibility models into a combined and classified landslide susceptibility map on a 10k scale.
5. To qualitatively/ quantitatively assess the landslide risk and to frame a generic mitigation/management plan on a 10k scale for relevant value addition and for direct use by the stakeholders

1.6 Acknowledgement

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CHAPTER – 2

GENERAL GEOLOGY AND GEOLOGICAL STRUCTURE

2.1 Regional Geology and Stratigraphic Set Up

The area lies in Western Dharwar Craton (WDC) comprising dominantly TTG (tonalite–trondhjemite–granodiorite) or Peninsular Gneiss intercalated with highly deformed supracrustal rocks of Sargur Group having ~3.4-3.0 Ga age (Naqvi and Rogers, 1987; Jayananda et al., 2008). The Coorg Block is welded with Dharwar craton to the north by the Mercara shear zone which is marked by steep gravity gradients (Sunil et al., 2010) and suggested the presence of underplated high-density material in the lower crust. The Dharwar craton comprises rocks of ancient supracrustals of 3400-3000 m.y of age range, Older and Younger Gneiss Complexes, Larger Schist belts (Dharwar type) of Late Archean age, Younger Granites (Closepet), Granulites and Younger Intrusives (Dykes) (Aijaz et al., 2019). Previous studies suggested that granulite facies rocks dominated by Charnokites and mafic granulites occur as massifs in Coorg block (Asha Manjari and Malur, 1997) while others revealed that Orthopyroxene-bearing greasy green charnockites are the dominant rock types followed by TTG (tonalite–trondhjemite–granodiorite) suite and minor amphibolite/hornblende gneisses in association with bands of BIF (banded iron formation) occur sporadically, mostly along the periphery of the block. Several thick bands of granulite-facies metapelites (Khondalites) with coarse garnet, sillimanite/kyanite occur along the northern and northeastern peripheries of the block where the present investigated area is located. Recent studies show Sm-Nd whole-rock isochron ages for the charnockites, garnet granulites, and migmatitic gneisses from the Coorg Block ranging from 2910 to 3700 Ma (Peucat et al., 2013) while reported U–Pb data on Zircons Mesoarchean crystallization ages ≥ 3.3 Ga. Unlikely, GSI has done systematic mapping on 1:50k to reveal the general geology in the present investigated area but has never taken further advanced or research-based studies on petrology, stratigraphy, geochronology, plate tectonics, geodynamics, structural geology, etc. to explore southern Indian shield and it is necessary to note here that GSI should take such advanced or research-based studies in future to give its contribution to the geoscience world. The present investigated area is a part of degree sheet 48P. Based on the systematic mapping, GSI has compiled the geological maps on a 1:50,000 scale of degree sheet 48P prepared by several workers of GSI from 1949-1986 and the compiled maps have been published as the second edition *Geological Quadrangle Map (GQM series)* in 2013. The regional stratigraphic set-up of the area is shown in table-2.1. The rock of the Sargur Group is the oldest in the area having Archean age and is equivalent to the Wyanad Group of rocks followed by Archean age rocks of Peninsular Gneissic Complex-I, Southern Granulite Complex, and Peninsular Gneissic Complex-II.

Table-2.1: Regional stratigraphic set up of area covered by degree sheet 48P after *Geological Survey of India, 2013 compilation.*

Supergroup	Group	Formation	Lithology	Age
		Kadappuram/Viyyam/Periyar	Sand/Clay/Sand	Holocene
		Guruvayur	Sand	Pleistocene
			Calcrete/Laterite	Cenozoic
		Warkali	Clayey sand/Sandstone	Mio-Pliocene
			Quartz vein/Pink Granophyre/	Neoproterozoic
			Gray Granophyre/Gabbro	
			Granite/Pegmatite/Quartz vein/Dolerite	Paleoproterozoic
		Closepet Granite	Granite	Archean
		Vengad	Mica Schist	Archean
Peninsular Gneissic Complex	Peninsular Gneiss-II		Garnet-Biotite-Gneiss	Archean
Southern Granulite Complex	Charnockite		Calc Granulite	Archean
			Hornblende-Diopside Gneiss	
			Hypersthene±Cordierite Gneiss	
			Charnockite/Pyroxene Granulite	
	Khondalite		Calc Granulite with Limestone	Archean
			Garnet-Biotite Gneiss	
			Garnet-Silliminite-Kyanite Gneiss	
			Garnet-Silliminite±Graphite±Cordierite Gneiss	
			Garnet Quartzite	
Peninsular Gneissic Complex	Peninsular Gneiss-I		Mylonite	Archean
			Garnet Gneiss	
			Granodiorite Gneiss	
			Granite Gneiss	
			Grey Hornblende Biotite Gneiss	
	Sittampundi-Mettupalayam Complex		Anorthosite/Peridotite	Archean
	Sargur (=Wyanad)		Meta-Pyroxinite/Meta-Ultramafite/Peridotite/Banded	Archean
			Quartzite/Amphibolite/Pyribolite/Kyanite	Magnetite
			Garnet-Mica Schist/Garnet-Silliminite-Kyanite	Graphite
			Gneiss/Garnet-Biotite-Silliminite	
			Kyanite Cordierite Gneiss/Quartzite	

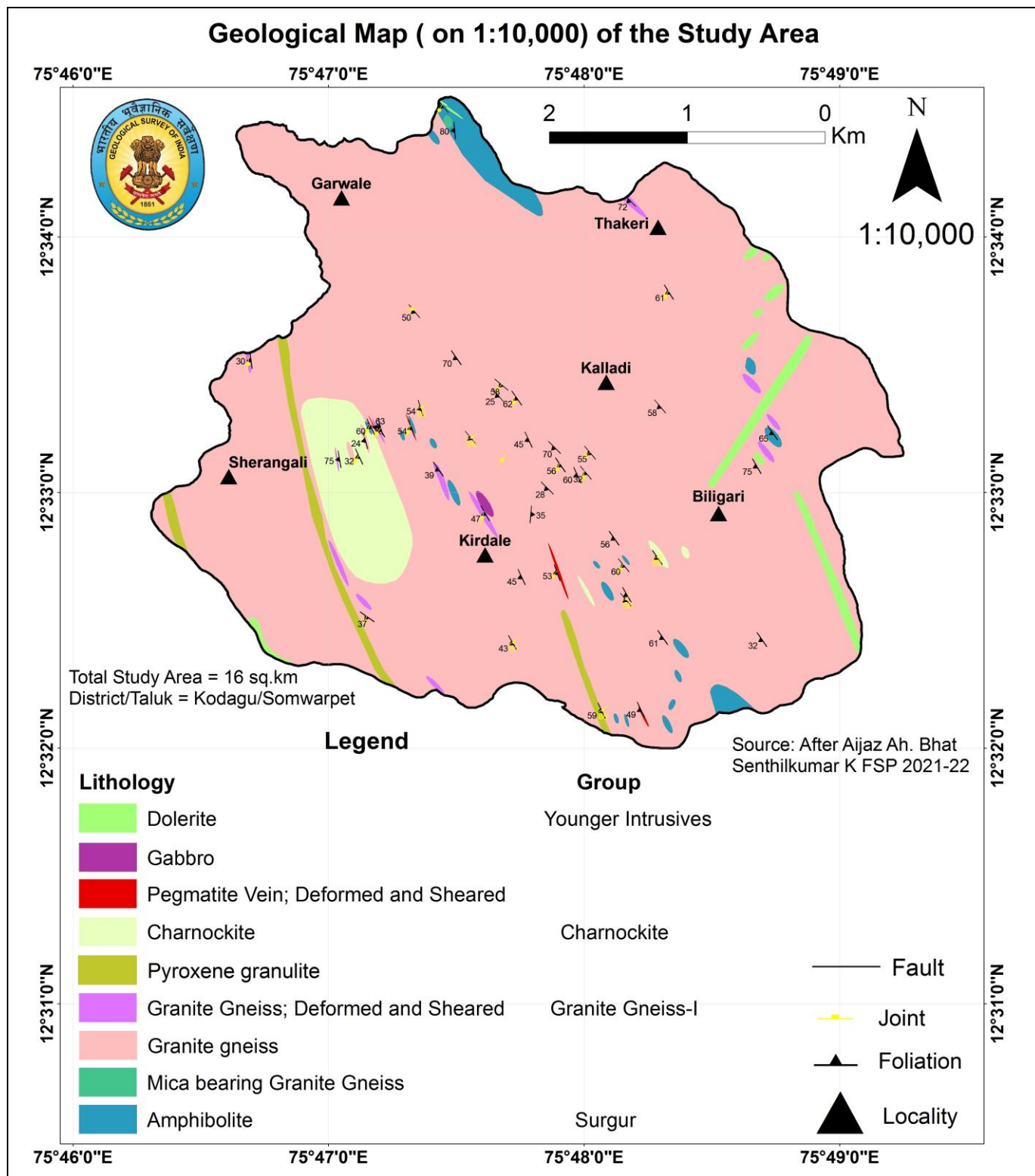


Figure-2.1: Geological Map (1:10,000 scale) of the study area (after Aijaz Ahmad & Senthilkumar K)

Table-2.2: Litho-stratigraphy of the study area after the *Geological Survey of India (from 1949-2021)*.

Supergroup	Group	Formation	Lithology	Age
			Alluvium/Overburden	Recent
	Younger Intrusives	Warkali	Dolerite Gabbro Pegmatite/Quartz Veins	Palaeoproterozoic
Southern Granulite Complex	Charnockite		Charnockite Pyroxene Granulite	Archean
Peninsular Gneissic Complex	Peninsular Gneiss-I	Gneisses	Granite Gneiss	Archean
	Sargur (=Wyanad)		Amphibolite	Archean

2.2 Geology of the Study Area

The investigated area of 16 sq. km is occupied by rocks of the Sargur Group followed by rocks of Peninsular Gneiss-I, Charnockite and Younger Intrusives Group. The rocks from all Groups are of Archean age except Younger Intrusives which are Palaeoproterozoic age and stratigraphically Sargur Group of rocks are the oldest (*GQM Second edition, 2013, Geological Survey of India*). The geological map (1:50,000 scale) has been modified in the present study on upscaled geological mapping (1:10,000) in a 16 sq. km area based on field mapping without petrographic studies.

2.2.1 Sargur Group

The Sargur Group is designated to highly deformed supracrustal sequences gone through high-grade metamorphism equilibrated at ~8kbar pressure and ~700-750°C temperature around 2430 Ma in the late-Archean. Both the Sargur Group of rocks and Peninsular Gneisses are overlain unconformably by rock sequences (2.9-2.5 Ga) of the Dharwar Supergroup which is less deformed and less metamorphosed than the Sargur group (*Martin Guitreau et al., 2017*). In the study area only the Amphibolite rock type of the Sargur Group is reported which is described as follows:

Amphibolite: This rock type is shiny black to dark green colour, medium to coarse-grained seen as enclaves of narrow bands oriented parallel to regional foliation within the Granite Gneiss. It is composed of amphibole and plagioclase in varying proportions with a minor amount of quartz, biotite, garnet, magnetite, and ilmenite (*Prantick Santra et al., 2021*). It is highly prone to chemical weathering as observed in the study area. At several places in the study area, this rock type occurs in large dimensions in association with complex dyke systems wherein the litho-contact of amphibolite with host rock has been observed as very vulnerable to slope failures.



Figure-2.2: Amphibolite rock reported in Billigeri village, Somvarpet taluk Kodagu

2.2.2 Peninsular Gneissic Complex (PGC)

The recent studies on rock types of different ages occurring in the Indian Peninsula have made successfully to recognize the Peninsular Gneissic Complex (PGC) into Older Gneiss Complex (OGC or ~Peninsular Gneiss-I) and Younger Gneiss Complex (YGC or ~Peninsular Gneiss-II). The Older Gneiss Complex is older than 3000 m.y having mainly Tonalite-Trondhjemite-Granodiorite (TTG) composition while the Younger Gneissic Complex is having largely reworked and mobilized Gneisses of around 2600 m.y. The Older Gneissic Complex (PGC-I) encompasses varieties of Gneisses, Migmatites, Hornblende-Biotite-Gneiss, Biotite-Gneiss, Biotite-Hornblende-Gneiss, Garnetiferous Hornblende-Biotite-Gneiss (Prantick Santra *et al.*, 2021) which are common varieties occurring at a regional scale.

Granite Gneisses: This rock type encompasses varieties of Gneisses which are banded, mesocratic to leucocratic in colour, coarse-grained, compositionally vary from tonalite to trondhjemite and are composed of quartz, plagioclase, hornblende, biotite, k-feldspar and rare garnet (Prantick Santra *et al.*, 2021) varieties. However T.S.S. Murthy *et al.*, 1979 reported these rock types as coarse-grained, leucocratic to mesocratic consisting of quartz, plagioclase and minor amounts of mafic minerals while B.R.C Iyengar, 1954 reported common varieties containing quartz and acid to intermediate varieties of feldspars, biotite and rarely hornblende. The accessory minerals include apatite, magnetite, and mica with pink garnet widespread and frequent (B.R.C Iyengar, 1954) and they vary in color from grey to pink with a regional strike of foliation N25°W (C.R. Veeraraghavan, 1961), NNW-SSE (B.R.C Iyengar, 1954). However, C.R. Veeraraghavan, 1961 witnessed from its microscopic study the presence of quartz, plagioclase feldspar, and biotite mica with microcline showing cross-hatched twinning. The gneissosity is very prominent and is defined by alternate dark and white compositional layering. The leucosome is white to pinkish white and composed of quartz, k-feldspar, garnet at places and occasionally magnetites and

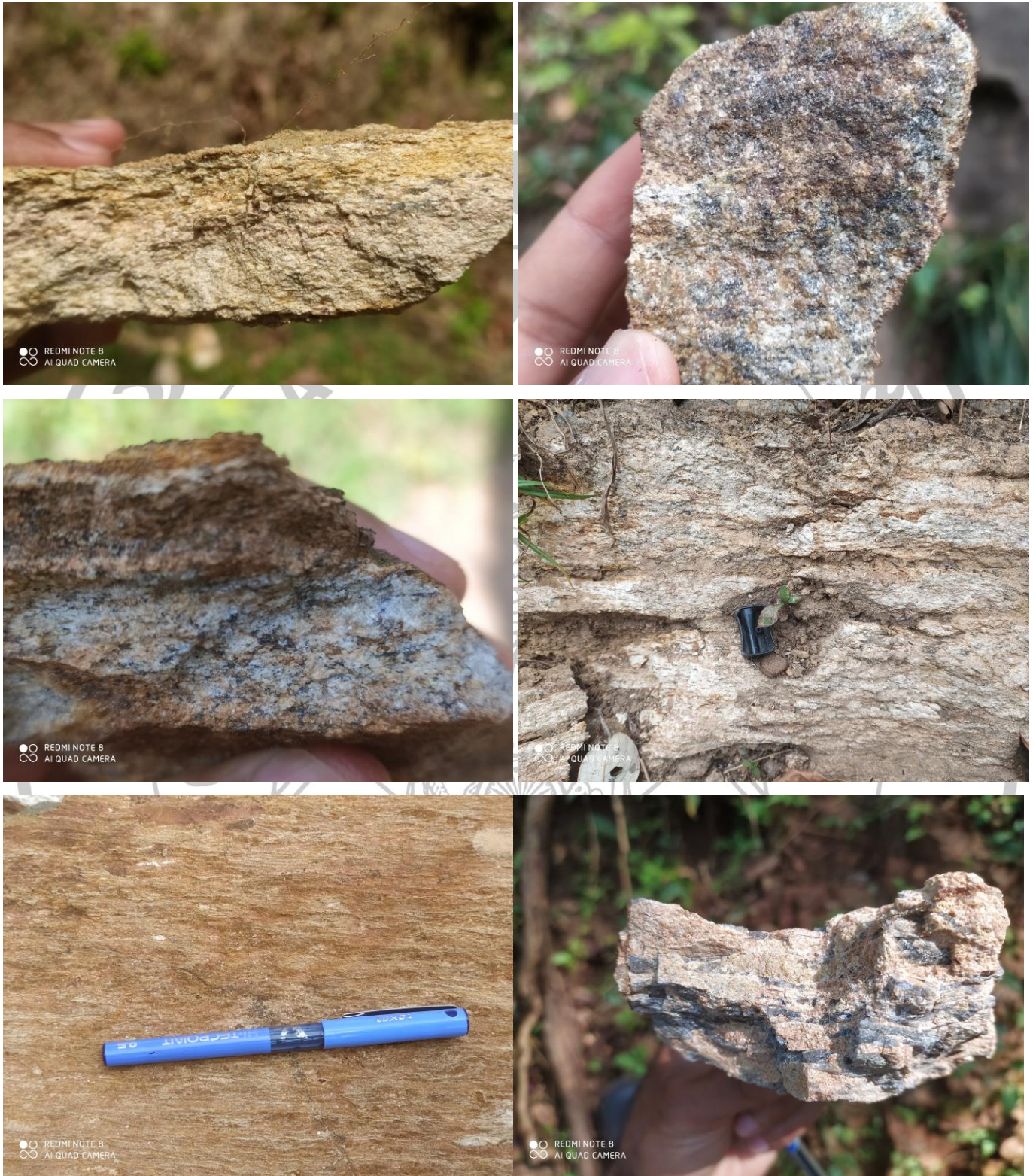


Figure-2.3: Granite Gneiss varieties occurring in the study area

other opaques, the paleosome is grey to greyish white and retains the pre-anatexis characteristics and the melanosome is very dark containing ferromagnesian, aluminium, or calcic-rich minerals such as

hornblende, biotite, plagioclase and garnets (*Prantick Santra et al., 2021*). In the present study, several deformed and highly sheared thin bands have been reported in the study area within Granite Gneiss. These deformed and highly sheared bands are sometimes associated with Pegmatite veins and are evolved to mylonite fabric. These deformed and highly sheared bands are witnessed as highly vulnerable to failure on slopes where these litho bands are oriented parallel to slope dip.

2.2.3 Charnockite

The Charnockite suite of rocks varies from Enderbite to Charnockite which contains K-feldspar, quartz, plagioclase, and orthopyroxene with a minor amount of garnet and hornblende and the proportion of plagioclase, quartz and K-feldspars vary widely (*Prantick Santra et al., 2021*). The Charnockite Group also comprises Mafic Granulites which are very dark in colour and contains garnet, clinopyroxene, orthopyroxene, plagioclase, and hornblende with minor amounts of magnetite, quartz and pyrite (*Prantick Santra et al., 2021*). The granoblastic texture is very prominently observed in the hand specimen. On the weathered surface, it shows reddish-brown colour.



Figure-2.4: Charnockite and Mafic Granulite rock types occurring in the study area

2.3 Geological Structure in the Study Area

The rock types in the study area are having well-developed foliation oriented at an average trend of 325° and dipping in the SW direction at an average dip amount of 55° . Four joint sets are recorded in the study area which is shown in table-2.3. Among these, the NW-SE trending joint set (J2) is traversing parallel to the foliation and the other three joint sets (J1, J3, J4) are trending NE-SW and dipping in different directions. These four joint sets along with foliation are making different interference patterns in the study area by which the rock types are breaking down (physical weathering) even into smaller orthogonal pieces (*figure-2.6*). Joint set J1 is closely spaced, mostly having a perpendicular relationship with the foliation and it would be the cleavage plane of the regional fold structure in the area. These joint sets are playing a prominent role in the evolution of hilly terrains and the development of different geomorphological features in the area. The NE-SW oriented joint sets J1, J3, and J4 are found the most responsible factors for developing, evolving, and orientation of lower-order drainage systems (1st, 2nd, 3rd, 4th & 5th) in the area. This factor is supported by the logarithm curve (*figure-2.5*) which yielded a straight line plot up to the 5th order and then shows major deviation further onward, this is possibly due to the reason that stream segments up to the 5th order in the area are following similar geological structure (J1, J3, J4) and there onwards the stream segments of higher orders are following the regional foliation plane.

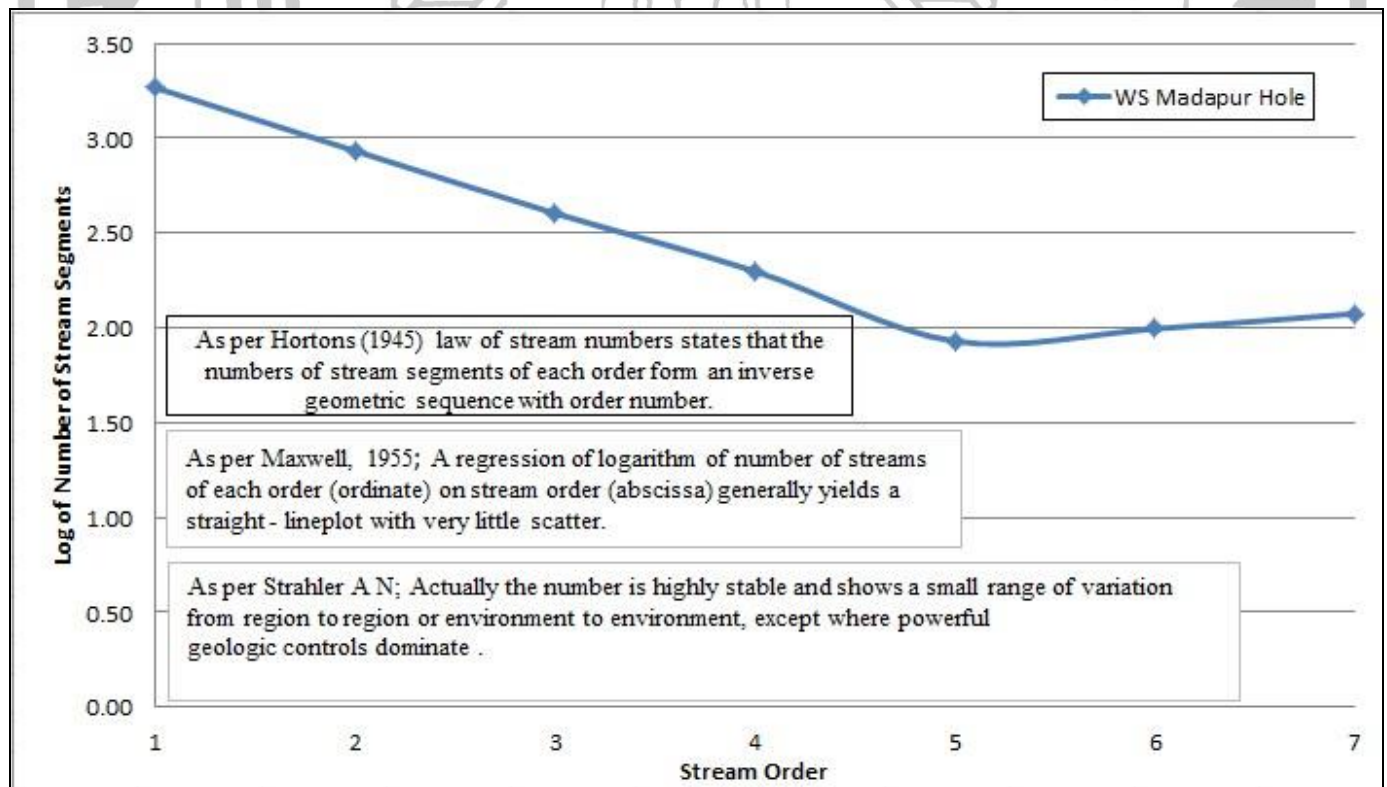
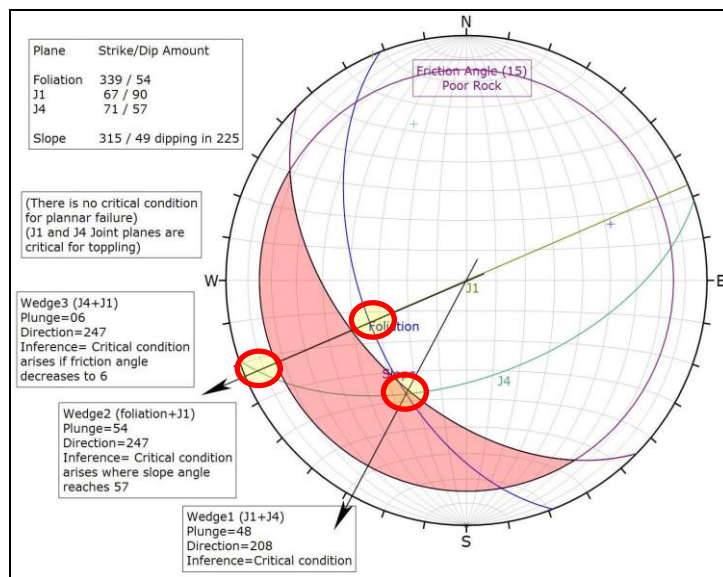


Figure-2.5: Logarithm curve of Madapur Hole watershed in which study area is situated



Figure-2.6: Disintegration of rock into smaller orthogonal pieces due to joint interference impact in the study area

The geological structures including foliation and four joint sets have been analysed thoroughly in kinematic analysis. At several places in the study area, the interference of these geological structures is one major cause for occurring landslide incidences. The foliation and joint set data of three different locations in the study area have been plotted on a stereonet plot which revealed three different conditions of interference (*figure-2.7*) among which joint interference between foliation+J1+J4 (condition 1) is the most favourable condition in the area to dislocate the rock blocks/fragments which later move down in south-west direction. The result of this joint interference has evolved the regional topography of the area and formed long ridges and valleys trending in the NW-SE direction and steep slopes in the SW direction. Besides these three different conditions of interference in the study area are making the rock domains vulnerable to planer, wedge, and topple failures where all eligible conditions meet w.r.t slope angle and direction.



→ Trend direction
○ Intersection

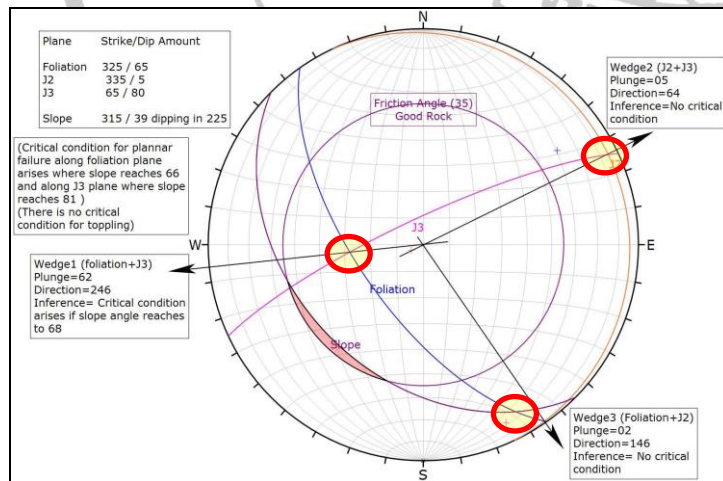
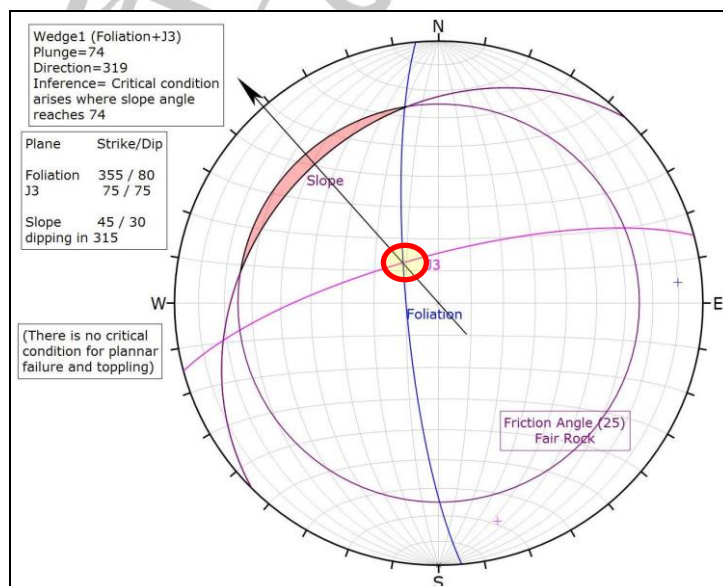


Figure-2.7: Stereonet plots of the geological structure of three different locations in the study area which show eligible conditions for different types of failures in the rock domain. The angle of internal friction used is determined from the RMR value

Table-2.3: Geometrical parameters of foliation and four different joint sets developed in the study area.

Foliation					
Location No.	Y	X	Strike	Dip	Azimuth
8	12.55337222	75.79625278	335	45	245
15	12.55552222	75.80484444	320	58	230
39	12.5457	75.80463889	325	65	235
59	12.5525	75.80027778	320	55	230
61	12.55119444	75.8	320	32	230
62	12.55105556	75.79944444	335	60	245
63	12.55172222	75.79833333	325	56	235
65	12.55283333	75.79794444	315	70	225
81	12.55625	75.79427778	320	25	230
82	12.55691667	75.7945	310	58	220
83	12.55608333	75.79547222	325	62	235
86	12.55872222	75.79152778	325	70	235
89	12.56172778	75.78881111	320	50	230
98	12.56297222	75.80541667	328	61	238
100	12.54516667	75.80247222	320	60	230
102	12.54694444	75.80183333	325	56	235
105	12.54325	75.80266667	330	65	240
106	12.54290556	75.80261944	320	80	230
111	12.54441667	75.79580556	335	45	245
114	12.540114	75.795224	330	43	240
118	12.54047222	75.805	325	61	235
125	12.54855556	75.79341667	330	47	240
133	12.55402778	75.78658333	330	60	240
134	12.55333333	75.78561111	345	24	255
135	12.55227778	75.78519444	335	32	245
139	12.55019444	75.79747222	315	28	225
154	12.55347222	75.7925	320	51	230
159	12.55544444	75.78922222	343	54	253

168	12.54033333	75.81147222	325	32	235
185	12.53208333	75.80522222	330	45	240
190	12.53575	75.80358333	335	49	245
192	12.53569444	75.80102778	335	59	245
200	13.04613889	75.80625	330	70	240
202	12.55163889	75.81113889	330	75	240
204	12.55383333	75.81216667	325	65	235
216	12.56969444	75.80213889	315	72	225
221	12.57358333	75.79141667	355	80	265
222	12.57511111	75.79066667	320	89	230
226	12.55425	75.78658333	345	70	255
235	12.54472222	75.79811111	340	53	250
240	12.55144444	75.79035556	325	39	235
241	12.55427778	75.78641667	310	63	40
242	12.55422222	75.78594444	334	60	244
243	12.55213889	75.78388889	350	75	260
244	12.55861111	75.77811111	353	30	263
245	12.55416667	75.78861111	339	54	249
248	12.54177778	75.78577778	305	37	215
260	12.56529444	75.80454444	315	70	225
262	12.56671944	75.80320556	320	45	230
264	12.56527778	75.80352778	310	25	220
267	12.56340278	75.8035	325	50	235
269	12.56331389	75.80622222	320	60	230
274	12.56225	75.80774722	320	58	230
285	12.56083333	75.80550556	325	55	235
301	12.56472222	75.79991667	295	24	205
303	12.56563889	75.79863889	350	65	260
306	12.56744444	75.79402778	320	60	230
311	12.54002778	75.78986111	335	28	245
312	12.55919444	75.78902778	300	18	210

326	12.53980556	75.79213889	335	55	245
334	12.54461111	75.78825	323	36	233
336	12.54538889	75.78891667	325	10	235
340	12.53722222	75.79844444	340	33	250
364	12.549	75.77788889	322	24	232
365	12.54738889	75.77705556	337	45	247
367	12.54663889	75.77569444	330	39	240
372	12.54566667	75.78252778	355	59	265
387	12.54366667	75.77705556	325	15	235
446	12.55830556	75.81358333	325	56	235
497	12.54177778	75.8125	330	62	240
503	12.53869444	75.81427778	330	30	240
507	12.53652778	75.81322222	337	39	247
513	12.54688889	75.81644444	335	85	245
520	12.54263889	75.815	350	68	80
524	12.54913889	75.81202778	320	70	230
533	12.5565	75.77641667	325	40	235
542	12.55780556	75.80763889	330	52	240
580	12.57075	75.78427778	320	75	230
608	12.56147222	75.78361111	310	50	220
640	12.55822222	75.79472222	320	69	230
648	12.56644444	75.787	290	43	200
653	12.56455556	75.79102778	310	58	220

Joint Set J1

Location No.	Y	X	Strike	Dip	Azimuth
39	12.5457	75.80463889	70	88	160
59	12.5525	75.80027778	40	90	0
61	12.55119444	75.8	80	90	0
63	12.55172222	75.79833333	65	90	0
82	12.55691667	75.7945	55	90	0
83	12.55608333	75.79547222	80	90	0

90	12.56197222	75.789	5	90	0
98	12.56297222	75.80541667	60	90	0
100	12.54516667	75.80247222	60	90	0
106	12.54290556	75.80261944	50	86	140
114	12.540114	75.795224	54	81	144
125	12.54855556	75.79341667	75	90	0
133	12.55402778	75.78658333	55	90	0
135	12.55227778	75.78519444	55	90	0
148	12.55230556	75.79477778	57	90	0
154	12.55347222	75.7925	60	86	150
159	12.55544444	75.78922222	62	88	152
185	12.53208333	75.80522222	65	90	0
192	12.53569444	75.80102778	55	88	145
200	13.04613889	75.80625	50	78	140
222	12.57511111	75.79066667	60	90	0
235	12.54472222	75.79811111	48	90	0
242	12.55422222	75.78594444	65	90	0
244	12.55861111	75.77811111	84	90	0
245	12.55416667	75.78861111	67	90	0
248	12.54177778	75.78577778	75	90	0
301	12.56472222	75.79991667	52	83	142
303	12.56563889	75.79863889	50	87	140
306	12.56744444	75.79402778	55	88	145
311	12.54002778	75.78986111	59	90	0
336	12.54538889	75.78891667	54	90	0
365	12.54738889	75.77705556	70	90	0
497	12.54177778	75.8125	60	90	0
503	12.53869444	75.81427778	65	90	0
507	12.53652778	75.81322222	70	90	0
533	12.5565	75.77641667	60	72	150
542	12.55780556	75.80763889	70	76	160

545	12.55663889	75.80958333	80	85	170
640	12.55822222	75.79472222	47	90	0
Joint Set J2					
Location No.	Y	X	Strike	Dip	Azimuth
15	12.55552222	75.80484444	285	27	15
59	12.5525	75.80027778	315	78	45
61	12.55119444	75.8	335	15	65
82	12.55691667	75.7945	270	26	360
89	12.56172778	75.78881111	320	6	50
90	12.56197222	75.789	285	90	0
114	12.540114	75.795224	292	65	22
135	12.55227778	75.78519444	287	82	17
148	12.55230556	75.79477778	334	65	64
153	12.55413889	75.79291667	319	71	49
168	12.54033333	75.81147222	334	80	64
204	12.55383333	75.81216667	335	5	65
222	12.57511111	75.79066667	280	90	0
226	12.55425	75.78658333	350	6	80
244	12.55861111	75.77811111	346	59	76
303	12.56563889	75.79863889	345	30	75
311	12.54002778	75.78986111	338	79	68
340	12.53722222	75.79844444	285	84	15
367	12.54663889	75.77569444	333	32	63
507	12.53652778	75.81322222	354	24	84
542	12.55780556	75.80763889	345	45	75
608	12.56147222	75.78361111	353	4	83
Joint Set J3					
Location No.	Y	X	Strike	Dip	Azimuth
15	12.55552222	75.80484444	45	80	315
65	12.55283333	75.79794444	80	87	350
82	12.55691667	75.7945	40	79	310

89	12.56172778	75.78881111	50	75	320
90	12.56197222	75.789	45	10	315
102	12.54694444	75.80183333	85	82	355
105	12.54325	75.80266667	50	82	320
111	12.54441667	75.79580556	55	82	325
134	12.55333333	75.78561111	65	79	335
153	12.55413889	75.79291667	37	33	307
159	12.55544444	75.78922222	30	22	300
168	12.54033333	75.81147222	83	78	353
190	12.53575	75.80358333	67	85	337
202	12.55163889	75.81113889	55	88	325
204	12.55383333	75.81216667	65	80	335
221	12.57358333	75.79141667	75	75	345
260	12.56529444	75.80454444	60	85	330
269	12.56331389	75.80622222	60	89	330
285	12.56083333	75.80550556	60	89	330
303	12.56563889	75.79863889	75	55	345
336	12.54538889	75.78891667	10	65	280
367	12.54663889	75.77569444	73	74	343
513	12.54688889	75.81644444	70	85	340
520	12.54263889	75.815	85	85	355
524	12.54913889	75.81202778	75	70	345
608	12.56147222	75.78361111	43	70	313
648	12.56644444	75.787	73	55	343

Joint Set J4

Location No.	Y	X	Strike	Dip	Azimuth
82	12.55691667	75.7945	10	41	100
153	12.55413889	75.79291667	85	45	175
159	12.55544444	75.78922222	42	49	132
243	12.55213889	75.78388889	40	10	130
245	12.55416667	75.78861111	71	57	161

267	12.56340278	75.8035	50	55	140
274	12.56225	75.80774722	75	83	165
306	12.56744444	75.79402778	75	5	165
524	12.54913889	75.81202778	60	6	150



CHAPTER – 3

LANDSLIDE INVENTORY

Historic information on landslide occurrences is considered as the fundamental part of the landslide susceptibility studies, which give shrewdness into the frequency, volumes, damage, and types of the landslide phenomena (Van Westen *et al.*, 2006; Regmi *et al.*, 2014; Youssef *et al.*, 2014). Therefore, landslide occurrences in the past and present are key to future spatial prediction, threshold modelling and hazard and vulnerability analysis. A landslide inventory map provides the basic information for evaluating landslide hazards or risks and is a prerequisite for such studies (Guzzetti *et al.*, 1999; Regmi *et al.*, 2014). The landslide inventory has been prepared in the area of investigation by exploring pre-field-based studies and later by field investigation to validate the pre-field data and collected geo-parametric data at landslide incidence locations. In the pre-field-based study, various remote sensing data sources, topographic maps, and previously reported landslide inventories by earlier workers have been utilized. The field survey has been carried out in the study area to investigate various aspects of landslides that occurred, prevailing geo-factor themes, various basin morphometric parameters, rainfall patterns, slope variations, and geological-slope forming material parameters; to prepare surface domain map and to collect the samples in different surface domains for geotechnical laboratory studies. However, such a type of landslide inventory study on a 1:10,000 scale is the first attempt in the present study area.

3.1 Remote Sensing Data Inputs

In pre-field studies, freely available satellite images were accessed through Google Earth and were utilized as a remote sensing source for the demarcation of visible landslide boundaries. Landslide locations earlier recorded by previous workers in the present study area were also explored and added to the pre-field-based landslide inventory. It is worthy utilizing freely available satellite images through Google Earth for landslide boundary demarcation but there were a few constraints of having vegetation cover and date of imagery capture. In the Western Ghats, the landslide-influenced areas quickly come under hiding vegetation cover after their occurrences. This factor minimizes the level of identifying and demarcating the landslide boundaries on satellite images accessed through Google Earth. The date of imagery capture plays a very important role during the whole investigation period. Therefore there was the least number of landslide incidences demarcated by utilizing satellite images through Google Earth; however, most of the landslides in the area were recorded during the field study. Keeping these constraints in the pre-field-based study in consideration, field check and validation is important even though high-resolution imageries were utilized. These constraints of pre-field studies were carefully handled and rectified during field studies.

3.2 Landslide Inventory

Preparing a landslide map is important to document the extend of landslide phenomena in a region, to investigate the distribution, type, pattern, recurrence and statics of slope failures, to determine the landslide susceptibility, hazard, vulnerability and risk and study the evaluation of landscapes dominated by mass-wasting processes. Initially, landslide inventory was prepared by the consulting landslide report and studying multi-temporal open-source Google imageries and later prefield landslide inventory has been validated during the field study. A total of 12 no's of the prefield landslide has been identified by morphology, different in the vegetation pattern and depletion of mass, etc. There was a constraint in the demarcation of the landslides in the Western Ghats due to quick vegetation growth. These 12 no's of landslides were validated and added 44 no's of landslides added up in the landslide inventory during the field study. Most of the landslides are in smaller dimensions, shallow translational and triggered by rainfall. As per the material concern 33 no's of debris slide, 14 no's of earth slide, 5 no's debris flows and 01 no's earth flow identified, and most of the landslides were initiated during the 2018 monsoon. Predisposing factors played a vital role in the initiation of the landslide in the study area. In the Kirudale road section many smaller cut slope failures are documented due to the presence of weathered material and slope angle etc.). In the study area towards the east NNE-SSE ridge identified 03nos of larger dimensional debris flows, that slope also failed due to the predisposing factors like slope angle and structural disposition of the litho-units. In the field, it is observed that the presence of sheared granite and its dip towards the slopping direction (cataclinal) lead to the initiation of slope failures. During the field investigation, the workers have given thrust upon landslide classification, causative factors for the occurrence of landslides, and identification of different thematic features accelerating mass/land movement in the area. The workers have suggested generic remedial measures after deliberation on all attributes of landslides that occurred in the area.

3.3 Landslide Types and Their Causative Factors

It is observed that most of the landslides have occurred in the overburden failure domain and were rainfall-induced/triggered. From the analysis of daily rainfall data collected from the study area, it is revealed that these rainfall-induced/triggered landslides may have occurred in multiple rainfall events (as discussed in section 1.3) in which the geotechnical parameters of overburden material may have fluctuated in response to changes occurring in material saturation limit, slope morphometry behaviour and drainage morphometric parameters. However, during the field investigation, both natural, as well as anthropogenic-related causes, were found to be responsible for landslide occurrences in the study area and the multiple causative factors in both natural as well as anthropogenic have acted in landslide occurrences in the study area. There were only 10% of debris/earth flows occurred in the study area and rest 90% were debris/earth

slides in overburden domain. The places where debris/earth flows were occurred, the overburden material may have been got saturated during intensive rainfall period before failure.

In natural causes, the decrease in shear strength of in-situ soil on moderate to steep slopes, erosion of stream bank material or toe cut of natural slopes by water action, and favorable joint interference pattern for detachment of rock fragments are included. These natural causes came into work by incessant rainfall trigger. The infiltration rate of rain waters into in-situ soil and its drain-out rate may not have run proportionately due to which the increasing pore water pressures may have decreased the in-situ soil's strength before the slope failures in the overburden domain may have occurred. Several surface cracks have developed in the overburden material by this water infiltration-related cause. The streams with large catchments received runoff waters in large quantities and this resulted in a huge accumulation of stream waters thereby causing intense stream bank erosion. The erosion of stream bank material which always forms the base of the uprising slope created instability in the uprising slope and lead to slope failures in the area. The interference between differently oriented joint sets and foliation plane is existing in rock surface domains in the study area and it became favorable with preferably oriented slopes at some places for detachment and sliding down of rock fragments/angular boulders under gravity effect.

In anthropogenic causes, cutting of natural slopes for road construction & settlement buildings for both domestic as well as commercial use and modification of natural slopes for cultivation purposes are included. Although it is found that most small dimensional landslides have occurred by anthropogenic causes but few large dimensional landslides have also occurred in the study area. The unplanned way of cutting natural slopes for road construction & settlement buildings is dominantly seen in the study area and the cut slopes are left behind without any reinforcement support. In the rainfall period, the cut-slopes in moderate to steep gradient slopes increase their unit mass slowly and fail under the gravity effect in under-saturated conditions. This process leads to the occurrence of small dimensional and shallow surface landslides along roads and in the surroundings of settlements in the study area. But where materials have allowed further saturation deep in the earth's surface along the existing slip plane, large dimensional and deep surface landslides have occurred under the same conditions.

Table-3.1: Details of landslide incidences reported in the study area.

Sl. No.	Landslide No.	Longitude (DMS)	Latitude (DMS)	Toposheet No.
1	ls3	75 ° 48' 10.600"E	12 ° 32' 40.600"N	48P/14
2	ls4	75 ° 48' 11.000"E	12 ° 32' 38.600"N	48P/14
3	ls5	75 ° 48' 5.850"E	12 ° 32' 41.040"N	48P/14

4	ls6	75 ° 47' 57.600"E	12 ° 32' 37.220"N	48P/14
5	ls7	75 ° 47' 47.870"E	12 ° 32' 40.810"N	48P/14
6	ls8	75 ° 47' 44.700"E	12 ° 32' 43.800"N	48P/14
7	ls9	75 ° 47' 12.000"E	12 ° 32' 58.000"N	48P/14
8	ls10	75 ° 47' 24.400"E	12 ° 33' 5.800"N	48P/14
9	ls11	75 ° 47' 18.100"E	12 ° 33' 6.400"N	48P/14
10	ls12	75 ° 47' 13.600"E	12 ° 33' 13.600"N	48P/14
11	ls13	75 ° 47' 17.600"E	12 ° 33' 12.140"N	48P/14
12	ls14	75 ° 47' 18.000"E	12 ° 33' 12.000"N	48P/14
13	ls15	75 ° 47' 42.000"E	12 ° 32' 59.300"N	48P/14
15	ls17	75 ° 47' 43.800"E	12 ° 32' 47.200"N	48P/14
16	ls18	75 ° 47' 29.700"E	12 ° 33' 14.600"N	48P/14
17	ls19	75 ° 47' 24.700"E	12 ° 33' 0.300"N	48P/14
18	ls20	75 ° 48' 42.100"E	12 ° 33' 16.500"N	48P/14
19	ls21	75 ° 48' 40.200"E	12 ° 33' 25.500"N	48P/14
20	ls22	75 ° 48' 39.600"E	12 ° 33' 27.100"N	48P/14
21	ls23	75 ° 47' 37.200"E	12 ° 34' 20.600"N	48P/14
22	ls24	75 ° 47' 37.100"E	12 ° 34' 18.000"N	48P/14
23	ls25	75 ° 47' 33.300"E	12 ° 34' 23.300"N	48P/14
24	ls26	75 ° 47' 26.400"E	12 ° 34' 30.400"N	48P/14
25	ls27	75 ° 47' 2.800"E	12 ° 33' 7.500"N	48P/14
26	ls28	75 ° 47' 8.700"E	12 ° 33' 17.500"N	48P/14
27	ls29	75 ° 46' 43.000"E	12 ° 33' 26.600"N	48P/14
28	ls30	75 ° 48' 6.300"E	12 ° 33' 46.900"N	48P/14

29	ls31	75 ° 47' 49.400"E	12 ° 33' 59.200"N	48P/14
30	ls32	75 ° 47' 41.900"E	12 ° 33' 59.900"N	48P/14
31	ls33	75 ° 47' 12.600"E	12 ° 32' 23.400"N	48P/14
32	ls34	75 ° 47' 22.700"E	12 ° 32' 31.500"N	48P/14
33	ls35	75 ° 47' 31.000"E	12 ° 32' 12.500"N	48P/14
34	ls36	75 ° 47' 42.200"E	12 ° 32' 20.000"N	48P/14
35	ls37	75 ° 46' 57.100"E	12 ° 32' 44.000"N	48P/14
36	ls38	75 ° 47' 4.000"E	12 ° 32' 25.000"N	48P/14
37	ls39	75 ° 48' 27.700"E	12 ° 32' 13.500"N	48P/14
38	ls40	75 ° 48' 29.500"E	12 ° 32' 17.500"N	48P/14
39	ls41	75 ° 48' 53.800"E	12 ° 33' 35.500"N	48P/14
40	ls42	75 ° 49' 0.800"E	12 ° 33' 21.200"N	48P/14
41	ls43	75 ° 48' 44.400"E	12 ° 32' 37.800"N	48P/14
42	ls44	75 ° 48' 37.500"E	12 ° 32' 41.600"N	48P/14
43	ls45	75 ° 48' 34.300"E	12 ° 32' 49.100"N	48P/14
44	ls46	75 ° 48' 30.700"E	12 ° 32' 49.600"N	48P/14
45	ls47	75 ° 48' 42.600"E	12 ° 32' 56.300"N	48P/14
46	ls48	75 ° 48' 35.000"E	12 ° 33' 4.400"N	48P/14
47	ls49	75 ° 48' 26.700"E	12 ° 33' 58.230"N	48P/14
48	ls50	75 ° 48' 27.960"E	12 ° 33' 54.340"N	48P/14
49	ls51	75 ° 48' 23.300"E	12 ° 33' 58.060"N	48P/14
50	ls52	75 ° 48' 22.140"E	12 ° 33' 59.390"N	48P/14
51	ls53	75 ° 48' 18.400"E	12 ° 33' 2.110"N	48P/14
52	ls54	75 ° 48' 10.560"E	12 ° 33' 47.510"N	48P/14
53	ls55	75 ° 47' 58.500"E	12 ° 33' 46.500"N	48P/14

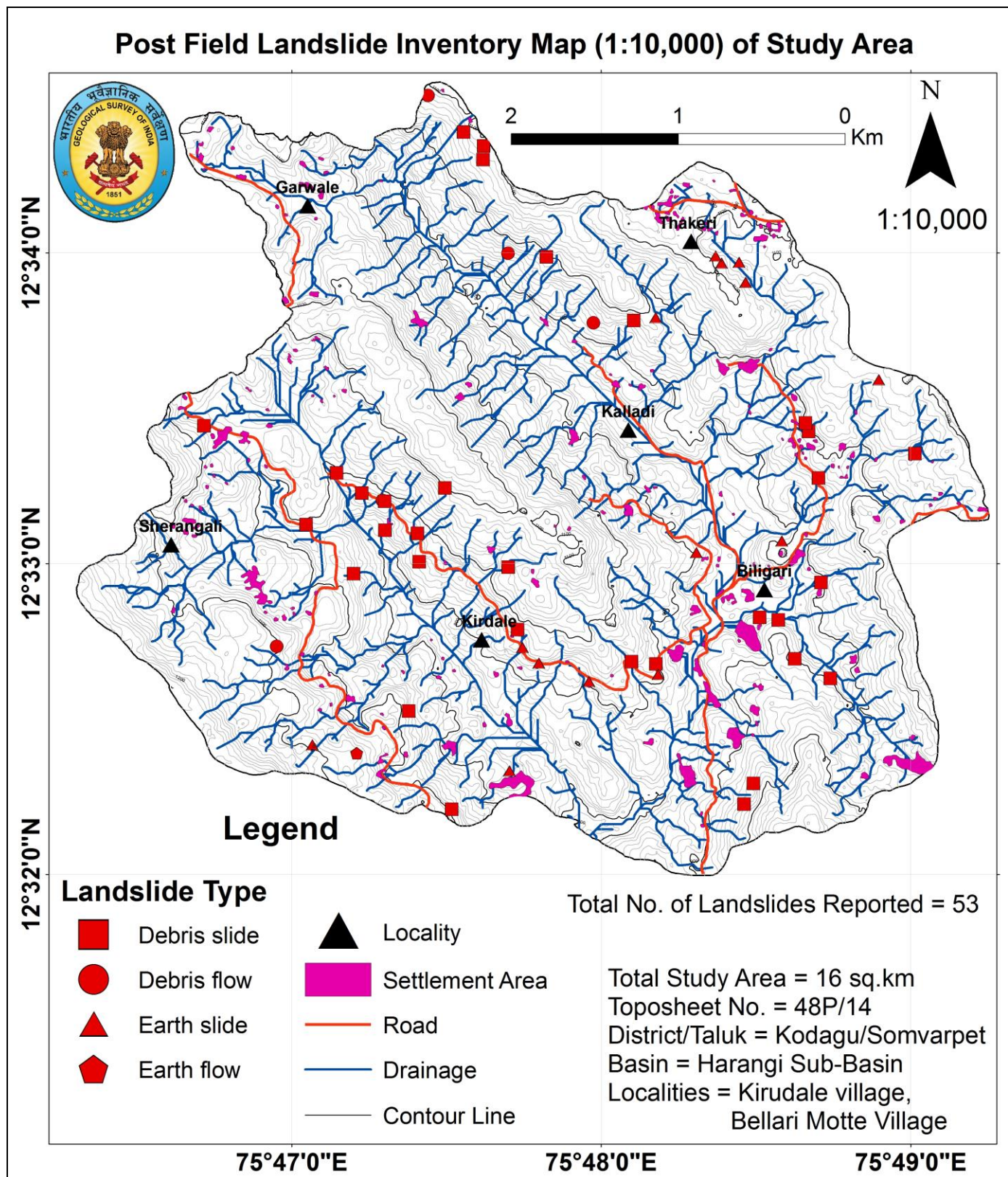


Figure-3.1: Landslide inventory map of the study area (Debris Slide/Flow=72%; Earth Slide/Flow=28%) Overall percentage of Flow Movement=10%



A)Debris flow near kalladi ($12^{\circ}33' 47.88''\text{N}/75^{\circ}48' 1.06'' \text{ E}$)



B)Debris flow near Hosakaralli ($12^{\circ}33' 30''\text{N}/75^{\circ}47' 26.26'' \text{ E}$)



C)Debris flow near the Kirudale road section
($12^{\circ}33' 16.67''\text{N}/75^{\circ}47' 18.78'' \text{ E}$)



D)Cut slope failure ($12^{\circ}33' 1.51''\text{N}/75^{\circ}47' 42.73'' \text{ E}$)



E)Surface cracks and its vertical displacement near kurra motte bane ($12^{\circ}34' 10.54''\text{N}/75^{\circ}47' 45.25'' \text{ E}$)



F)Cutslope failure near Shrangalli
($12^{\circ} 33'6.78''\text{N}/75^{\circ} 47' 3.77'' \text{ E}$)



G) Surface cracks and its vertical displacement in and around Garwale ($12^{\circ} 33' 38.10''\text{N}/75^{\circ} 47' 6.80''\text{E}$)



H) Developments of the cracks on the drying yard in and around Garwale ($12^{\circ} 33' 38.96''\text{N}/75^{\circ} 47' 3.95''\text{E}$)



I) Cut slope failures along Kirudale road section ($12^{\circ} 32' 42.31''\text{N}/75^{\circ} 48' 5.93''\text{E}$)



J) Cut slope failure near Biligeri school ($12^{\circ} 33' 25.50''\text{N}/75^{\circ} 39.96''\text{E}$)



K) Debris slide in and around Shrangalli falls ($12^{\circ} 32' 59.74''\text{N}/75^{\circ} 47' 11.16''\text{E}$)



L) Development of cracks on the wall at Biligeri Ghandi house ($12^{\circ} 27' 28.33''\text{N}/75^{\circ} 48' 26.83''\text{E}$)

Figure-3.2: List of photographs of various landslide types (A to L) recorded in the study area

CHAPTER – 4

GEO-THEMATIC MAPPING AND LANDSLIDE SUSCEPTIBILITY IN DIFFERENT LANDSLIDE FAILURE DOMAINS

4.1 Concept of Geo-Factor Map and Landslide Failure Domain

A geo-factor map commonly known as a thematic geo-factor map is spatially prepared to show a particular theme connected with a specific geographic area (Aijaz A Bhat *et. al.*, 2021). This map is of any kind of surface, subsurface features, or their parametric theme showing variations at smaller or larger scales which can accelerate any kind of earth's mass movement. Recent studies on landslide/mass movement have gained advanced methods of predicting slope failure susceptibility by analyzing and integrating various feature classes of geo-themes/geo-factors. Integration of various kinds of themes on the desired mapping scale and adopting a precise modeling methodology leads to preparing a categorized landslide susceptibility map. In the present investigation, the upscaled mapping methodology is adopted for the preparation of various geo-factor feature classes which are generic in nature. A landslide failure domain-based approach is adopted in the present investigation for predicting landslide susceptibility in each failure domain with defined responsible causative factors (see table-4.1). The relevant geo-factor maps in each landslide failure domain were prepared by incorporating both remote sensing as well as field inputs to enhance the qualitative property of each feature class. Although many geo-factors are being acted together in the occurrence of landslides in the study area, the focus was given to the most relevant and responsible geo-factor themes. By definition, a landslide failure domain is characterized by distinct and categorized units on the earth's surface which comprise well-defined earth-forming material of either rock or overburden. Broadly, the landslide failure domain can be the rock slide domain, rockfall domain in rock-covered areas or it can be debris slide/earth slide domain in overburden-covered slopes. There can be cut-slope domains both in rock-covered and overburden-covered domains after getting natural or man-made modifications. Each domain type is characterized by several thematic geo-factor feature classes as well as certain inherent geotechnical properties commonly known as variables that control the slope stability condition (see table-4.1). The first attempt at this kind of domain-based mapping and landslide susceptibility modeling is adopted in the present study so that a qualitative and land use management-based landslide susceptibility classification would be done.

Table-4.1: Failure domains and their relevant thematic geo-factors

Failure Domain	Field Variables	Thematic Variables
Rockslide	1. Daylighted slope 2. Poor rock mass	a. Kinematic failure map (Planar & Wedge) b. Geotechnical map (Rock)

Rockfall	1. Daylighted slope 2. Poor rock mass	a. Kinematic failure map (Toppling) b. Geotechnical map (Rock)
Debris slide and Earth slide	1. Rill or gully erosion 2. Micro landform 3. Strength of material (C & ϕ) 4. Vegetation cover and root	a. Stream Power Index (SPI) map b. Landform map c. Geotechnical map (Overburden) d. Landuse/landcover map e. Debris flow impact probability map
Cut-slope	1. Loose overburden material 2. Shallow regolith depth 3. Moderate to Steep slope	a. Regolith thickness map b. Slope gradient map b. Geotechnical map (Rock & Overburden) c. Relative relief map

4.2 Methodology

Landslide hazard zonation mapping is a practical approach for the categorization of hill slopes into zones of varying degrees of susceptibility based on the weightage of prevailing geo-factor themes (Aijaz A Bhat et. al., 2021). There are several methods to carry out landslide susceptibility zonation studies based on a knowledge-based/data-driven approach on regional scales (1:50000). However, methodologies/guidelines for landslide susceptibility zonation on a larger scale (1:5000/10000) are very few. Among these (Ghoshal T, 2013) proposed a multi-thematic and deterministic cum heuristic approach for the landslide susceptibility zonation mapping on Meso-scale (1:10000) and this model has a similar relevance in some parts of the model adopted for the present study. The present study is carried out as per the SOP for Meso Scale Landslide Susceptibility mapping, 2021 in which a terrain-specific rating system has been suggested in separate landslide failure domains.

In the present study, a pixel of 10m resolution has been taken as a mapping unit because it is easy to integrate data in GIS for spatial analysis and mathematical calculations. However, the slope facet map is used for field mapping use only. The geo-factor thematic maps for each landslide failure domain are being prepared by incorporating; pre-field-based inputs from remote sensing sources; field mapping-based inputs and laboratory-based inputs. The relevance of each geo-factor thematic map is being quantified in each landslide failure domain to ensure that the causative factor of one single landslide failure domain would not be extrapolated to other landslide failure domains. CartoDEM 10m derived geo-factor thematic maps (slope angle, stream power index, landform, slope aspect) were prepared in the pre-field study and were validated in field mapping. More than 75% of data from the pre-field study has been found satisfactory during the field validation. The preparation of landslide inventory is important for any model

to validate the susceptibility score map at the final. By keeping this thing on priority, the landslide inventory comprising 52 nos. of landslide incidences, has been prepared precisely, initially from multi-temporal satellite images through Google Earth, data from old reports of GSI, and other literature, and then later validated and updated during field studies. In field mapping, the natural hill slopes were surveyed and categorized into overburden and rock domain. The overburden domain has been further categorized based on slope-forming material type and its shear parameters (Cohesion and angle of internal friction) whereas rocky slopes were categorized based on RMR_{basic} .

In the post-field study, several geo-factor thematic maps were finalized after incorporating the field mapping inputs and the laboratory inputs. The LSER ratings of relevant geo-factor thematic classes in each landslide failure domain were determined heuristically after considering the study area-specific conditions. All rated geo-factor thematic maps were integrated in GIS software by using the Weighted Multi-class Index Overlay method. The categorization of the final landslide susceptibility score map of each landslide failure domain into low, moderate, and high have been performed by keeping into consideration the satisfactory level of field visualization assessment of hill slope vulnerability to failures and the validation of the susceptibility score map by landslide inventory.

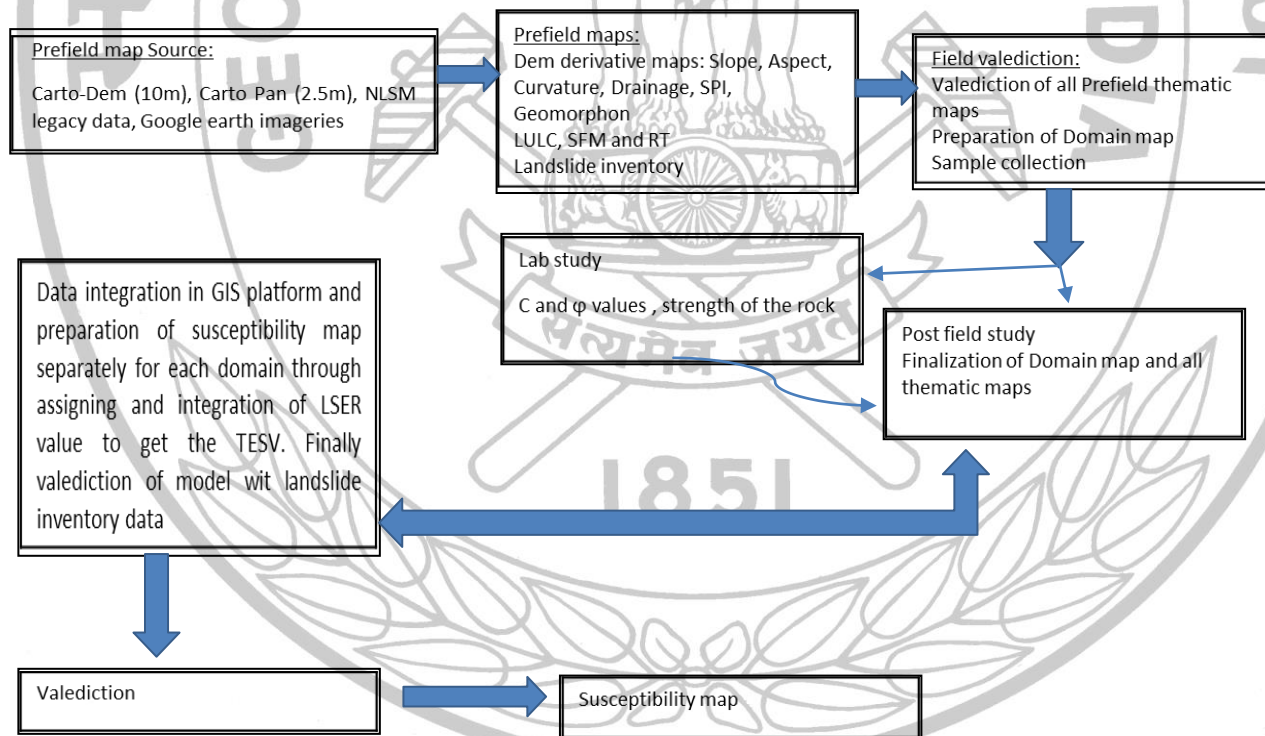


Figure-4.1: Flow chart showing methodology for the preparation of Meso-scale susceptibility map

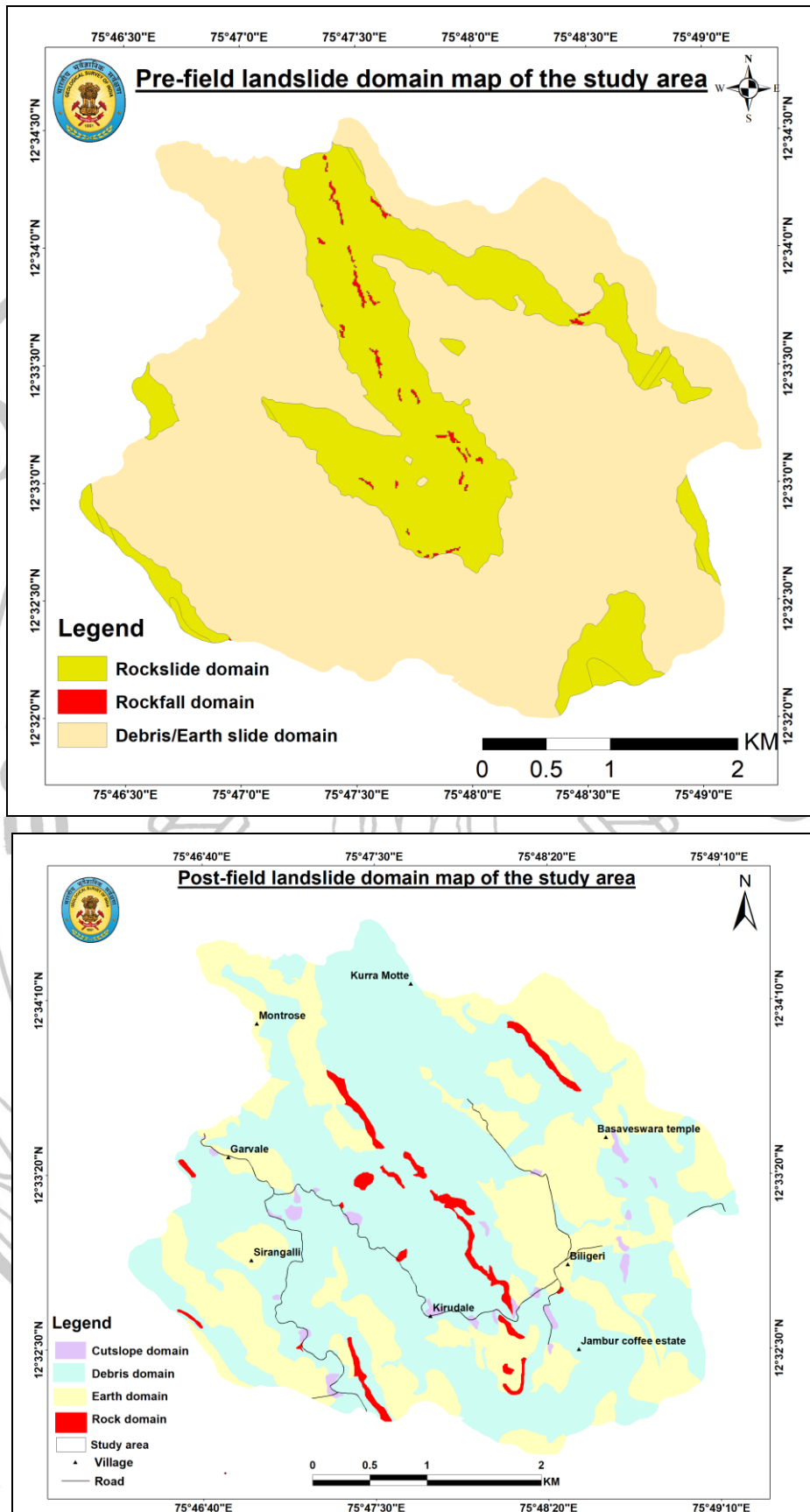


Figure-4.2: Pre-field and post field landslide failure domain map of the study area

4.3 Rock Slide and Rock Fall Domains

The rock slide and rockfall domains are failure domains restricted to the rocky slopes on the earth's surface. The stability of rock slopes is significantly influenced by the structural elements of the rock on the slope. Structural elements refer to naturally occurring weak planes in the rock such as bedding planes, joints, and faults, which are generally termed as discontinuities (Aijaz A Bhat *et. al.*, 2021). The significance of discontinuities is that they are planes of weakness in the intact and much stronger rock which tends to fail preferentially along these surfaces. The rock failure types, rock slide, and rockfall are very often determined by the orientation of discontinuities often dip direction and dip amount with respect to the orientation of the corresponding slope. In the present study, the significance of the orientation of discontinuities in the rock and the orientation of the corresponding slope is taken as an advantage to determine the type of failure that may occur in rock domains shown in *figure-4.3*. The very purpose to study the rock slide and rockfall domains separately is to select the most relevant variables which will determine the strength of the rock mass. Apart from the slope angle map, the kinematic failure analysis and rock mass rating (RMR_{basic}) are the two geo-factors that have been taken into account for landslide susceptibility modeling in both the rock slide and rockfall domain.

4.3.1 Kinematic Failure Analysis

The kinematic failure analysis means identifying possible modes of slope failure by determining the influence of the discontinuities on slope stability, which involves studying the relationship between the orientation of the discontinuity and the slope face. The analysis of this relationship is possible only after the well-planned geological mapping on the desired scale in which different sets of discontinuities in rock would be recorded as more as possible by the field Geologist.

In the present study, the data on the orientation of the discontinuities and the slope faces has been recorded in rock slopes through field-based geological mapping techniques. The recorded data has been geometrically classified into different sets of discontinuities (*see table-4.3*) to use in kinematic failure analysis. There is a maximum of 5 sets of discontinuities including the foliation plane which are existing in rocks in the study area. The kinematic failure analysis is being done to identify the potential failures of the planar, wedge, and topple by adopting Markland's test for kinematic failures. The data of orientation of different sets of discontinuity planes are being fed in GIS software using a fishnet toolset as a 10m x 10m polygon for identifying planar and topple failures. However, for identifying the wedge failure, the stereonet projections for each single data set of discontinuity planes are prepared. The resulting trend and plunge data of each intersection is being also fed in GIS using a 10m x 10m fishnet polygon. For either plane or wedge failure to take place, it is fundamental that the dip of the sliding plane in the case of plane

failure or the plunge of the line of intersection in the case of wedge failure, be less than the dip of the slope face. That is, the sliding surface “daylights” in the slope face.

For a toppling failure to occur, the dip direction of the discontinuities dipping into the face must be within about 10° of the dip direction of the face so that a series of slabs are formed parallel to the face. Also, the dip of the planes must be steep enough for the interlayer slip to occur. Moreover, in the case of planar failure, the dip of the sliding plane must be greater than the angle of internal friction (ϕ) and in the case of wedge failure, the plunge of the line of intersection must be greater than the average friction angle of the two slide planes.

The relationship between the direction in which the block of rock will slide and the orientation of the face can be readily identified by plotting the discontinuity data on the stereonet. However, it does not account the external forces such as water pressures or reinforcement procedures. Therefore, the usual practice is to use kinematic analysis to identify potentially unstable rock outcrops followed by a detailed stability analysis of those rock outcrops. In the present study, the slope face direction and slope angle which were used in the kinematic analysis are derived from CartoDEM 10m and the ϕ (angle of internal friction) has been proxy determined from RMR of the corresponding rock outcrop (see table-4.2) as suggested by GHRM Division, GSI, CHQ, Kolkata. The critical condition to failure in each pixel is calculated through given formulas as per Markland’s test. The critical condition “0” is considered a no-failure condition.

Table-4.2: Relationship between the RMR and angle of internal friction.

Property of Rock	Class				
RMR Value	100-81	80-61	60-41	40-21	<20
Rock Quality	Very Good	Good	Fair	Poor	Very Poor
Angle of internal friction	>45	45-35	34-25	24-15	<15

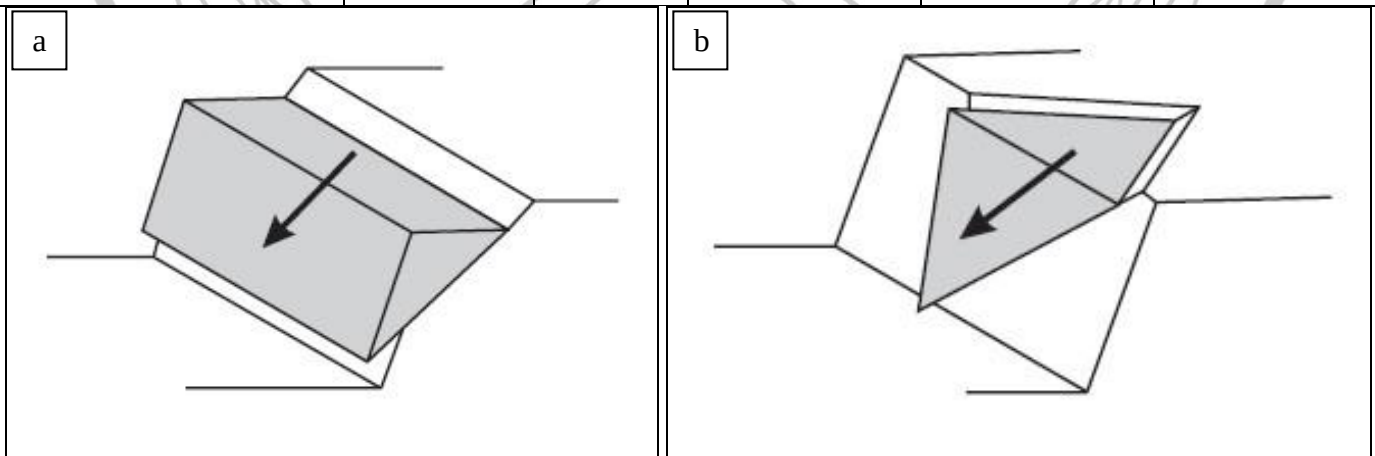


Figure-4.3: Block diagrams for (a) planar failure; (b) wedge failure

In case of planar failure, the critical condition to failure in each pixel is calculated by assigning class algorithm condition in ArcGIS platform as “**angle of internal friction of rock mass < dip amount of corresponding discontinuity plane < corresponding slope angle**” (as per the SOP guidelines).

In case of wedge failure, the critical condition to failure in each pixel is calculated by assigning class algorithm condition in ArcGIS platform as “**angle of internal friction of rock mass < plunge amount of intersection of corresponding discontinuity planes < corresponding slope angle**” (as per the SOP guidelines).

In case of toppling failure, the critical condition to failure in each pixel is calculated by assigning class algorithm condition in ArcGIS platform as “**corresponding slope angle $\geq$ angle of internal friction of rock mass + (90°- dip amount of corresponding discontinuity plane)**” (as per the SOP guidelines).

Table-4.3: Geometrically classified data of different sets of discontinuities (J1, J2, J3, J4 and Foliation) recorded in the study area.

Rock Outcrops Having 1 Joint Set Data				
Location No.	Y	X	DA_1set_1	DD_1set_1
8	12.55337222	75.79625278	45	245
62	12.55105556	75.79944444	60	245
81	12.55625	75.79427778	25	230
86	12.55872222	75.79152778	70	235
118	12.54047222	75.805	61	235
125a	12.54855556	75.79666667	35	95
139	12.55019444	75.79747222	28	225
216	12.56969444	75.80213889	72	225
240	12.55144444	75.79035556	39	235
241	12.55427778	75.78641667	63	40
262	12.56671944	75.80320556	45	230
264	12.56527778	75.80352778	25	220
312	12.55919444	75.78902778	18	210
326	12.53980556	75.79213889	55	245

334	12.54461111	75.78825	36	233
364	12.549	75.77788889	24	232
372	12.54566667	75.78252778	59	265
387	12.54366667	75.77705556	15	235
446	12.55830556	75.81358333	56	235
545	12.55663889	75.80958333	85	170
580	12.57075	75.78427778	75	230
653	12.56455556	75.79102778	58	220

Rock Outcrops Having 2 Joint Set Data						
Location No.	Y	X	DA_2set_1	DD_2set_1	DA_2set_2	DD_2set_2
39	12.5457	75.80463889	65	235	88	160
63	12.55172222	75.79833333	56	235	90	0
65	12.55283333	75.79794444	70	225	87	350
83	12.55608333	75.79547222	62	235	90	0
98	12.56297222	75.80541667	61	238	90	0
100	12.54516667	75.80247222	60	230	90	0
102	12.54694444	75.80183333	56	235	82	355
105	12.54325	75.80266667	65	240	82	320
106	12.54290556	75.80261944	80	230	86	140
111	12.54441667	75.79580556	45	245	82	325
125	12.54855556	75.79341667	47	240	90	0
133	12.55402778	75.78658333	60	240	90	0
134	12.55333333	75.78561111	24	255	79	335
148	12.55230556	75.79477778	90	0	65	64

154	12.55347222	75.7925	51	230	86	150
185	12.53208333	75.80522222	45	240	90	0
190	12.53575	75.80358333	49	245	85	337
192	12.53569444	75.80102778	59	245	88	145
200	13.04613889	75.80625	70	240	78	140
202	12.55163889	75.81113889	75	240	88	325
221	12.57358333	75.79141667	80	265	75	345
226	12.55425	75.78658333	70	255	6	80
235	12.54472222	75.79811111	53	250	90	0
242	12.55422222	75.78594444	60	244	90	0
243	12.55213889	75.78388889	75	260	10	130
248	12.54177778	75.78577778	37	215	90	0
260	12.56529444	75.80454444	70	225	85	330
267	12.56340278	75.8035	50	235	55	140
269	12.56331389	75.80622222	60	230	89	330
274	12.56225	75.80774722	58	230	83	165
285	12.56083333	75.80550556	55	235	89	330
301	12.56472222	75.79991667	24	205	83	142
340	12.53722222	75.79844444	33	250	84	15
365	12.54738889	75.77705556	45	247	90	0
497	12.54177778	75.8125	62	240	90	0
503	12.53869444	75.81427778	30	240	90	0
513	12.54688889	75.81644444	85	245	85	340
520	12.54263889	75.815	68	80	85	355
533	12.5565	75.77641667	40	235	72	150
640	12.55822222	75.79472222	69	230	90	0
648	12.56644444	75.787	43	200	55	343

Rock Outcrops Having 3 Joint Set Data

Location No.	Y	X	DA_3set_1	DD_3set_1	DA_3set_2	DD_3set_2	DA_3set_3	DD_3set_3
15	12.55552222	75.80484444	58	230	27	15	80	315
59	12.5525	75.80027778	55	230	90	0	78	45
61	12.55119444	75.8	32	230	90	0	15	65
89	12.56172778	75.78881111	50	230	6	50	75	320
90	12.56197222	75.789	90	0	90	0	10	315
114	12.540114	75.795224	43	240	81	144	65	22
135	12.55227778	75.78519444	32	245	90	0	82	17
153	12.55413889	75.79291667	71	49	33	307	45	175
168	12.54033333	75.81147222	32	235	80	64	78	353
204	12.55383333	75.81216667	65	235	5	65	80	335
222	12.57511111	75.79066667	89	230	90	0	90	0
244	12.55861111	75.77811111	30	263	90	0	59	76
245	12.55416667	75.78861111	54	249	90	0	57	161
306	12.56744444	75.79402778	60	230	88	145	5	165

311	12.54002778	75.78986111	28	245	90	0	79	68
336	12.54538889	75.78891667	10	235	90	0	65	280
367	12.54663889	75.77569444	39	240	32	63	74	343
507	12.53652778	75.81322222	39	247	90	0	24	84
524	12.54913889	75.81202778	70	230	70	345	6	150
542	12.55780556	75.80763889	52	240	76	160	45	75
608	12.56147222	75.78361111	50	220	4	83	70	313

Rock Outcrops Having 4 Joint Set Data

Location No.	Y	X	DA_4set_1	DD_4set_1	DA_4set_2	DD_4set_2	DA_4set_3	DD_4set_3	DA_4set_4	DD_4set_4
82	12.55691667	75.7945	58	220	90	0	26	360	79	310
159	12.55544444	75.78922222	54	253	88	152	22	300	49	132
303	12.56563889	75.79863889	65	260	87	140	30	75	55	345

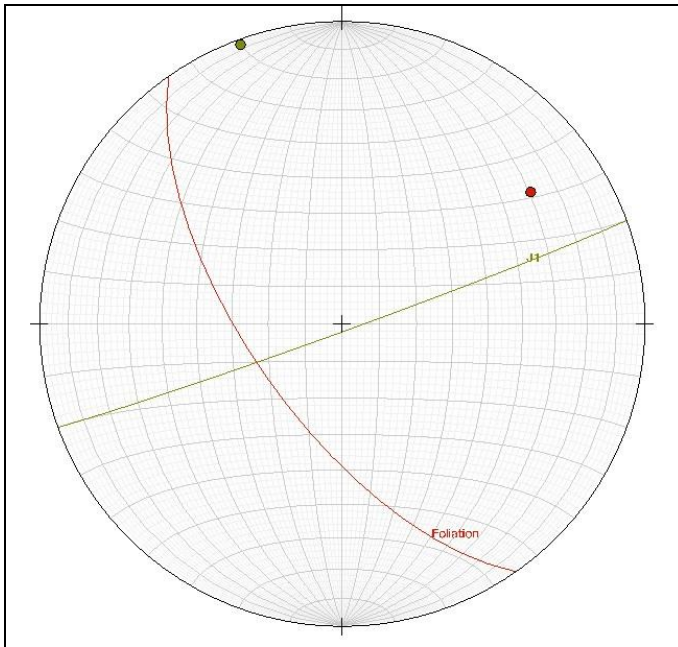
Table-4.4: Rock wedges formed by the intersection of different sets of discontinuities (J1, J2, J3, J4 and Foliation) recorded in the study area.

Rock Wedges Formed on Rockoutcrops having 2 Joint Set Data					
Location No.	Y	X	W1_Trend	W1_Plunge	Stereonet No.
39	12.5457	75.80464	246	64	1
63	12.55172	75.79833	245	56	2
65	12.55283	75.79794	266	64	3
83	12.55608	75.79547	260	60	4
100	12.54517	75.80247	240	60	5
102	12.54694	75.80183	274	49	6
105	12.54325	75.80267	248	65	7
106	12.54291	75.80262	208	79	8
125	12.54856	75.79342	255	46	9
134	12.55333	75.78561	250	24	10
148	12.55231	75.79478	57	65	11
190	12.53575	75.80358	253	48	12
192	12.53569	75.80103	232	58	13
248	12.54178	75.78578	255	30	14
260	12.56529	75.80454	252	68	15
269	12.56331	75.80622	242	60	16
274	12.56225	75.80775	244	57	17
340	12.53722	75.79844	288	27	18
533	12.5565	75.77642	224	40	19

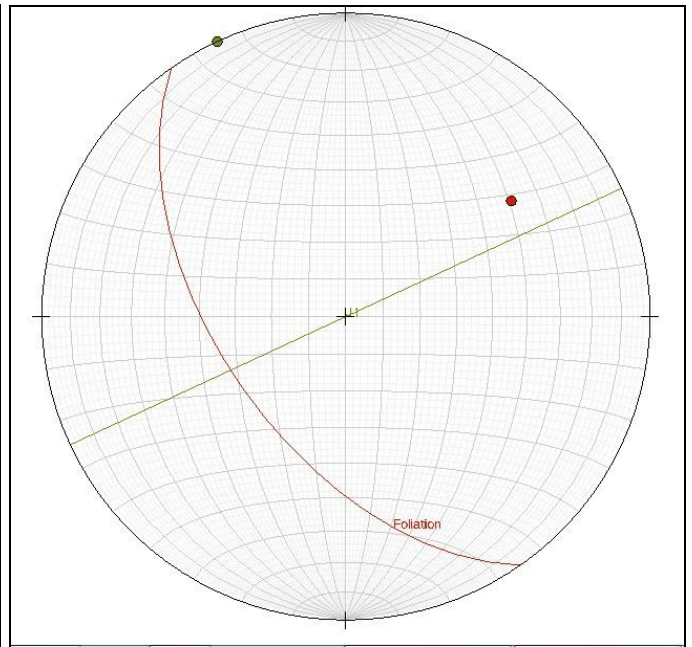
Rock Wedges Formed on Rockoutcrops having 3 Joint Set Data									
Location No.	Y	X	W1_Trend	W1_Plunge	W2_Trend	W2_Plunge	W3_Trend	W3_Plunge	Stereonet No.
59	12.5525	75.80028	220	55	316	6	40	78	20
61	12.55119	75.8	260	29	144	3	80	15	21
89	12.56173	75.78881	320	0	248	49	48	6	22
90	12.56197	75.789	0	90	5	7	285	9	23
114	12.54011	75.79522	226	42	303	23	68	56	24
135	12.55228	75.78519	235	32	291	24	55	80	25
153	12.55414	75.79292	331	31	126	33	246	18	26
245	12.55417	75.78861	247	54	208	46	247	6	27
311	12.54003	75.78986	239	28	158	1	59	79	28
367	12.54664	75.77569	152	1	265	36	63	32	29

Rock Wedges Formed on Rockoutcrops having 4 Joint Set Data															
Location No.	Y	X	W1_Tr end	W1_Pl unge	W2_Tr end	W2_Pl unge	W3_Tr end	W3_Pl unge	W4_Tr end	W4_Pl unge	W5_Tr end	W5_Pl unge	W6_Tr end	W6_Pl unge	Stereonet No.
82	12.55692	75.7945	235	57	301	14	237	57	55	16	235	53	36	22	30
159	12.55544	75.78922	239	53	330	19	191	31	242	12	63	22	219	4	31
303	12.56564	75.79864	224	60	349	3	315	51	52	28	52	30	53	28	32

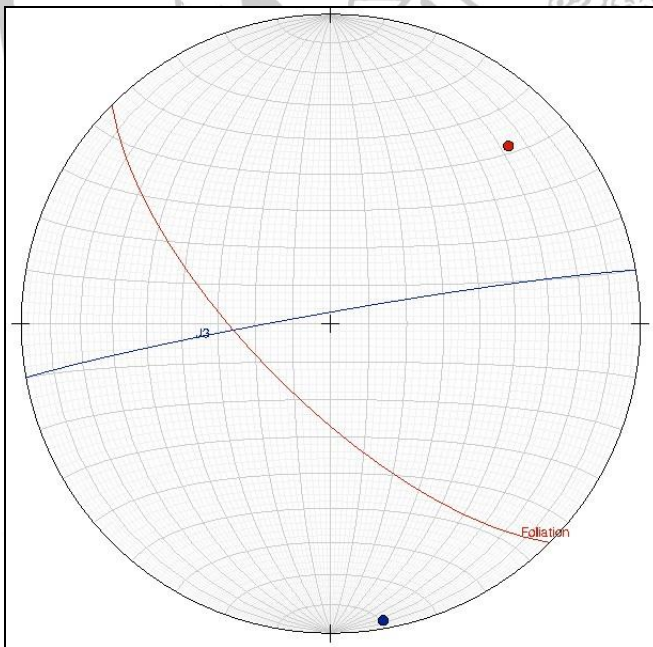
Stereonets for Rock Outcrops Containing 2 Joint Sets:



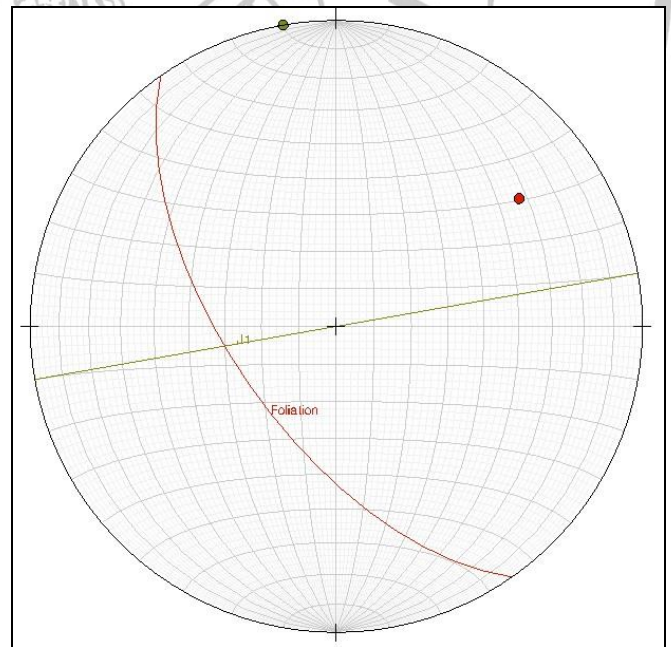
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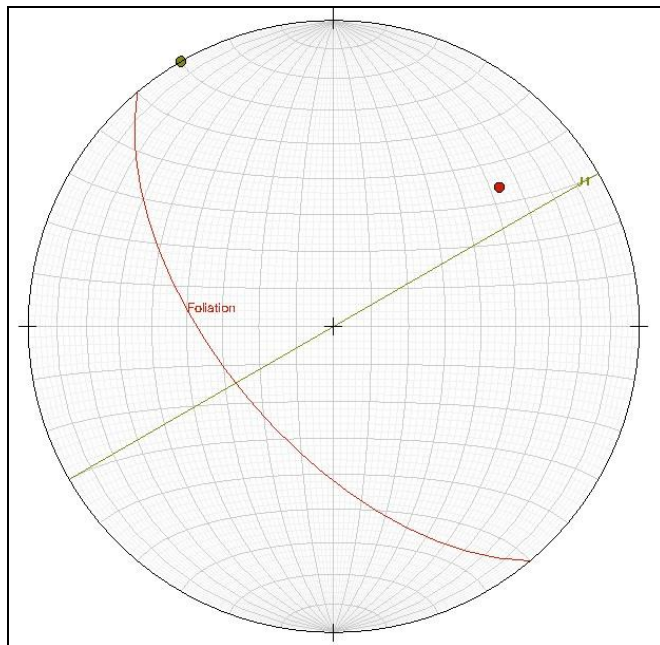
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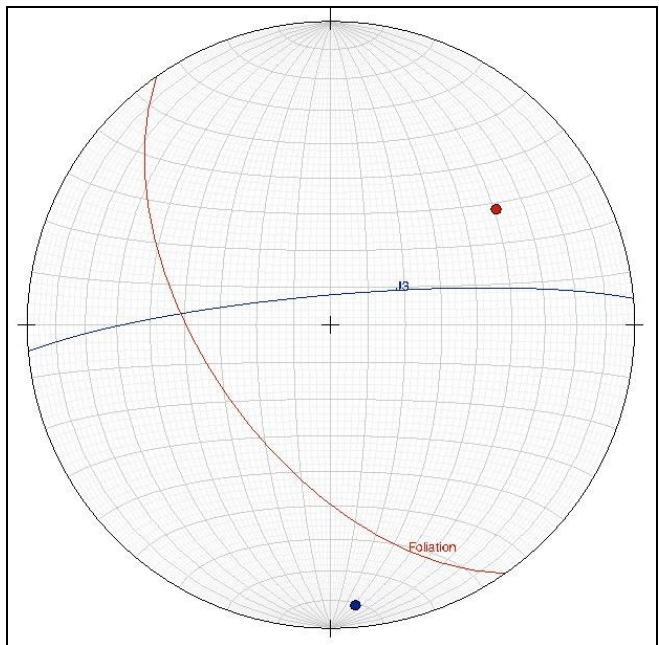
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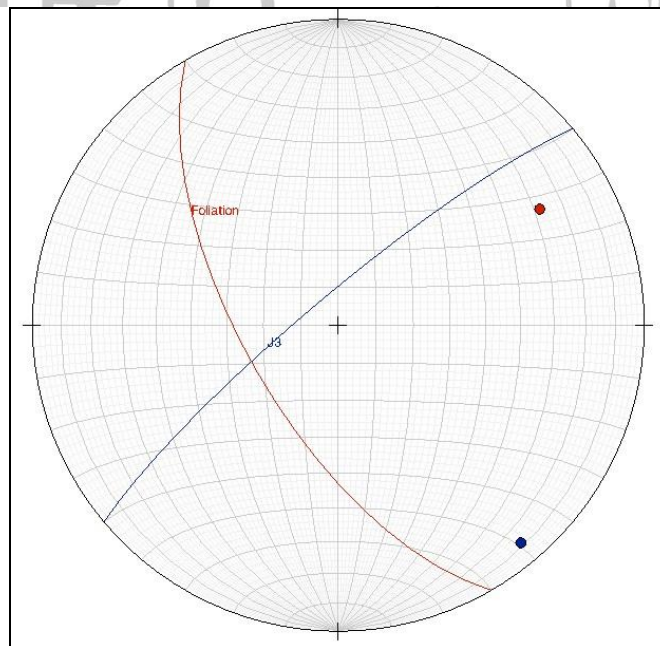
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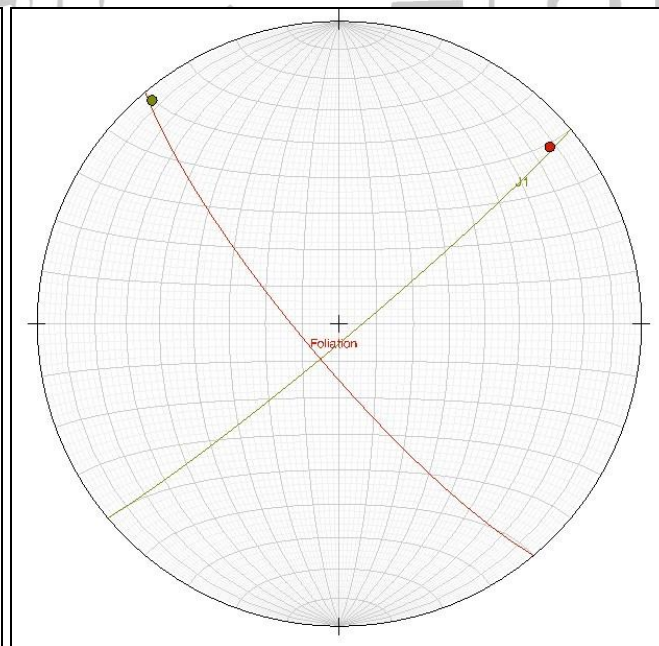
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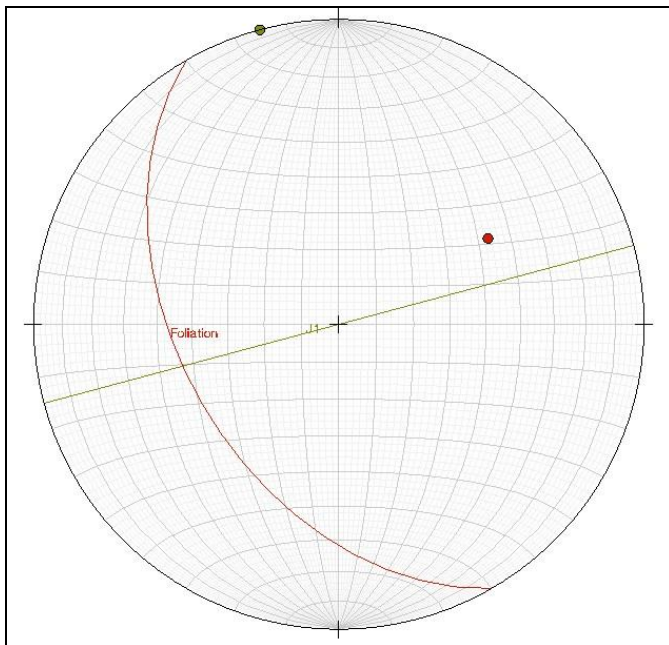
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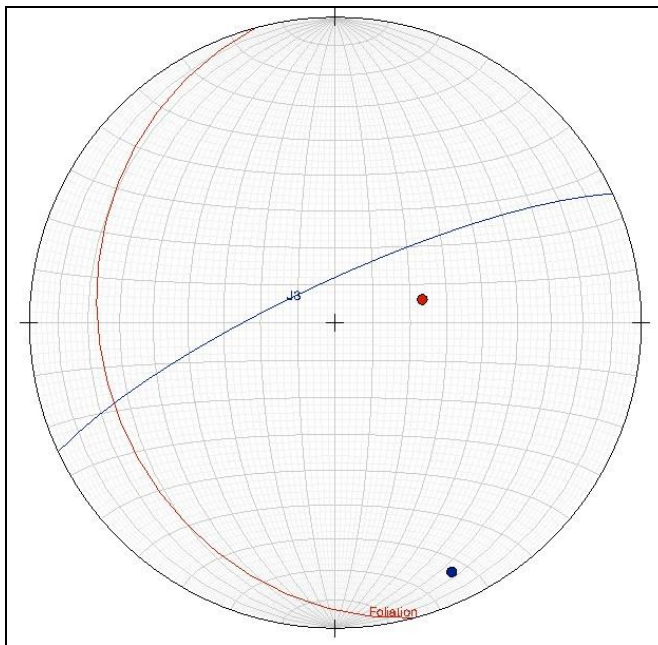
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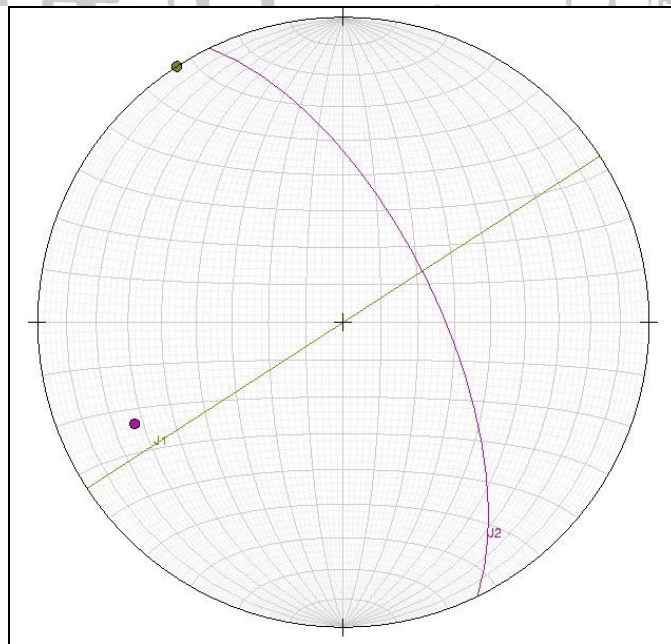
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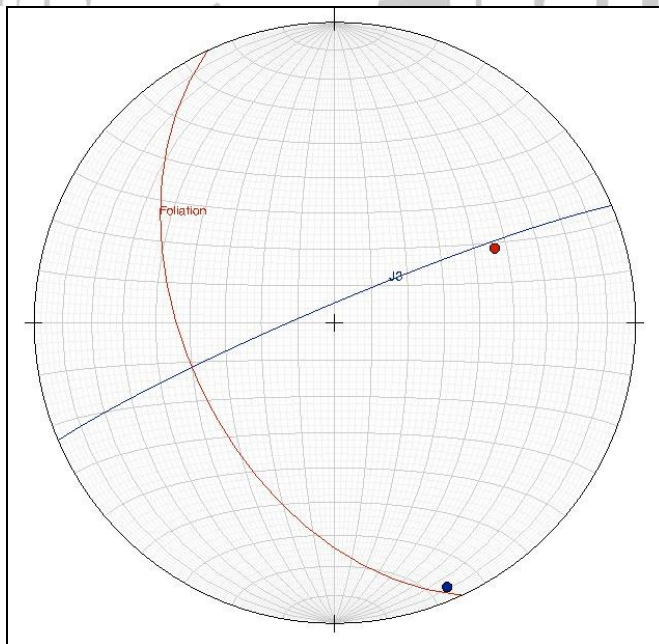
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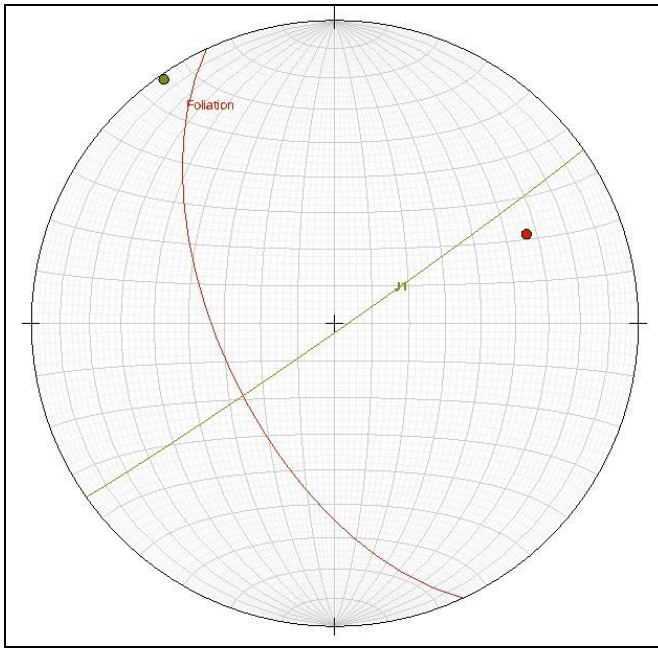
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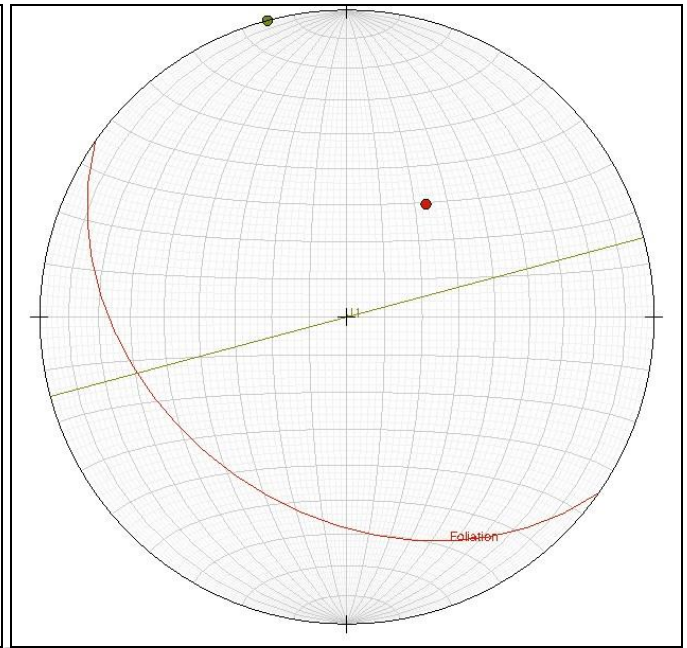
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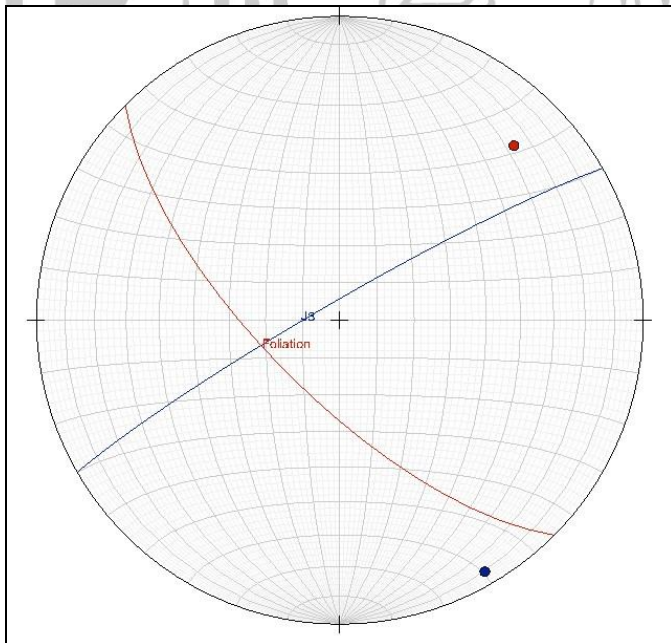
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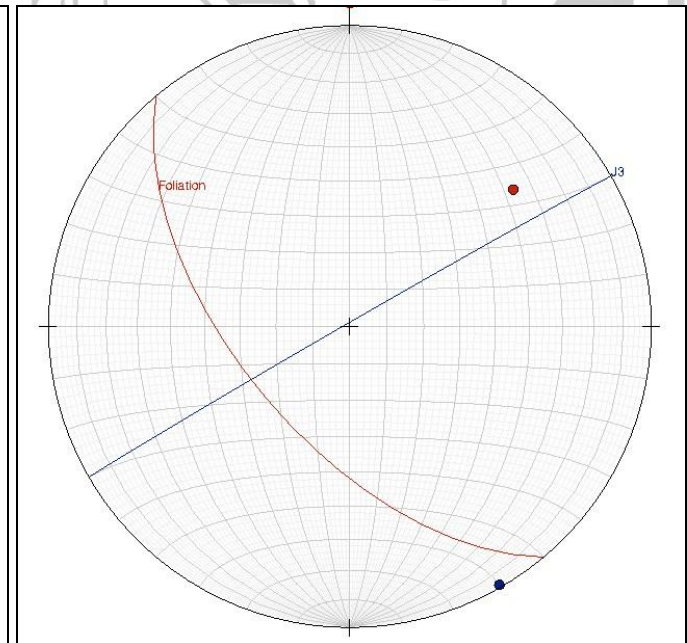
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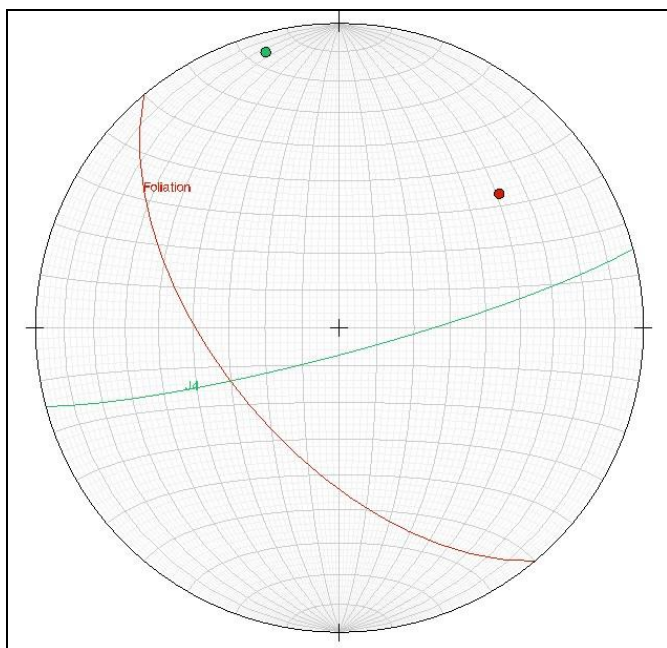
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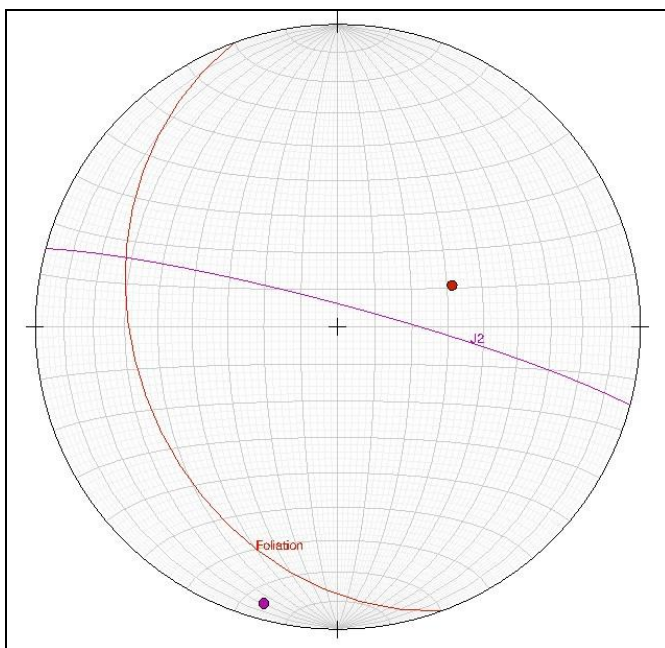
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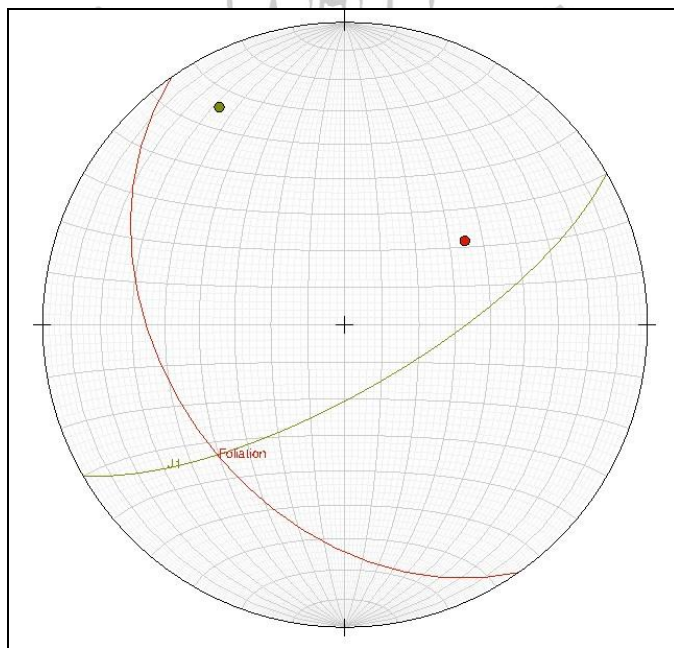
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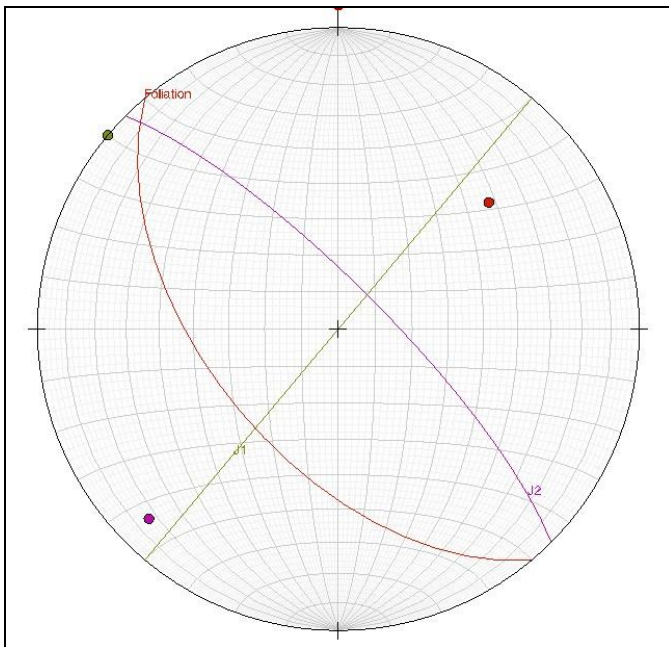


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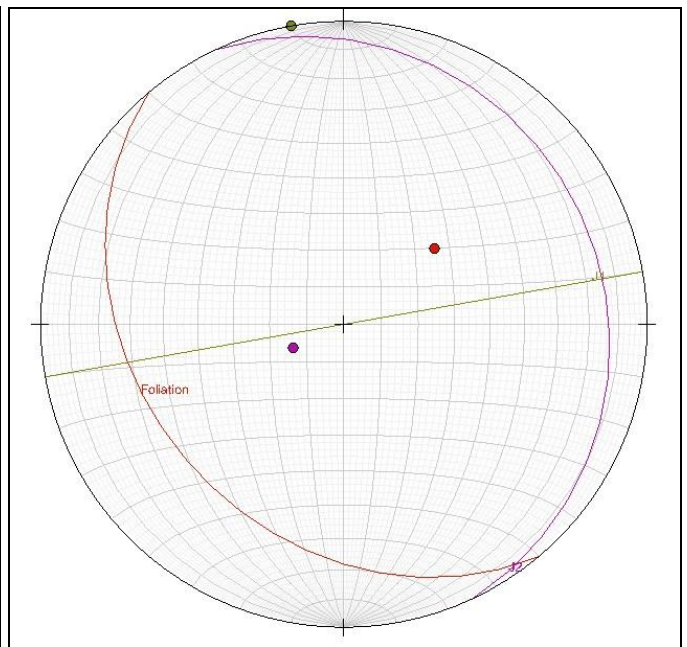


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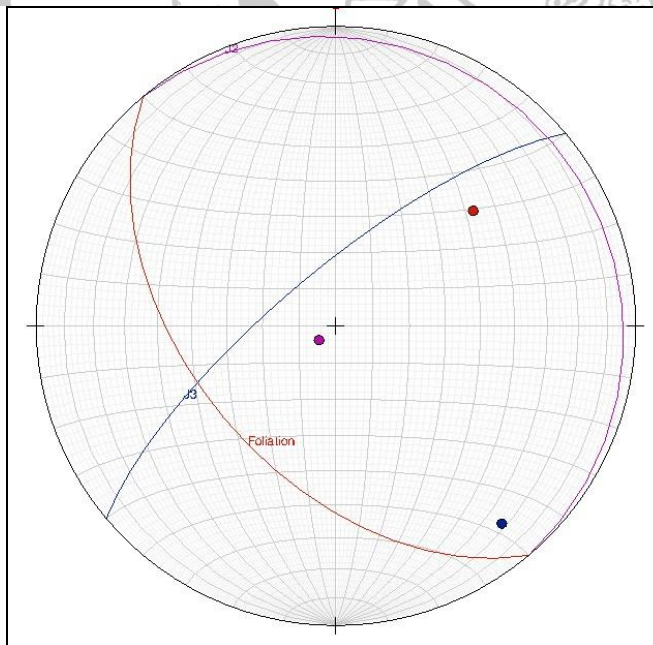
Stereonets for Rock Outcrops Containing 3 Joint Sets:



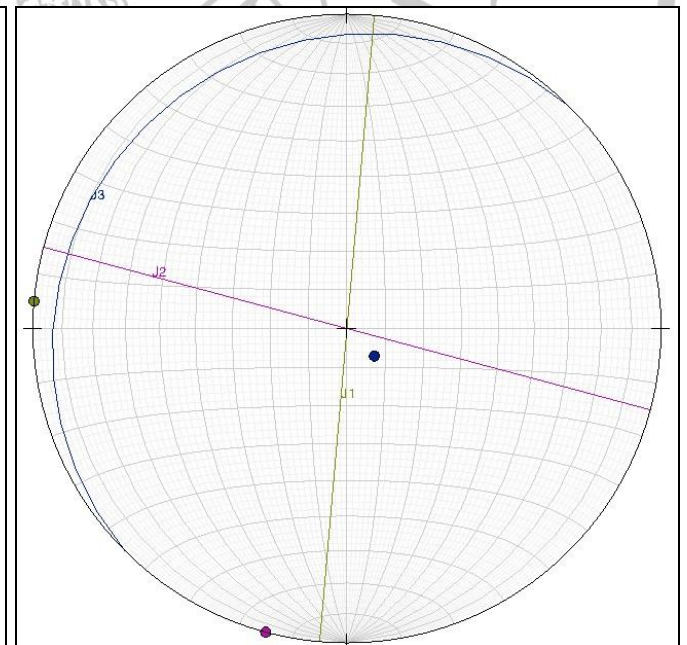
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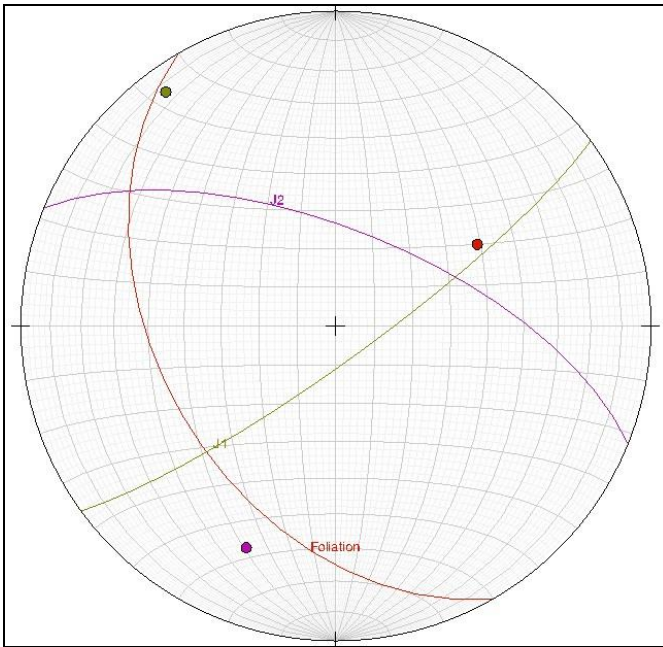
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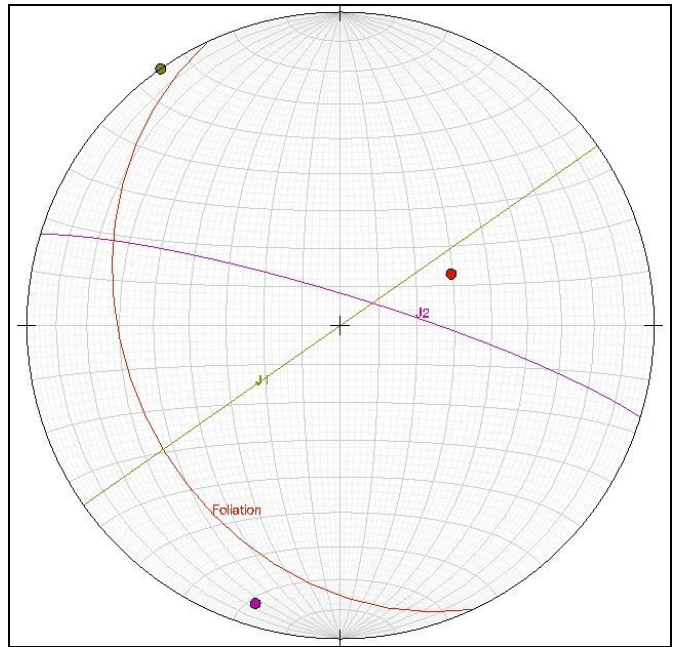
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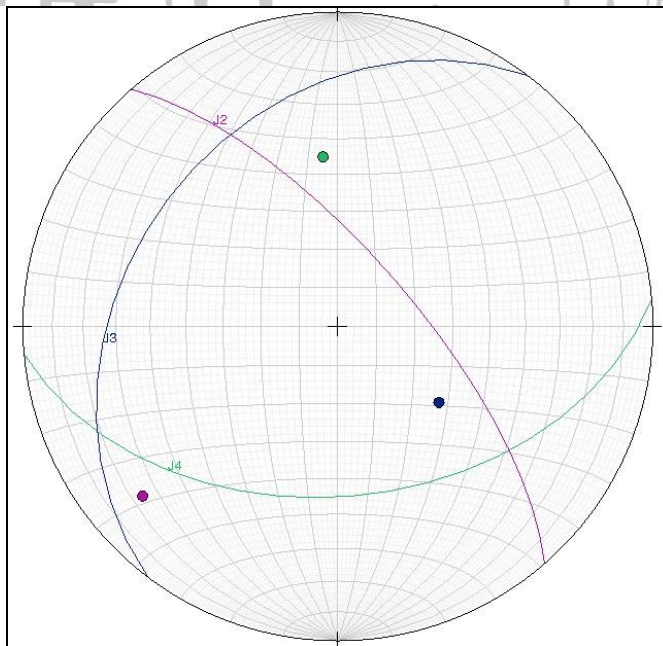
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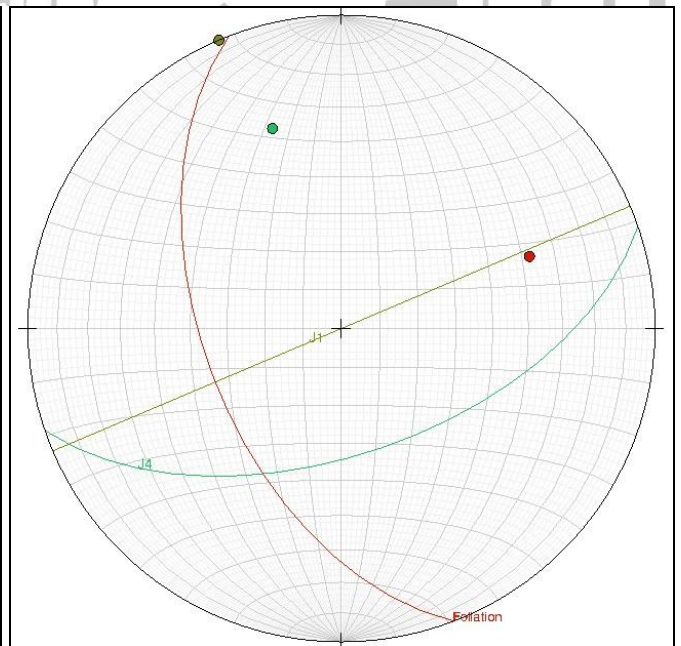
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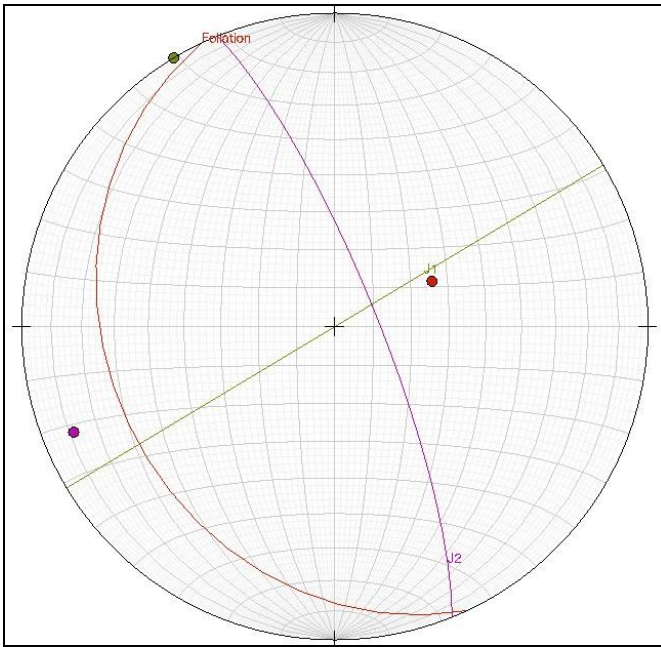
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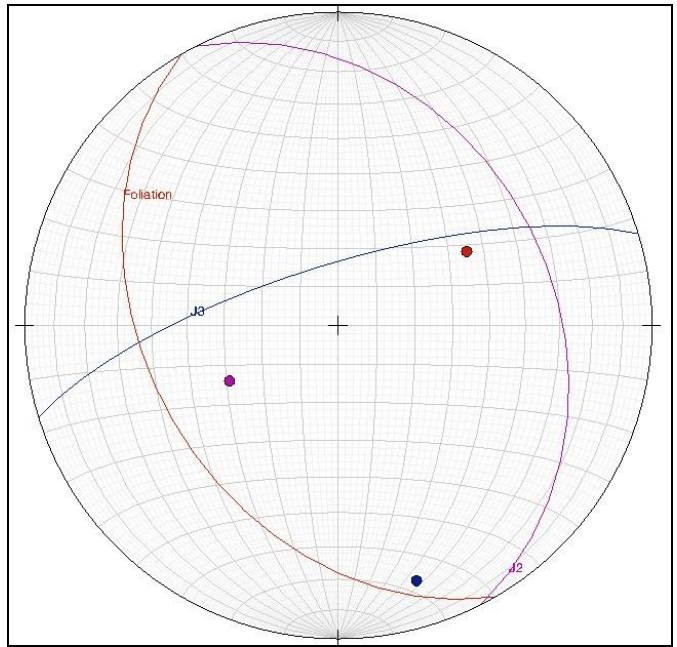
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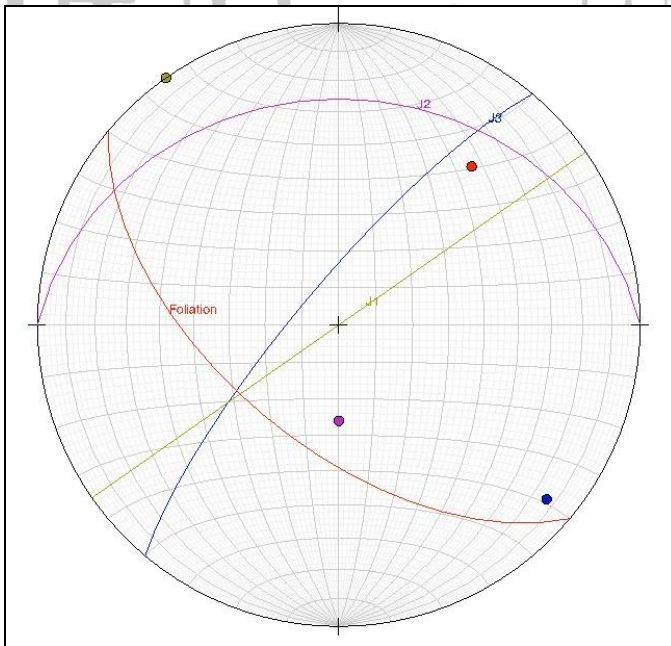


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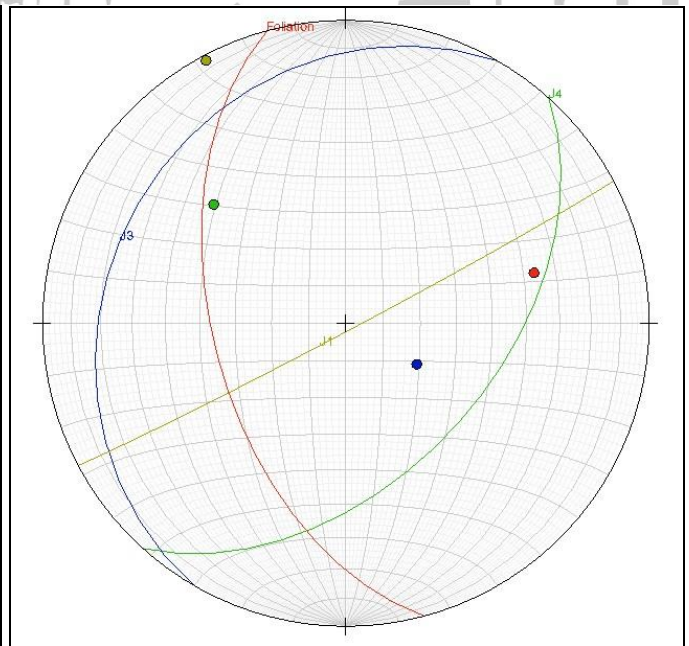


Stereonet No. 29 (Location No. 367)

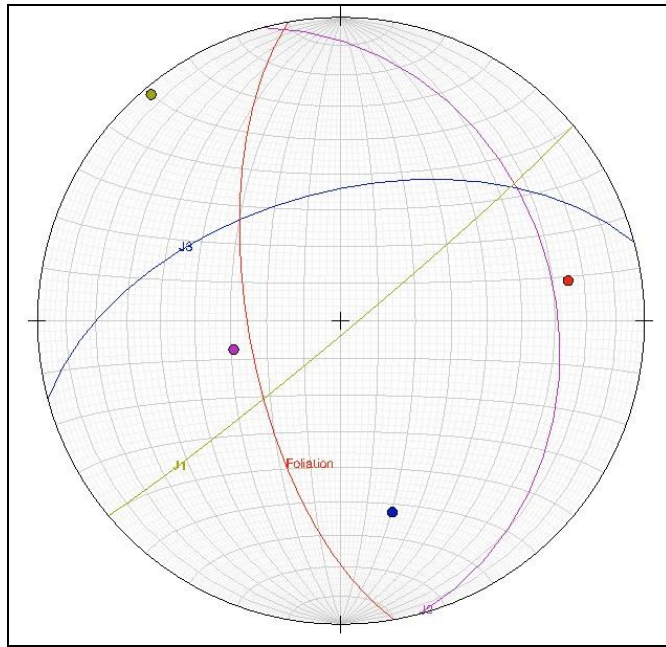
Stereonets for Rock Outcrops Containing 4 Joint Sets:



Stereonet No. 30 (Location No. 82)



Stereonet No. 31 (Location No. 159)



Stereonet No. 32 (Location No. 303)

4.3.2 Geotechnical Geological Mapping of Surface Rock Outcrops and Rock Mass Rating

The surface rock outcrops are variably distributed and can be separated from overburden cover by using basic field geological mapping techniques. The topographical contour map of the desired scale and a calibrated GPS are essential for field geological mapping to draw the contact between rock outcrop and overburden material. This step is initially required for the preparation of a geotechnical map. Once the surface rock outcrops are demarcated, specifically the geotechnical investigation is conducted to assess the rock mass condition. The purpose of geotechnical geological mapping is that the surface rock outcrops may be investigated to categorize the rock mass with similar geological behavior. This may include considering the physical characteristics of the intact rock mass and the control of structural geological features thereon. Therefore one must visualize the rock mass as an assemblage of intact rock blocks separated by different types of geological discontinuities. The importance of the physical properties of intact rock mass must not be overshadowed by the properties of the geological discontinuities in the rock masses. Both the things may be given equal attention as if the intact rock is incompetent, deformed, and altered or the geological discontinuities are multiple, widely spaced with wet surfaces, this all in a cumulative manner will influence the overall strength of the intact rock mass. It is worth noting that in many instances the RMR in a given area does not vary across the RMR scale by Z. T. Bieniawski 1989 and remains in the single value range because of the uniform physical properties of rock outcrop. The reconciliation would be possible to correlate the resulted RMR of the given outcrop to its corresponding stability assessment condition (stable, fairly stable, unstable) based on stereonet analysis. Because of this

constraint, this type of correlation matrix procedure is being utilized in the present study to improve the RMR value and rock quality category.

Finally, the geotechnical mapping of the surface rock outcrops may ensure the investigator to classify the intact rock mass into different categories for the stability purpose which is commonly known as rock mass classification. The fundamental aim of the rock mass classification is to divide the intact rock mass into a number of structural regions. These regions are geological zones of rock masses in which certain features are more or less uniform. Rock mass classification is a rated base system developed by Z. T. Bieniawski in 1989. This classification is commonly known as the rock mass rating system (RMR). RMR system combines the most significant geological parameters of influence and represents them with one overall comprehensive index of rock mass quality, which is widely used for design and construction purposes in tunnels, mines, foundations, and often in rocky slope stability assessment. The following six parameters are used to classify a rock mass using the RMR system;

1. Uniaxial compressive strength of rock material (UCS) or Point load test of rock material
2. Rock quality designation (RQD)
3. Spacing of discontinuities
4. Condition of discontinuities
5. Groundwater conditions
6. Orientation of discontinuities

Each of the above six parameters is assigned a value corresponding to the characteristics of the intact rock mass. The assigned values are derived from geotechnical geological mapping and in-situ rock or laboratory tests. The sum of the six parameters is the "RMR value", which lies between 0 and 100.

Table-4.5: Rock mass classification after Z. T. Bieniawski 1989.

RMR Value	Rock Quality
100-81	Very Good
80-61	Good
60-41	Fair
40-21	Poor
20-0	Very Poor

In the present study, a geotechnical map/engineering geological map has been prepared by incorporating RMR values for rocky areas while for overburden-covered slopes the geotechnical map has been prepared by incorporating the C and ϕ values received from the laboratory. As per the availability, CartoDEM 10m derived topographic contour map has been utilized for field mapping purposes. The

physical properties and the behavior of geological discontinuities of intact rock outcrops were investigated in detail during field mapping to ensure the rock mass classification as per the RMR system and to collect the input data for kinematic failure analysis. The compressive strength of rock has been assessed by the use of a Schmidt Hammer. The RQD has been assessed in one cubic meter area of the rock outcrop at multiple locations. These procedures were adopted as an alternative to laboratory-based UCS and drill core-based RQD. Both the parameters could not be performed through real procedures because of the limited resources available at present. However, it is found that the below-shown interference patterns of different joint sets at several parts in the study area are responsible to degrade the rock mass quality.

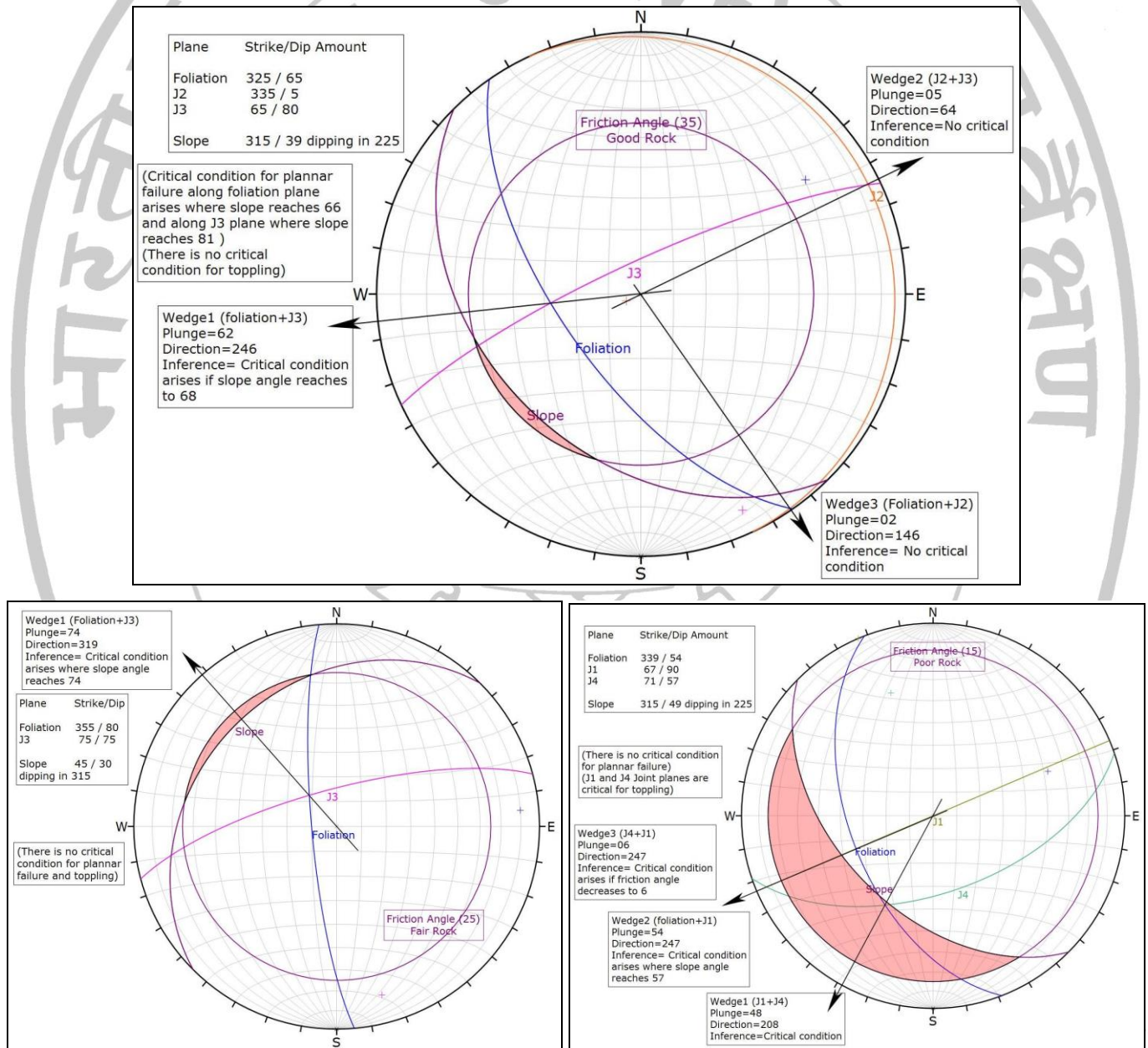


Figure-4.4: Interference patterns of different joint sets in the study area which are responsible for shaping/development of the overall landform/geomorphology geometry

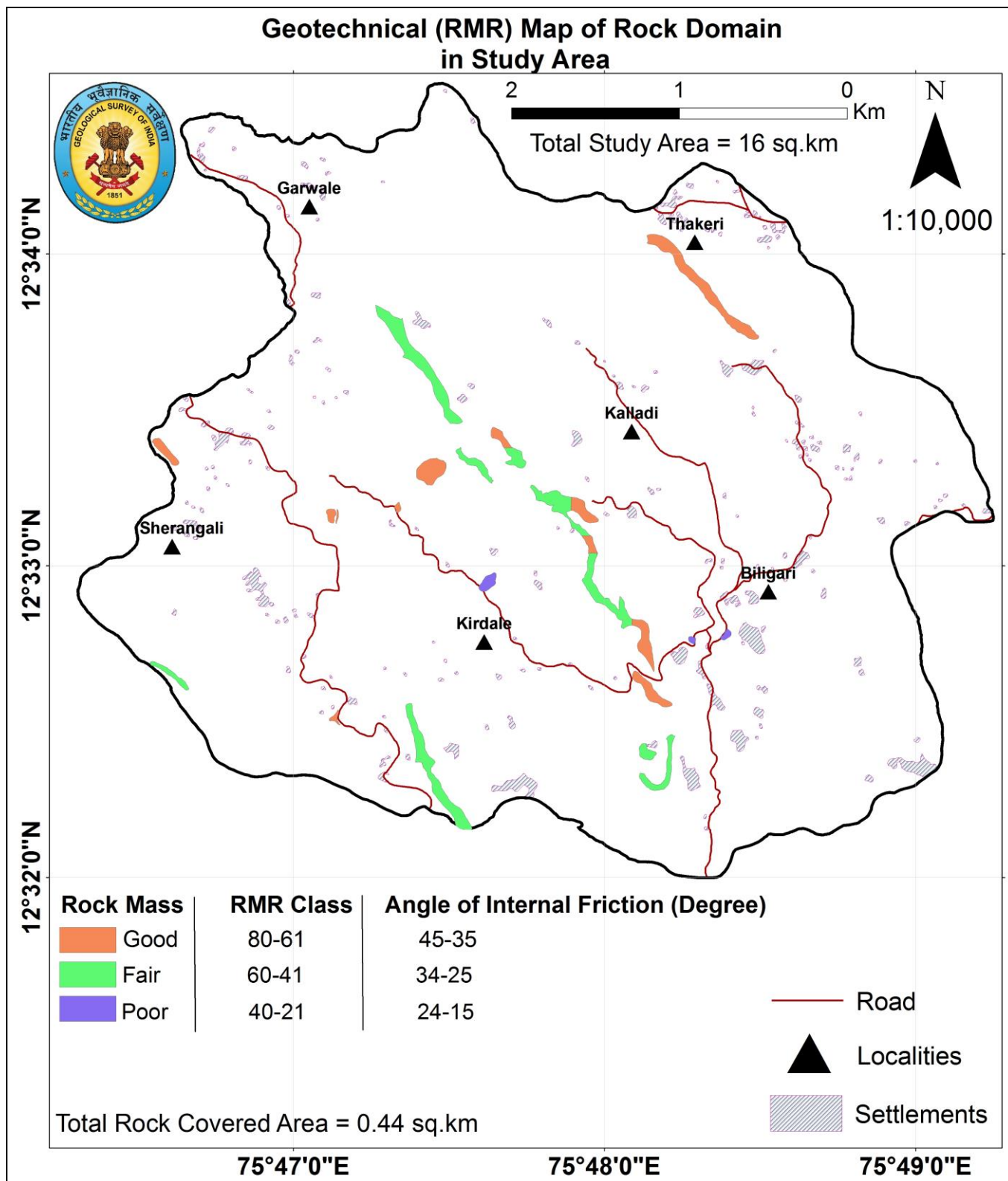


Figure-4.5: Geotechnical map of rock outcrops in the study area prepared based on RMR

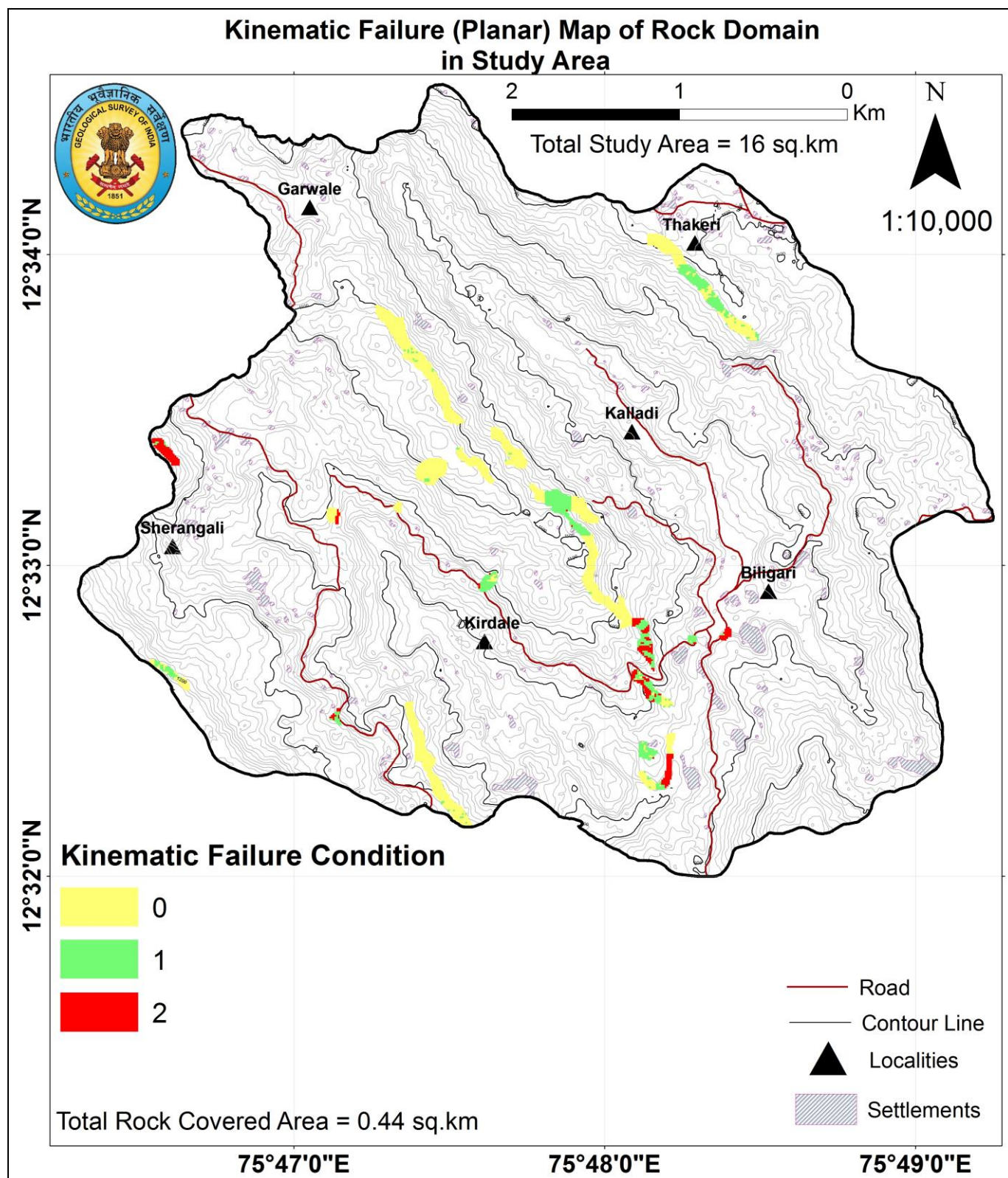


Figure-4.6: Kinematic failure (Planar) map overlapped on CartoDEM 10m derived contour map (0=no planar failure; 1=one planar failure; 2=two planar failure)

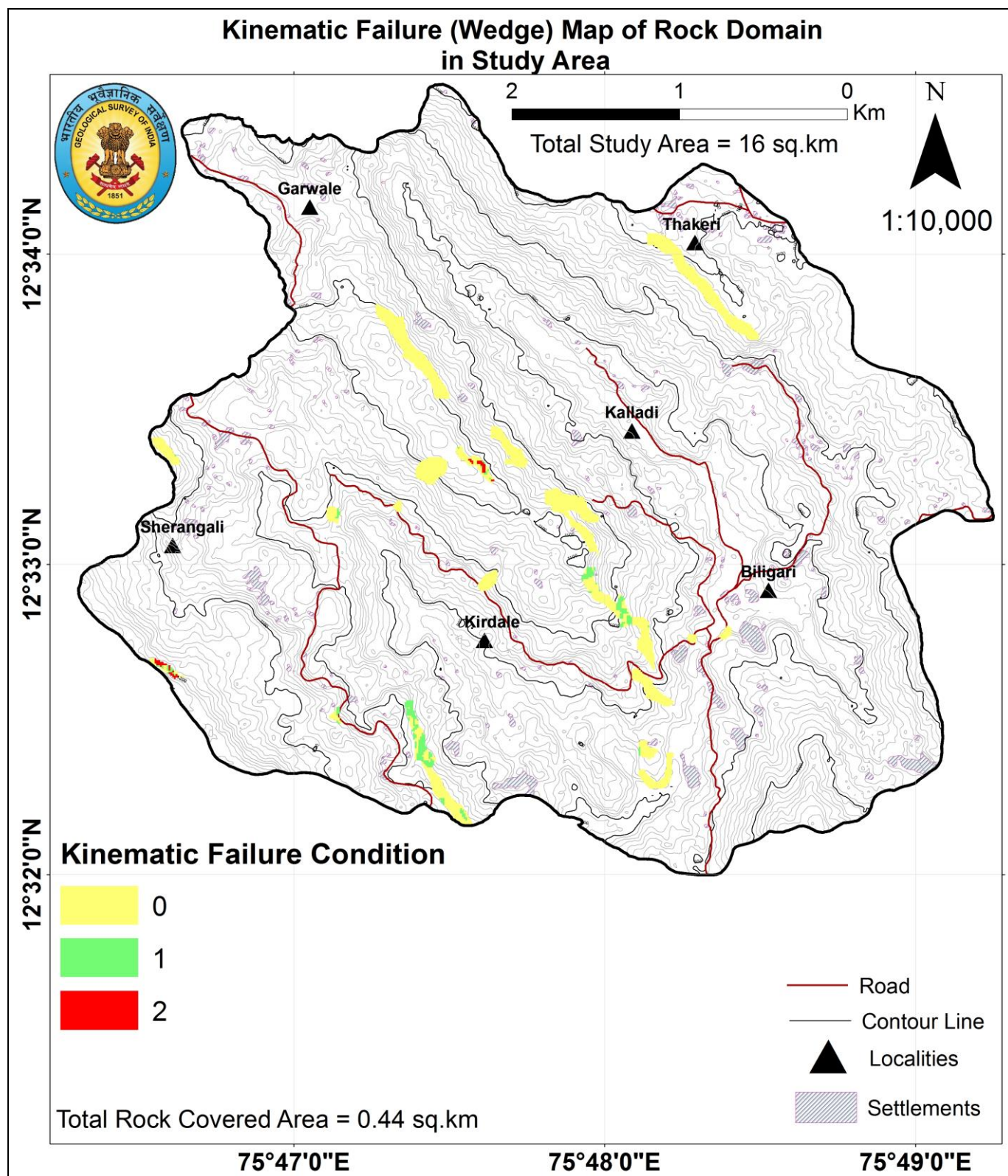


Figure-4.7: Kinematic failure (Wedge) map overlapped on CartoDEM 10m derived contour map (0=no wedge failure; 1=one wedge failure; 2=two wedge failure)

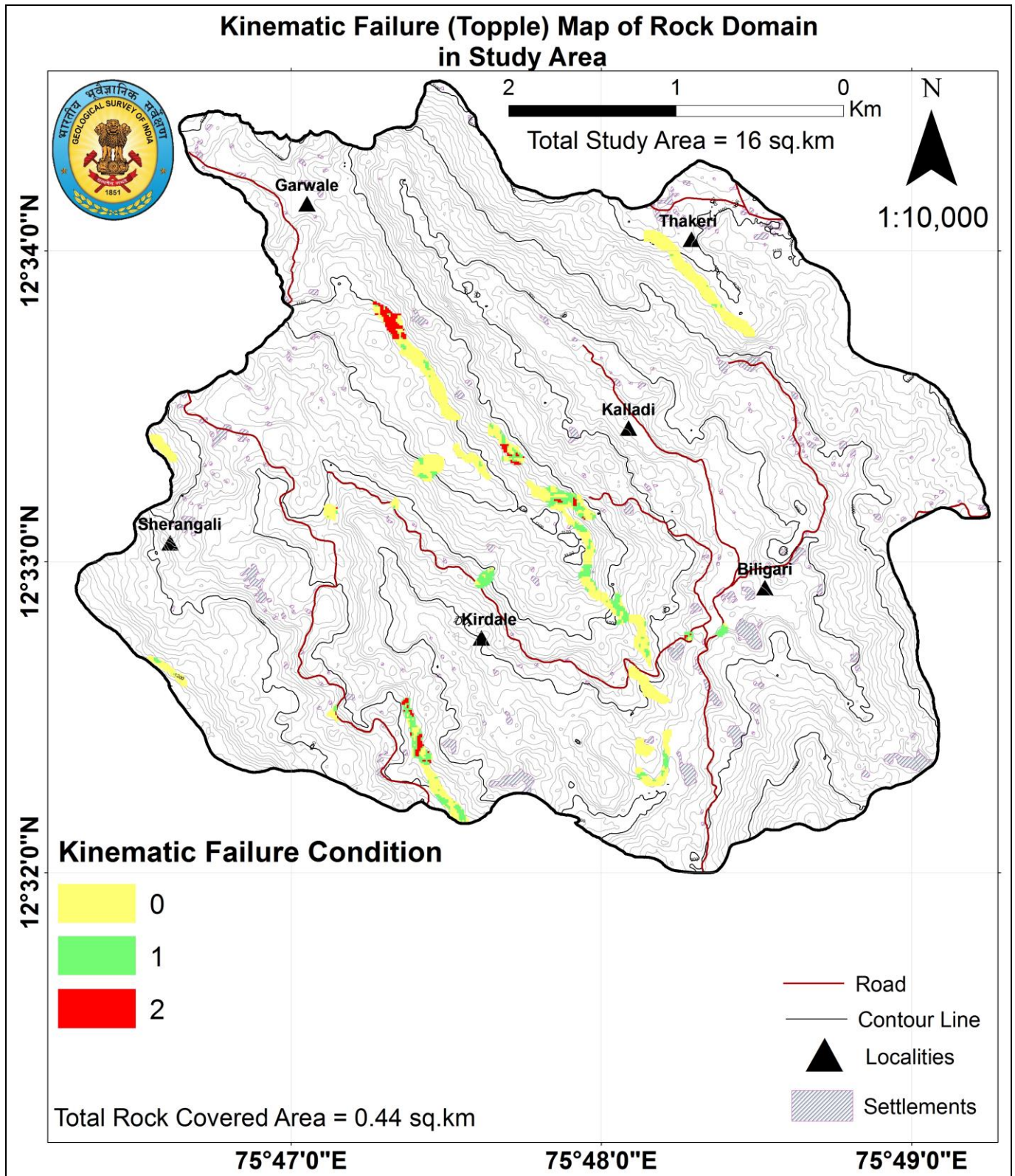


Figure-4.8: Kinematic failure (Topple) map overlapped on CartoDEM 10m derived contour map (0=no topple failure; 1=one topple failure; 2=two topple failure)

4.3.3 Ratings and Integration of Geo-Factor Maps

In rock slide and rock fall domains, the inherent properties of the rocks such as failure condition and rock quality are being assessed based on kinematic analysis and a rock mass rating system. Besides, the slope angle is being incorporated as one of the geo-factor maps in the rock fall domain because of two factors other than the toppling failure condition. These two factors are highly fractured conditions under the high strained zone and closely spaced cleavage planes and they are playing an important role to dislocate rock fragments from intact rock. The dislocated rock fragments have a high tendency to fall under the gravity effect wherever the slope angle gets steep, particularly during rainfall periods. The external forces that are applied to rock outcrops during periods of varying climatic and tectonic conditions, were not accounted for in this study. But evidently, the change in the stability condition of any rock outcrop by external forces is a matter of concern. The LSER value has not been kept as 0 (zero) because, under the effect of external forces at any time, the minimum LSER value to any geo-factor class may show a tendency towards increasing vulnerability. The landslide susceptibility evaluation rating (LSER) is being determined heuristically (knowledge-driven approach) as per the current SOP by considering the different failure conditions in kinematic failure analysis and the rock quality based on the RMR system. It has been observed that by incorporating slope angle in rock slide or rock fall domain the results proved more satisfactory. A few exercises were carried out to determine the slope angle classes and their LSER, however, the given classes and their LSER have been found satisfactory for the study area. The increasing critical conditions for toppling failure have been found compatible with slope angle class $>45^{\circ}$, therefore their LSER has been kept towards the higher side so that the ground reality would prevail on the susceptibility map. The landslide susceptibility evaluation ratings will be taken for each geo-factor class in the study area from the given rating system as follows;

Table-4.6: Landslide susceptibility evaluation rating (LSER) for planar and wedge failure conditions

Kinematic Failure Condition	LSER
No critical condition	0.2
1 critical condition	0.4
2 critical condition	0.6
3 critical condition	0.8
4 critical condition	1.0

Table-4.7: Landslide susceptibility evaluation rating (LSER) for toppling failure conditions

Kinematic Failure Condition	LSER
No critical condition	0.2

1 critical condition	0.8
2 critical condition	1.0

Table-4.8: Landslide susceptibility evaluation rating (LSER) for RMR-based geo-technical map

Rock Quality	LSER
Very Good	0.05
Good	0.2
Fair	0.3
Poor	0.5
Very Poor	1.0

Table-4.9: Landslide susceptibility evaluation rating (LSER) for slope angle map

Slope Angle	LSER
0°-35°	0.2
36°-45°	0.5
>45°	1.0

The heuristically determined landslide susceptibility evaluation ratings (LSER) mentioned in table-4.6, 4.7, 4.8 & 4.9 will be given to each thematic class of geo-factor maps selected for the generation of landslide susceptibility maps in the rock slide and rockfall domains. The landslide susceptibility evaluation ratings (LSER) for each geo-factor class will be then integrated. The landslide susceptibility evaluation ratings (LSER) for each geo-factor class have been deliberately put below 1 so that the total estimated susceptibility value (TESV) remains below or equal to 10. The calculation of the total estimated susceptibility value (TESV) was performed in the GIS platform by using the below-mentioned calculation for the rock slide and rockfall domains separately (Aijaz Ahmad & Senthilkumar, 2021);

Total estimated susceptibility value (TESV) for rock slide domain = $\sum(\text{LSER}_{\text{Planar failure map}} + \text{LSER}_{\text{Wedge failure map}} + \text{LSER}_{\text{Geo-technical map}})$

Total estimated susceptibility value (TESV) for rock fall domain = $\sum(\text{LSER}_{\text{Topple failure map}} + \text{LSER}_{\text{Geo-technical map}} + \text{LSER}_{\text{Slope angle map}})$

Table-4.10: Maximum LSER of geo-factor maps selected for generation of landslide susceptibility map in rock slide domain.

Geo-factor Map	Factor Class	Maximum LSER
Planar failure map	No critical condition	0.2
	1 critical condition	0.4
	2 critical condition	0.6
Wedge failure map	No critical condition	0.2
	1 critical condition	0.4
	2 critical condition	0.6
Geo-technical map	Good	0.2
	Fair	0.3
	Poor	0.5

Table-4.11: Maximum LSER of geo-factor maps selected for generation of landslide susceptibility map in rockfall domain.

Geo-factor Map	Factor Class	Maximum LSER
Topple failure map	No critical condition	0.2
	1 critical condition	0.8
	2 critical condition	1.0
Geo-technical map	Good	0.2
	Fair	0.3
	Poor	0.5
Slope angle map	0°-35°	0.2
	36°-45°	0.5
	>45°	1.0

4.3.4 Landslide Susceptibility Map of Rock Slide and Rock Fall Domain

A landslide susceptibility map is a picture of the total estimated susceptibility value (TESV) calculated for each mapping unit (facet or pixel). The total estimated susceptibility value over an area of investigation would remain below or equal to 10 as per the opinion of the worker. The ratings for each geo-factor class were given as per terrain-specific conditions but at places, the ratings were changed as per the slope stability assessment carried out by the workers on the ground. The landslide susceptibility map has been generated by the overlay method in which the summation of LSER of all geo-factor maps has

been done in the GIS platform. The rock slide and rockfall susceptibility have been assessed for a 0.44 sq. km area covered by rock.

Rock Slide Domain: In the rock slide domain, the resulting total estimated susceptibility value (TESV) ranges from 0.6 to 1.3 and divided the map area into five classes as mentioned in table- 4.12. Later the five classes were reclassified into three classes of landslide susceptibility as mentioned in table- 4.13.

Table-4.12: Landslide susceptibility map attributes for rock slide domain

Value	Pixel Count	TESV
1	975	0.6
2	1757	0.8
3	926	0.9
4	242	1.1
5	62	1.3

Table-4.13: Modified landslide susceptibility map attributes for rock slide domain

Value	Pixel Count	TESV	Susceptibility Class	Map Area Percentage	Landslide Ratio
1-2	2732	0.6-0.8	Low	68.95	0
3	926	0.9	Moderate	23.37	1
4-5	304	1.1-1.3	High	7.67	0
Total	3962			100%	03 nos.

A total of 3 nos. of rock slides were recorded in the study area which has been validated with the susceptibility map area percentage in which the rock slide ratio is 0 (low): 1 (moderate): 0 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to rock slides. However, the places showing high susceptibility of rock slides are having day-lighted slopes which may failure in low angle of internal friction circumstances. Whereas moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 23.37 percent. This signifies that qualitatively the adopted model has predicted 77 percent of the map area with efficacy and there is the least uncertainty in terms of moderate susceptible class over 23 percent map area. It would be noted that the impact of external forces especially rainfall may change the resulting susceptibility scenario in the study area at any time. The basic parameters like the angle of internal friction, slope angle, and slope

window direction may change by either natural agencies or anthropogenic activities that would favor the rock slide failures.

Rock Fall Domain: In the rock fall domain, the resulting total estimated susceptibility value (TESV) ranges from 0.6 to 2.5 and it divides the map area into five classes as mentioned in table- 4.14. Keeping the proneness of the study area to rockfall in consideration, later the four classes were reclassified into three classes of landslide susceptibility as mentioned in table- 4.15.

Table-4.14: Landslide susceptibility map attributes for rock fall domain

Value	Pixel Count	TESV
1	1520	0.6
2	1635	0.7
3	182	1.8
4	543	1.9
5	133	2.2
6	243	2.3
7	4	2.5

Table-4.15: Modified landslide susceptibility map attributes for rock fall domain

Value	Pixel Count	TESV	Susceptibility Class	Map Area Percentage	Landslide Ratio
1-2	3155	0.6-0.7	Low	74.06	0
3-4	725	1.8-1.9	Moderate	17.01	1
5-7	380	2.2-2.5	High	8.92	1
Total	4260			100%	03 nos.

A total of 3 nos. of rock slides were recorded in the study area which has been validated with the susceptibility map area percentage in which the rock slide ratio is 0 (low): 1 (moderate): 1 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to rockfall due to the topple favourable joint planes and poor strength of rock on the steep slope. This poor strength rock condition does not bring due to toppling failure condition in the study area but it is a result of the highly fractured condition under the high strained zones and closely spaced cleavage planes. These two factors are playing an important role to dislocate rock fragments from intact rock. The dislocated rock fragments have a high tendency to fall under the gravity effect wherever the slope angle gets steep, particularly during rainfall periods. That is why the slope angle has been incorporated as one of the geo-

factor maps for integration and susceptibility modeling in the rock fall domain. Whereas moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 17.01 percent. This signifies that qualitatively the adopted model has predicted 83 percent of the map area with efficacy and there is the least uncertainty in terms of moderate susceptible class over 17 percent map area. It is also to be mentioned that the impact of external forces particularly rainfall water action and anthropogenic activities may change the resulting susceptibility scenario in the study area at any time.

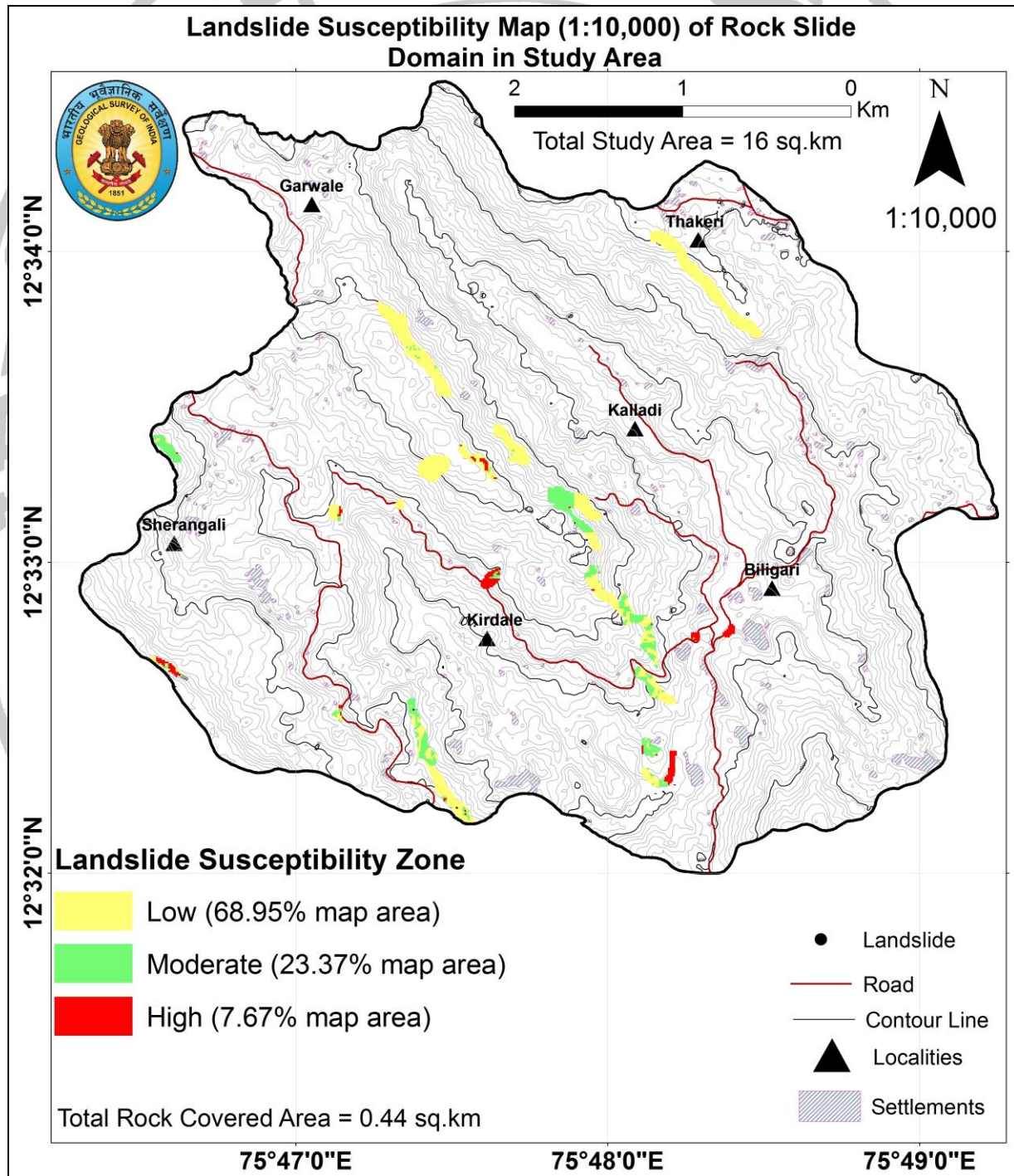


Figure-4.9: Landslide susceptibility map of rock slide domain in the study area

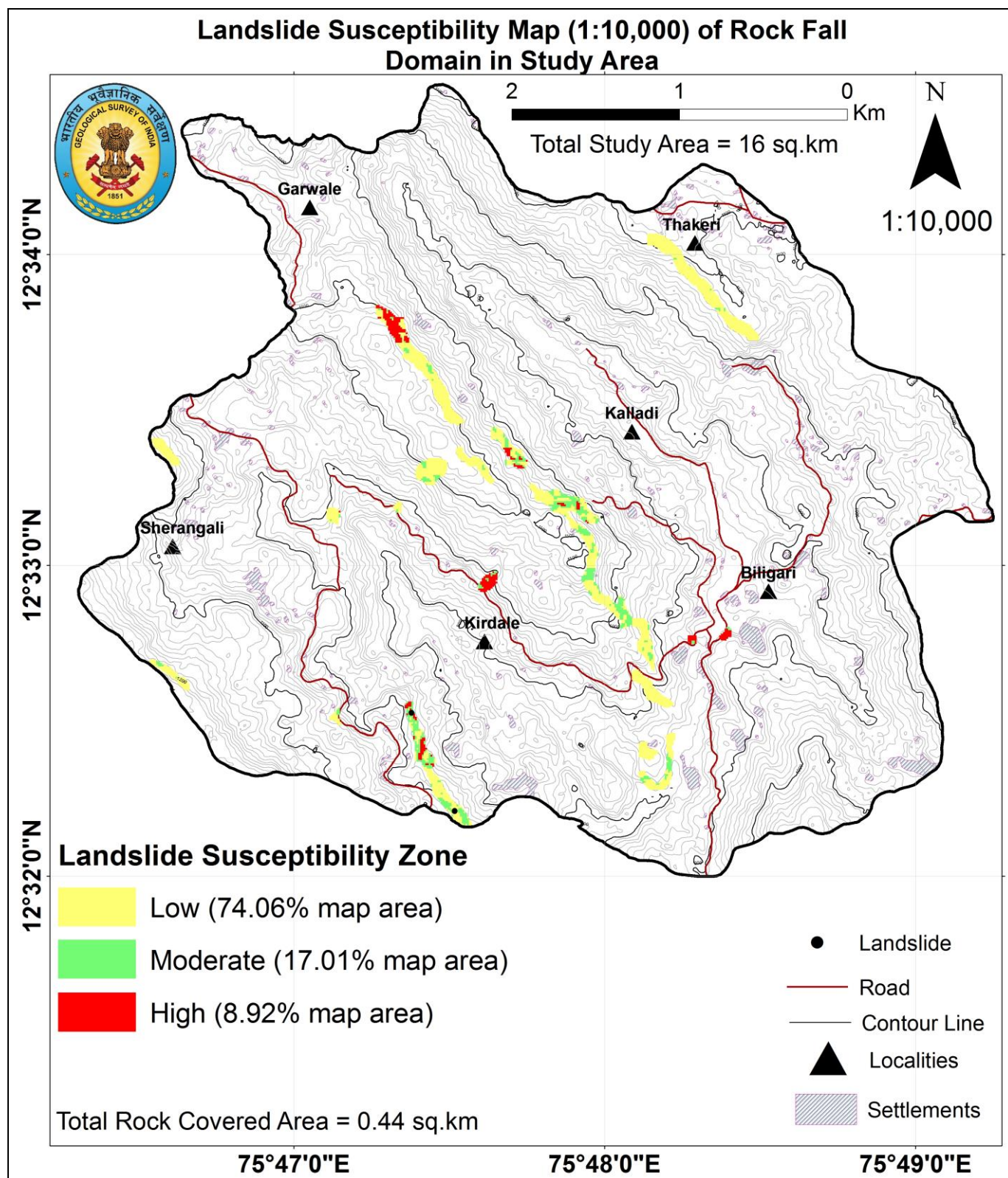


Figure-4.10: Landslide susceptibility map of rockfall domain in the study area

4.4 Debris/Earth Slide Domains (Overburden Domain)

Overburden characters are very important in landslide susceptibility depending on the type of material resting on a particular slope. The landslide domain represents areas having similar physiographic and geological characteristics that control the type of landslide occurring within it. It also helps in understanding the dominant landslide processes in the respective domain. The debris and earth slide susceptibility have been assessed for a 15.59 sq. km area covered by overburden in the present study area.

The debris/earth domains are being prepared by using the slope-forming material map prepared during field mapping. Later the debris/earth domains will be further refined by using the grain size analysis results from the laboratory. The immature soil, colluvium, boulder material, and loose debris are being classified into the debris domain by assuming that the above-mentioned materials occurring in the study area have a probability of debris slope failure. So far the areas covered with mature soil and/or high clay proportions are being classified into the earth domain based on field observations. Around 93% of the study area comes under the overburden domain (debris domain 61.79% and earth domain 35.6%). A total of 27 no's of landslides are falling in the debris domain, and 11 no's of landslides are falling in the earth domain. During monsoon season, the soil and the weathered rock failed together due to saturation giving the appearance of a debris slide. The documented earth failures are mostly restricted to adjacent to the anthropogenic activity and toe erosion by the stream but most of the debris flow occurred on the natural slope. For debris and earth material, four thematic variables are considered to generate the susceptibility map i.e. Landuse/Landcover, Stream power index (SPI), Geomorphon, and Geotechnical map.

4.4.1 Land Use/Land Cover Map

Land use and land cover changes (LULCCs) in mountainous areas may increase the susceptibility to landslides due to modifications of topography, vegetation, and material characteristics. Understanding the relation between LULCCs and landslide occurrences is important for landslide prevention and land resources management. Land cover change denotes a change in certain continuous characteristics of the land such as vegetation type, soil properties, and so on, whereas land-use change consists of an alteration in the way certain area of land is being used or managed by humans. Land cover change denotes a change in certain continuous characteristics of the land such as vegetation type, soil properties, and so on, whereas land-use change consists of an alteration in the way certain area of land is being used or managed by humans. Land use is too often considered a static factor in landslide hazard studies. Changes in land cover and land use resulting from human activities such as deforestation, forest logging, road construction, fire, and cultivation on steep slopes, and urbanization also disturb the natural equilibrium and affect the slope

stability. Vegetation effects on slope stability may be broadly classified as either hydrological or mechanical in nature.

The pre-field Landuse/Landcover map of the study was initially generated by using the high-resolution open source of Google Earth imagery 2021, later the map was verified in the field by accessing possible each part of the study area. In the pre-field LULC map, the maximum area is marked as thick vegetation and small patches of plantations, settlements, cultivation, etc. The types of plantations could not be identified by using Google Earth. A substantial modification has been done by incorporating field inputs. Most of the thick vegetation portion of the prefield LULC map has been changed into Coffee, silver oak and Jungle wood, Coffee, silver oak plantation, coffee, and jungle wood. Likewise, the plantation area changed into coffee, silver oak, Banana, Areca nut, and coffee with mixed plantation. The mixed plantation includes silver, orange, rosewood, etc. and Jungle wood mostly includes Athi (*Ficus racemosa* L.). The density of the Athi tree was maximum noticed in the downslope of the SLN estate, Jankhad A and B. Coffee plantations were noted all over the study area and silver oak plantations were done along the roads, around the settlements, and Coorg river valley guest house. SLN top and its downslope of the Landcover pattern totally changed by removing the natural forest and the land is being used for different types of plantation. In the larger area, the mixed plantation was done on the SLN top. The patches of cultivated land are restricted to the low-lying valley portion. The Kirudale road section was constructed by cutting the natural slopes with various heights and different slope angles, which leads to cut slope failures during the monsoon seasons at different places of the road sections. In the course of the field study several small dimensional cut slope failures are marked all along the road in the cut slope domain and its heights, materials also documented for the modelling purpose. The slope profile modification has been duly considered in the cut slope domain. The larger dimension of the 04 debris flow landslides falling in the LULC feature class of coffee, jungle wood, and also maximum nos of landslides around 50% of the landslides falling in the coffee, silver oak, Jungle wood class of LULC and followed by coffee, silver oak and coffee, Jungle wood classes. The maximum LSER 0.6 is assigned for Coffee, silver oak, Jungle wood classes as per the landslide incidences and Minimum LSER 0 is assigned for water body.

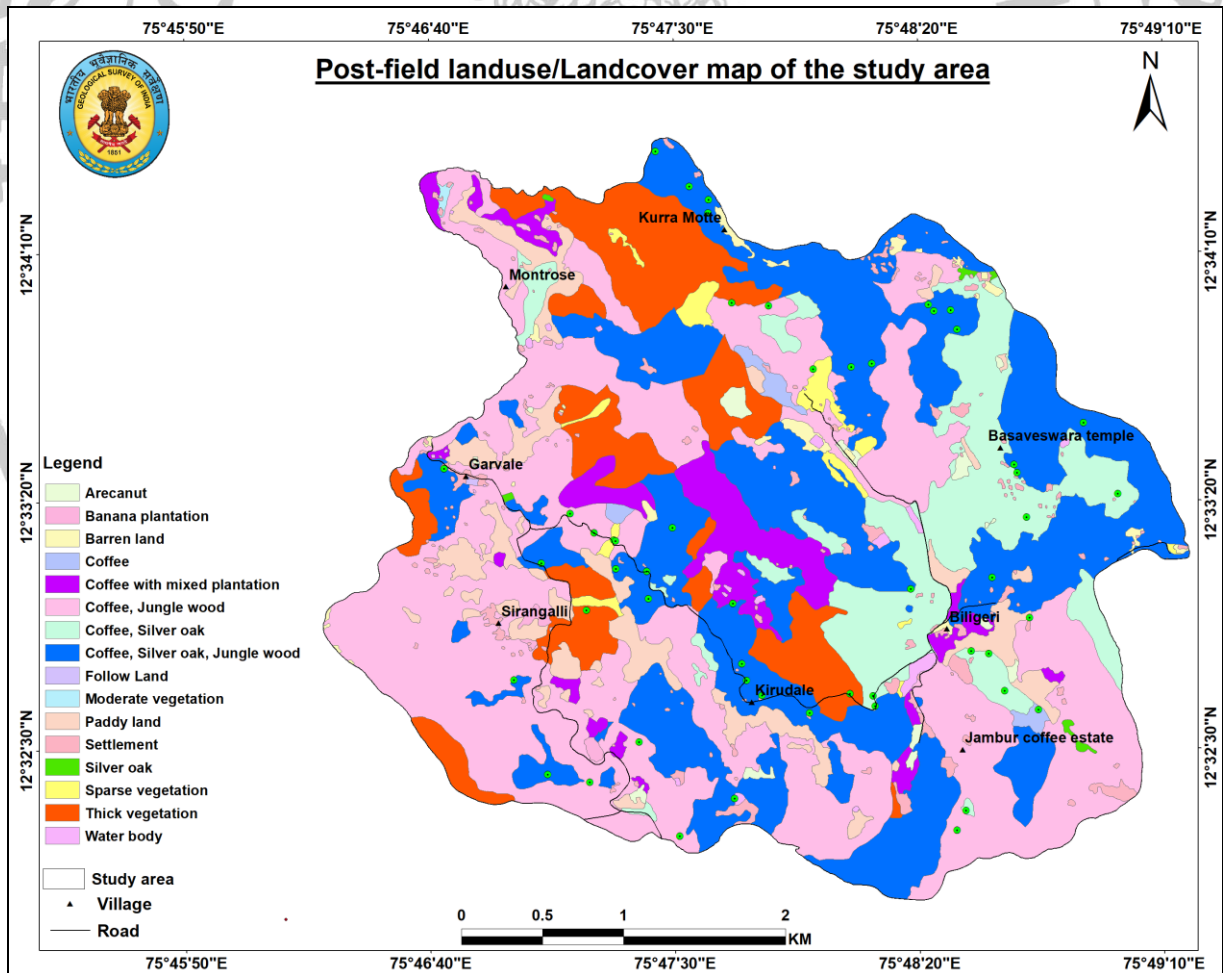
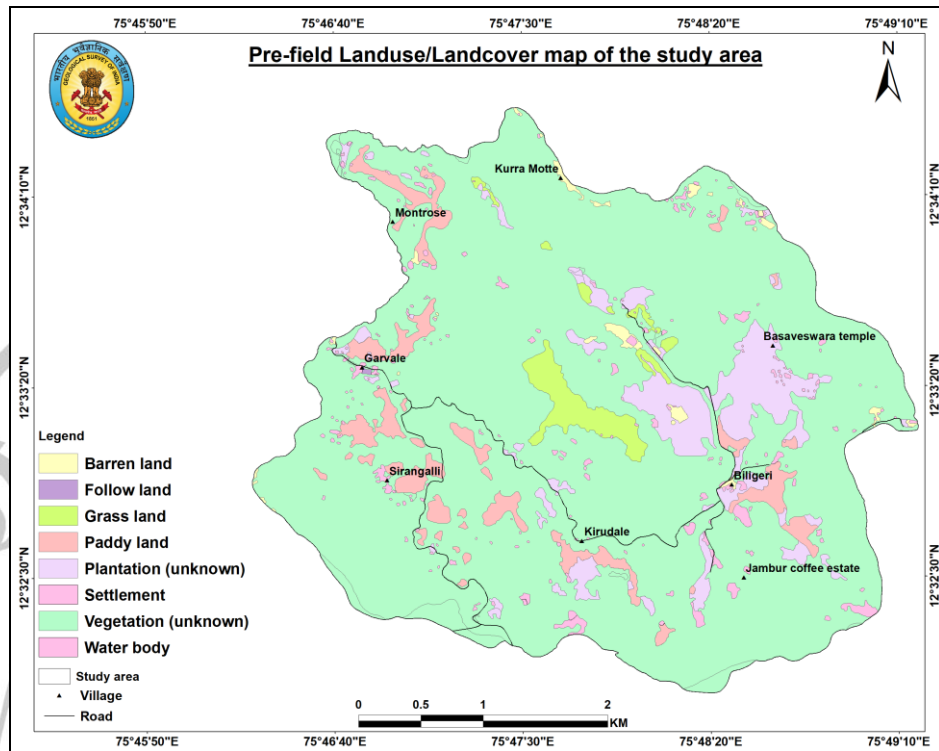


Figure-4.11: Pre-field and post field land use/Land cover map of the study area

Table-4.16: Landslide susceptibility evaluation rating (LSER) for the Landuse/Landcover map.

Sl.No.	Class	LSER
1.	Arecanut	0.2
2.	Banana plantation	0.2
3.	Barren land	1
4.	Coffee	0.3
5.	Coffee with mixed plantation	0.3
6.	Coffee, Jungle wood	0.4
7.	Coffee, Silver oak	0.5
8.	Coffee, Silver oak, Jungle wood	0.6
9.	Follow Land	0.2
10.	Moderate vegetation	0.3
11.	Paddy land	0.1
12.	Settlement	0.2
13.	Silver oak	0.2
14.	Sparse vegetation	0.4
15.	Thick vegetation	0.2
16.	Water body	0

4.4.2 Geomorphon/Landform Map

At a larger scale (1:10,000) the identification of individual geomorphological classes becomes difficult due to the confinement of the observation to a very small area on the large scale. At this scale, it is also difficult to match the boundary condition of the geomorphological processes resulting in landslides with the classes as shown in the land surface model of Dalrymple et al. (1968). To overcome this limitation a new concept of Landform mapping using 10 m CartoDEM has been introduced.

The landform map is obtained by a manual or automatic process from a DEM. There is a number of existing methodologies through which landforms can be prepared automatically by using the geomorphometric variables (Evans, 1972; Pike, 1988; MacMillan et al., 2004; Olaya, 2009), whereas manual classification involves the recognition of whole topographic patterns corresponding to specific landforms. The manual process can bring in errors depending on experience and field knowledge of the terrain. The concept of geomorphon is based on the process of manual classification of landforms using tools in computers to reduce human subjectivity. Geomorphon is a relief-invariant, orientation-invariant, and size-flexible abstracted elementary unit of terrain. It uses the 8- tuple pattern ($8^3=6561$ possibility) and compares the focus pixel with its eight neighbors starting from the one located to the east (Jasiewicz and Stepinski, 2013). Out of these 8-tuplets, in a typical terrestrial landscape, the most frequent and commonly recognizable geomorphons are flat, peak, ridge, shoulder, spur, slope, hollow, footslope,

valley, and pit (Fig. 2). Figure 3 shows the different geomorphic classes observed in the study area. The above-simplified reclassification of geomorphons is prepared in GRASS GIS (Neteler and Mitasova, 2007) by utilising the script `r.geomorphon` written in ANSI C (Jasiewicz and Stepinski, 2013). In the study area, most of the natural debris flow initiated in the slope, Hollow, Spur units, and the slides flow path along Valley of the geomorphon unit. As per the field condition, the LSER are assigned to the different geomorphon units, the maximum LSER one assigned to hollow followed by slope, spur, and shoulder, etc. and the least 0.2 LSER is assigned to flat, summit, valley, etc. even the anthropogenic induced landslide also comes under the geomorphon unit of the slope. The above-simplified reclassification of geomorphons is prepared in GRASS GIS (Neteler and Mitasova, 2007) by utilising the script `r.geomorphon` written in ANSI C (Jasiewicz and Stepinski, 2013). In the study area, most of the natural debris flow initiated in the slope, Hollow, Spur units, and the slides flow path along Valley of the geomorphon unit. As per the field condition, the LSER are assigned to the different geomorphon units, the maximum LSER one assigned to hollow followed by slope, spur, and shoulder, etc. and the least 0.2 LSER is assigned to Foot slope, Ridge, summit, valley, etc. even the anthropogenic induced landslide also comes under the geomorphon unit of the slope.

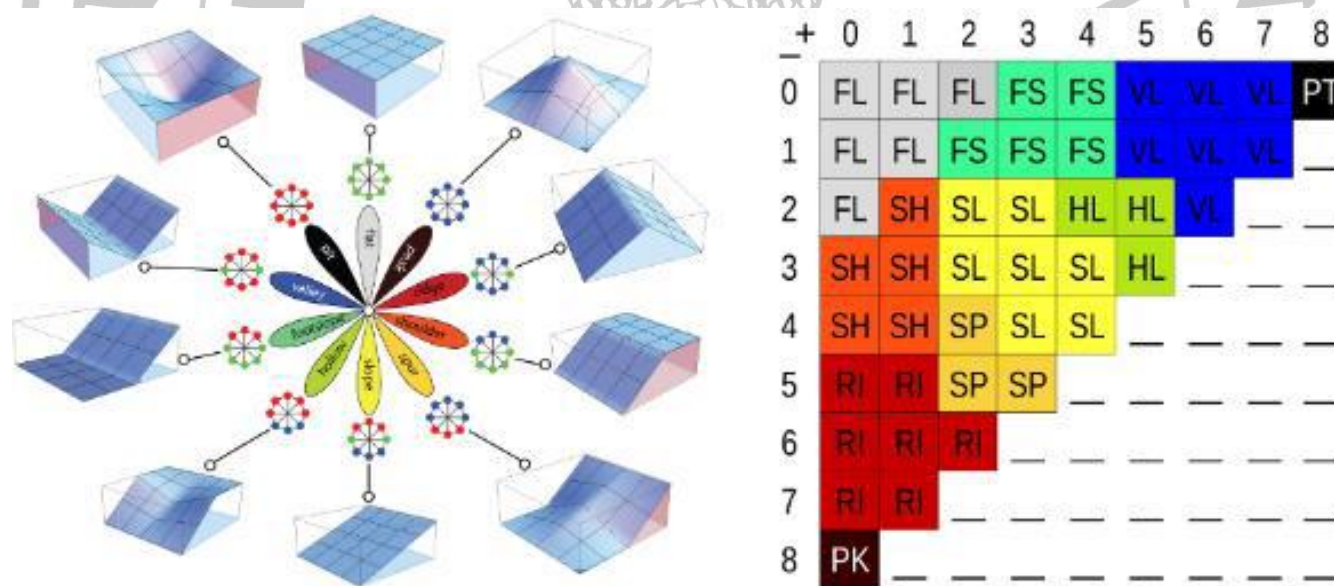


Figure-4.12: Representative 3-D pattern of 10 most common landforms and lookup table for reclassification of landforms into the 10 common landform types. Rows/columns in a table indicate the number of (-1)/(1) ternary elements in the landform pattern. Abbreviations for common landform elements are: FL — flat; PK — peak; RI — ridge; SH — shoulder; HL — hollow; SL — slope; SP — spur; FS — footslope; VL — valley; PT — pit

Table-4.17: Landslide susceptibility evaluation rating (LSER) for Geomorphon

Sl. No.	Class	LSER
1.	Summit	0.2

2.	Ridge	0.2
3.	Shoulder	0.3
4.	Spur	0.6
5.	Slope	0.8
6.	Hollow	1
7.	Footslope	0.2
8.	Valley	0.2
9.	Depression	0.4

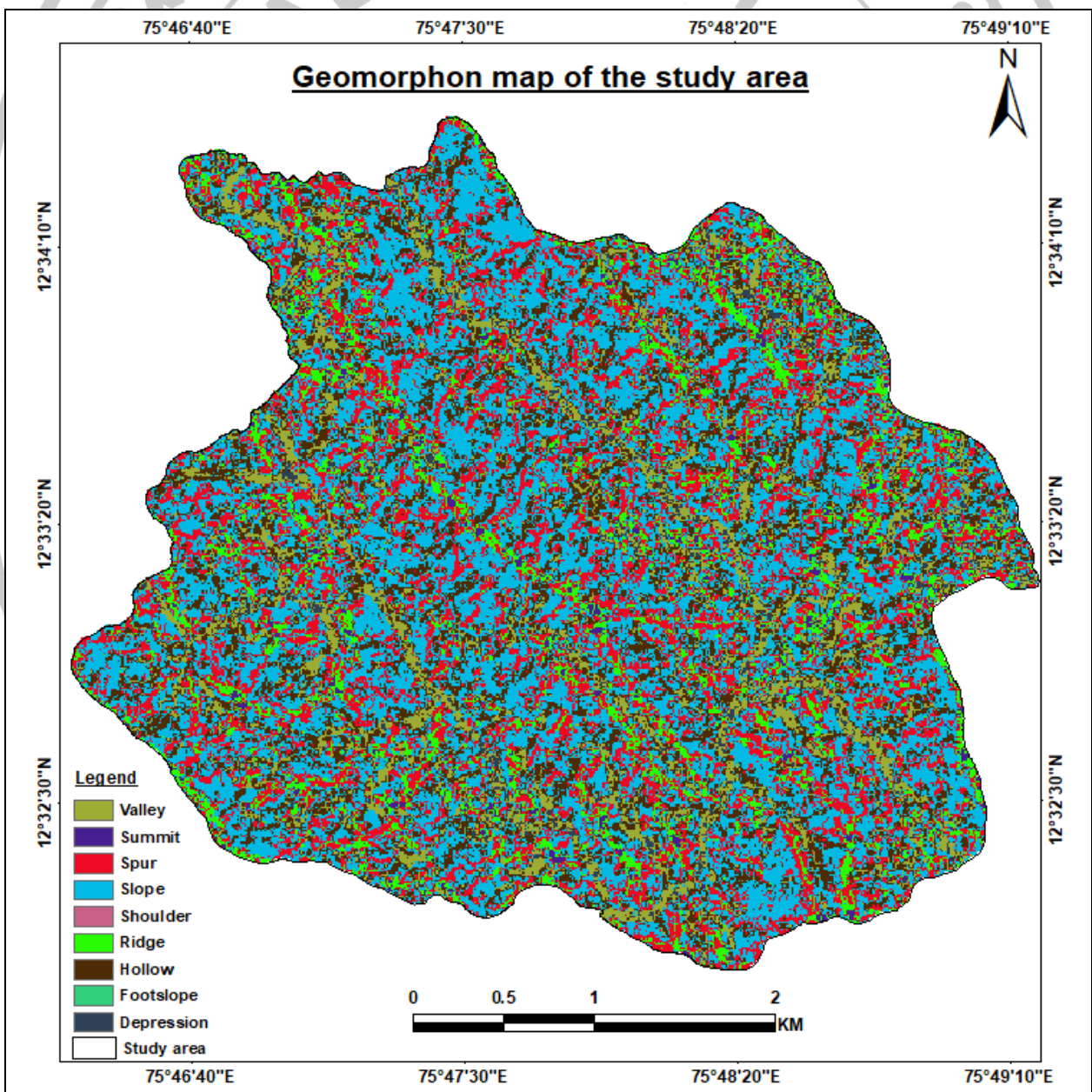


Figure-4.13: Geomorphon map of the study area derived from 10 m × 10 m Cartosat-DEM

4.4.3 Stream Power Index (SPI)

The landslide occurrence near the stream in the study area shows that most of the debris, earth slide, and debris flow has occurred near the streams due to natural toe erosion. Erosion triggered by rainfall disturbs the slope equilibrium and causes landsliding (Lévy et al., 2012), it was observed by Wistuba et al. (2015) that landsliding and erosion, once triggered by precipitation, can occur alternately in years with average precipitation and reinforce one another. Stream power index (SPI) (Moore et al., 1991) is a tool to define the potential flow erosion at a given point of the topographic surface and has been widely used for landslide susceptibility mapping (Pourghasemi et al., 2012a, b; Devkota et al., 2013; Park et al., 2013; Pradhan and Kim, 2014; Saadatkhah et al., 2014). It is a way of measuring the erosive power of water flow based on the assumption that discharge is proportional to a specific catchment area (Conforti et al., 2011). As catchment area and slope gradient increase, the amount of water contributed by upslope areas and the velocity of water flow increase, hence stream power index, and erosion risk increase (Florinsky, 2016). The SPI was calculated for every pixel and the map was reclassified into five classes. SPI is expressed as $SPI = \alpha \times \tan(\beta)$, where α is the specific catchment area and β is the local slope gradient measured in degrees (Moore et al., 1988; Park et al., 2013). The higher SPI value represents higher erosion rates in the catchment area.

The SPI map is prepared for the debris and earth slide domain at the slope scale using the 10 m × 10 m Carto-DEM. The pre-processed filled DEM is used to develop several intermediate raster datasets like slope, flow direction, and flow accumulation. Percent slope also referred to as ‘percent rise’ was calculated by the rise divided by run multiplied by 100. Flow direction raster is used for the preparation of flow accumulation. With the use of the raster calculator in Map algebra tool of ArcGIS 10.3, SPI was calculated for each pixel using the following equation: $SPI = \ln([FlowAccum_Raster] + 0.001) * ((Slope_Raster]/100) + 0.001)$.

The erosion condition along the slopes is a function of the linear distance of drainage. However, the study area represents slopes of varying gradients which will affect the erosive power of the streams depending on both the gradient and catchment area. Therefore, it is thought to be necessary to use a matrix of the linear distance of stream and stream power index for the classes and ratings.

For the stream power index map, maximum LSER is assigned to 8-11 classes assuming that the erosive power of the stream is maximum in that area, likewise, the minimum LSER is assigned -13 to -5 values, where the erosive power is minimum. But in the ground, the maximum nos of landslides are falling in the very low to moderate erosion. So it is considered that some other parameters are playing a vital role to initiate the landslides in that particular area. To counter this problem, the modelling part considered a stream buffer.

Table-4.18: Landslide susceptibility evaluation rating (LSER) for Stream power Index (SPI)

Sl. No.	Class	LSER
1	-13 to -5 (Very low erosion)	0.2
2	-5 to 0 (Low erosion)	0.3
3	0 to 4 (Moderate erosion)	0.4
4	4-8 (High erosion)	0.6
5	8-11(Very high erosion)	1

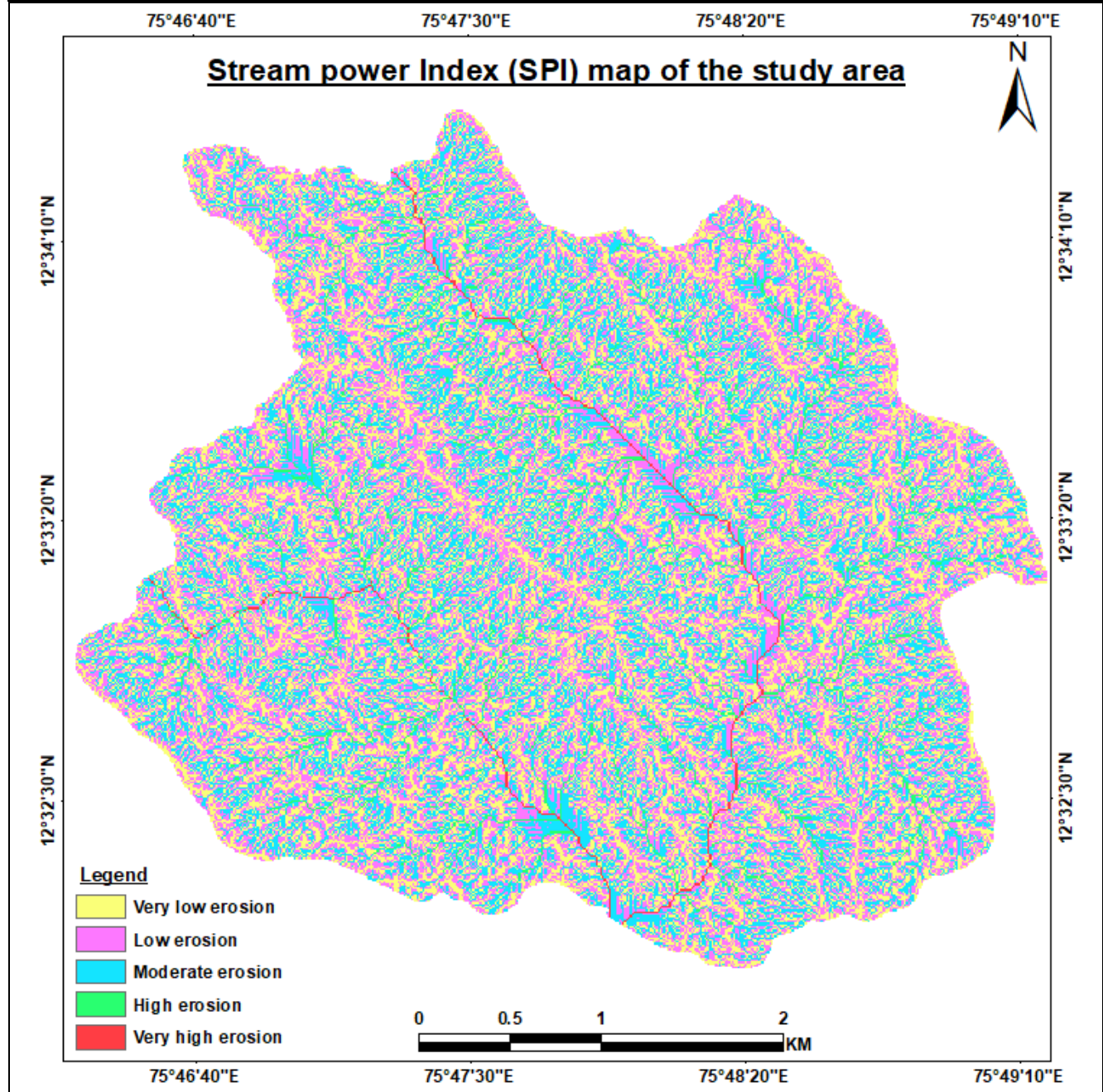


Figure-4.14: Stream Power Index map of the study area

4.4.4 Slope Forming Material Map (SFM)

SFM is one of the important static factors for causing landslides that controls the spatial distribution of landslides. The distribution of SFM units largely depends on underlying lithology, their degree of weathering and structural disposition, mass wasting history, and sometimes anthropogenic intervention.

SFM map has been prepared by using the 1:50000 scale geological maps as the base map, by down scaling the map from the NLSM project (Ankur Kumar Srivastava et al., 2017) and using Google Earth image, Cartosat-1 panchromatic image with 2.5 m spatial resolution and several proxies viz. geomorphology, geology, slope, LULC, landslide incidence. The entire study area has been classified into two basic SFM units i.e. overburden cover and rock cover. The slope having less than 1 m thick overburden cover has been considered a rocky slope. Overburden cover slopes are identified using geomorphology, geology, slope, LULC, and landslide incidence maps. From the LULC map, all the cultivated areas of the plantation have been extracted assuming the probable locale of a superficial deposit, likewise from the geomorphology map, alluvial plains, valley fill, and palaeo-landslides polygons have been imported as a superficial deposit. From the slope map all the gently sloping areas viz. ridge tops, on either side of rivers are mapped as superficial deposit polygons. During the extensive field study, the slope-forming map was validated and modified as per the ground conditions.

A total of 11 different types of slope-forming materials have been identified in the field. At a larger scale of the map, more detailed information on SFM classes was captured of which few are significant to slope stability. In the SFM classes, immature soil has the maximum spatial distribution (39%) followed by mature soil (21.8%), Boulder material (6.4%), soil+ gravel material (13.41%) and the rest (19.36%) area is covered by other SFM classes. Figure- 4.15 shows the different slope-forming material classes observed in the study area. The spatial distribution of the colluvium and boulder materials are identified in the SLN estate, Janakhad A and B, and towards Siranhalli. The association of the boulder material and colluvium are mostly adjacent to each other. The distribution of the immature and mature soil was noted all around the study area and soil+gravel material and transported materials occupying the low-lying area however soil+gravel material was noted in higher elevations also. Among the 11 different SFM classes, a few classes like Colluvium, Boulder material, weathered rock, loose slide material, and certain pockets of immature soils are identified as significant for the initiation of the landslides in the study area.

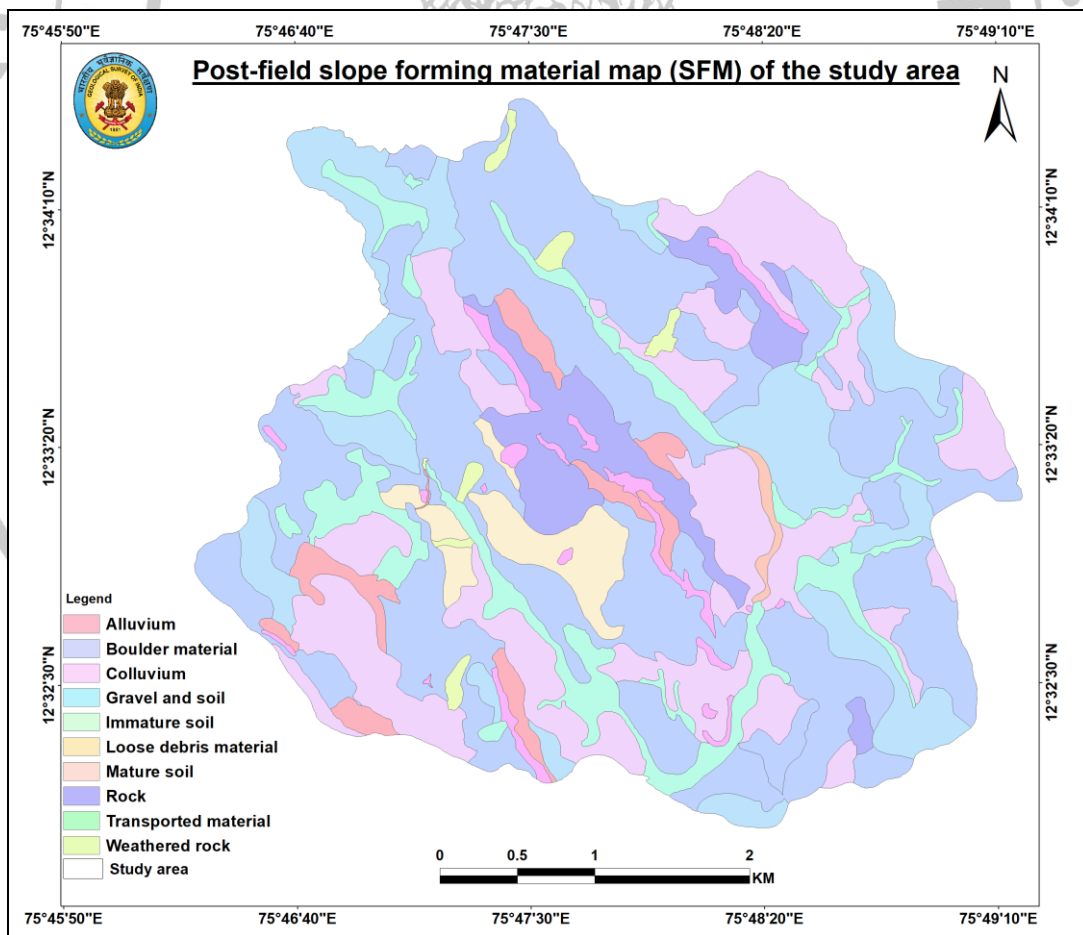
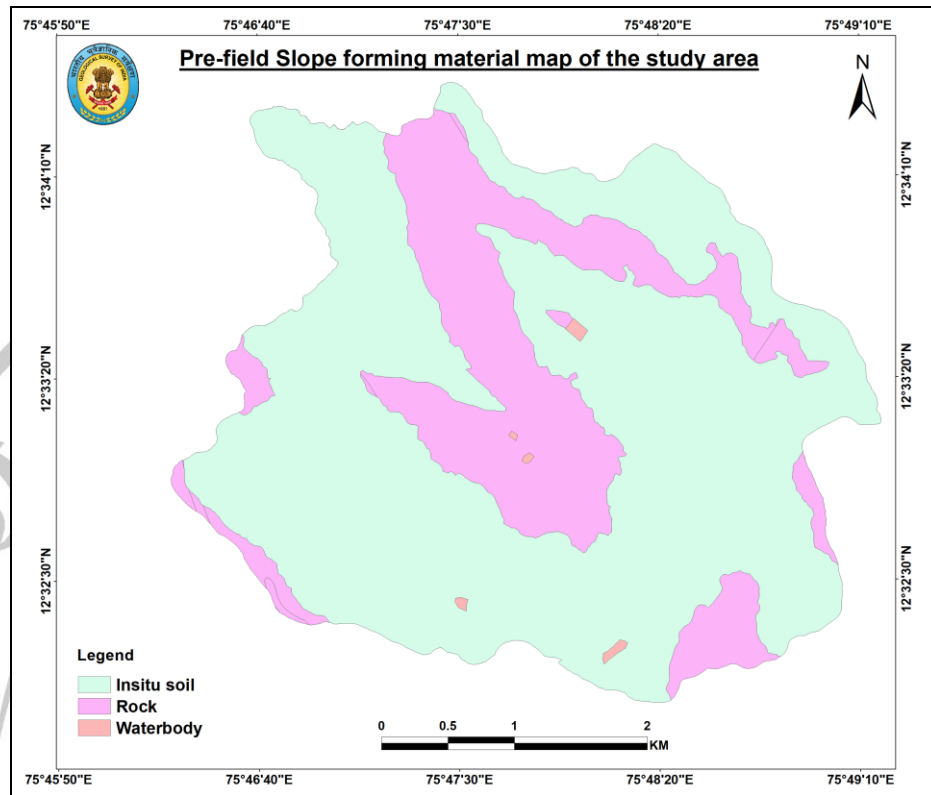
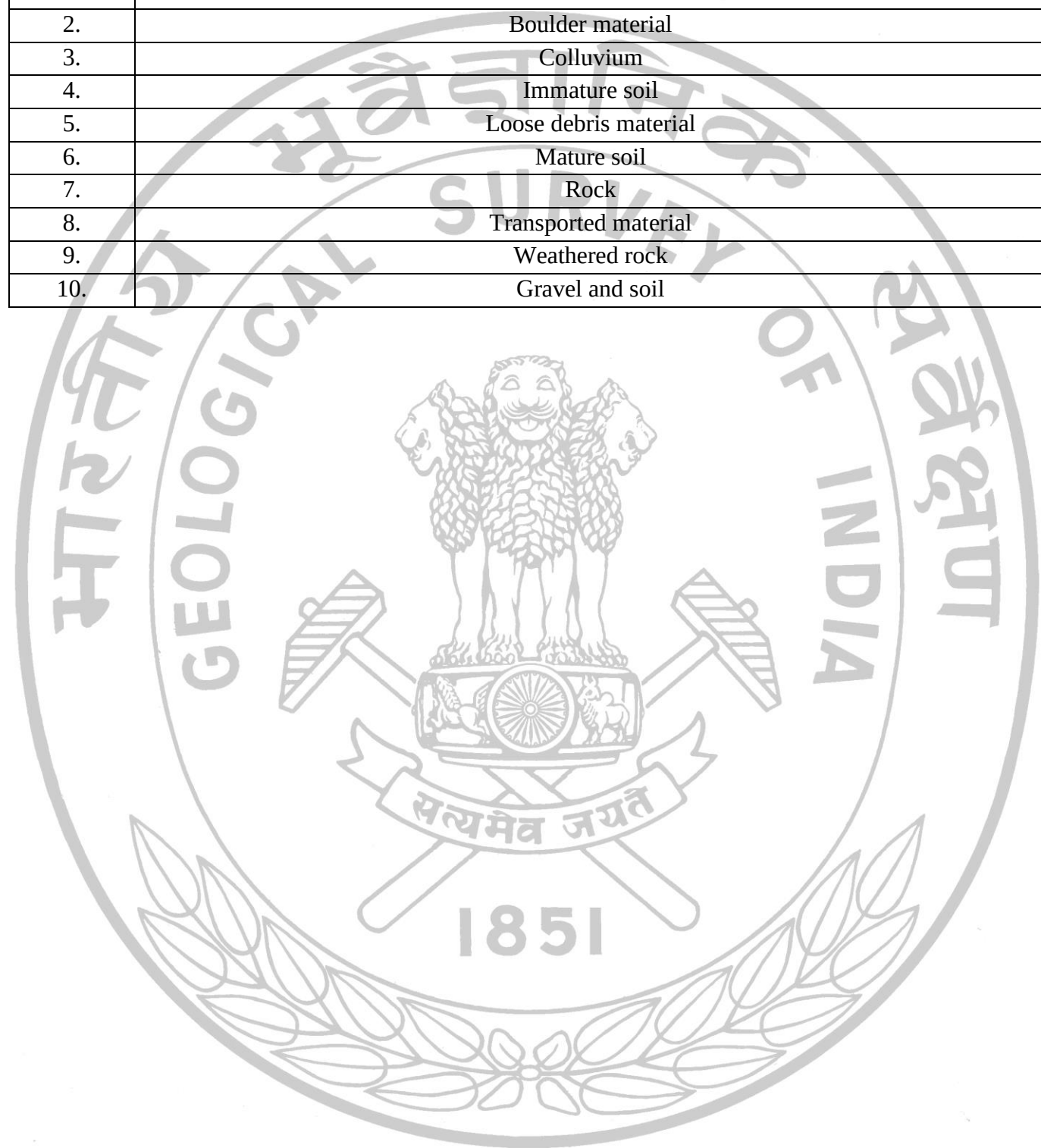


Figure-4.15: Pre-field and post field slope forming material map of the study area

Table- 4.19: Slope Forming Material classes identified in the field mapping

Sl. No.	Class
1.	Alluvium
2.	Boulder material
3.	Colluvium
4.	Immature soil
5.	Loose debris material
6.	Mature soil
7.	Rock
8.	Transported material
9.	Weathered rock
10.	Gravel and soil



4.4.5 Stream Buffer Map

During the field investigation, it was observed that 2nd and 3rd-order streams are cutting the slopes very deep and leaving the slopes vertical. This kind of erosion and formation of such vertical slopes seems very vulnerable to slope failures in the study area. Therefore the workers decided to use the 2nd and 3rd stream buffer maps in doing landslide susceptibility modeling. The stream buffer map was classified as below:

Table- 4.20: Stream buffer classes identified for modelling

Sl. No.	Class	LSER
1.	25m	1
2.	25-500m	0

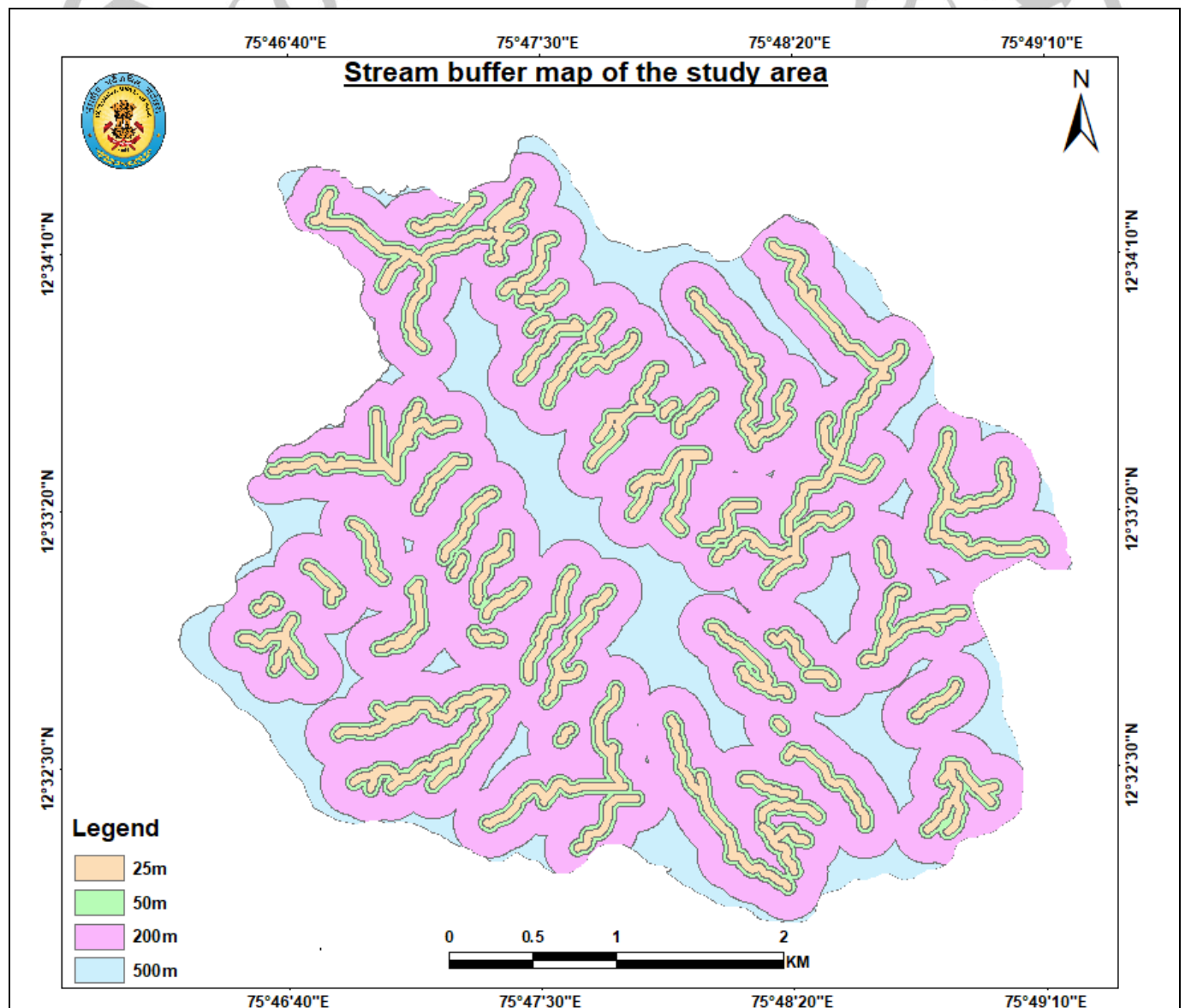


Figure-4.16: Stream buffer map of the study area

4.4.6 Geotechnical/Engineering Geological Map

The stability of a slope depends on the nature of the material, its inherent disposition, shear strength, pore water pressure, groundwater regimes, etc. The geotechnical properties of the soil/overburden material and the slope mass ratings provide the basis for stability analysis of any rock/overburden material. This requires a detailed mapping of the site and geotechnical properties of the rock and overburden. An engineering geological map tells about the material properties that indirectly account for the pore pressure, rock mass character, infiltration, etc. of the slope-forming material. The field-based slope forming material map hence is converted to the engineering geological map that represents the overall characteristics of the material based on the rock mass condition in rock outcrops and geotechnical properties of the overburden material.

The geotechnical parameters of the overburden including cohesion (C) and internal angle friction (ϕ) are the important geo-factors that determine the shear strength of the material and the ability to resist failure. In the present study, the samples from different slope-forming material classes in overburden cover were collected in the gridded pattern (1*1 Sqkm) at different contour levels considering different elevations. A total of 32 no's of UDS samples were collected. Cohesion ranges from 18 to 47 kN/m² while the angle of internal friction is 20° to 28°. Since the geotechnical results fall only in one class of C and ϕ matrix classification outlined by Ghoshal et al., 2013, hence Ghoshal et al., 2013 matrix is readjusted as per the present study area condition. After the readjustment of the Ghoshal et al., 2013 matrix as pre the filed the classes approaches towards very bad to good category. As per the Geotechnical values, very good categories are not found but very low-lying areas and no scope of landslide areas are given in the very good category.

Table- 4.21: Matrix table of cohesion and angle of internal friction for classification of overburden material with LSER rating.

Cohesion (C) as per Ghoshal et al., 2013	Cohesion (C) Re-adjusted	Angle of Internal Friction (ϕ)) as per Ghoshal et al., 2013	>30°	21°-30°	11°-20°	<=10°
		Angle of Internal Friction (ϕ) Re-adjusted	<20	20-25	26-31	>31
<5 kN/m ²	<24		(1) Very bad	(1) Very bad	(0.8) Bad	(0.6) Fair
5-15 kN/m ²	24-29		(0.8)Bad	(0.8)Bad	(0.8)Bad	(0.4)Good
16 to 30 kN/m ²	30-34		(0.8)Bad	(0.6)Fair	(0.6)Fair	(0.2)Very good
>30 kN/m ²	>34		(0.6)Fair	(0.4)Good	(0.4)Good	(0.2)Very good

After the above classification, the overburden material map was further classified with help of the relationship between the internal friction angle and slope used (Roopnarine, 2013). Initially, the slope of each pixel was subtracted from the friction angle. The higher values imply low susceptible zones and the lower values imply higher susceptible zone. Now in the overburden material, one class degraded according to the slope and internal friction angle. For example, the high class is degraded into very high susceptible level. The good category overburden material was found to be mainly restricted to the areas having matured soil, soil+gravel and colluvium, boulder material, and some places of immature soil. whereas as per the disposition at higher slope the same material also falls fair to bad category. The loose debris material falls in the Very bad to fair class likewise immature soils and mature soils also fall in the Very bad to good classes. The bad category occupies mainly the middle and NNE parts of the study area.

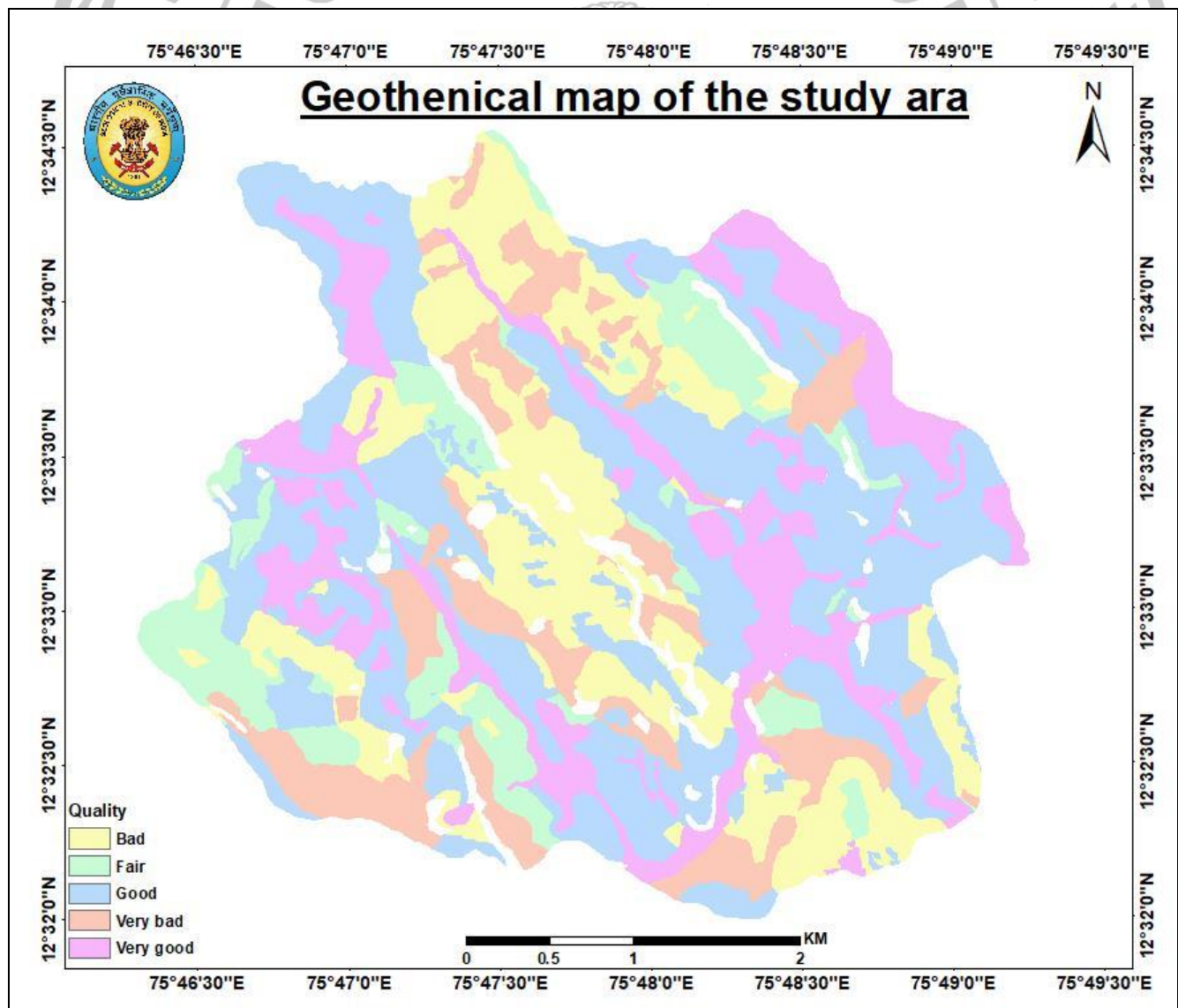


Figure-4.17: Geotechnical map of the debris slide and earth slide domains (overburden)

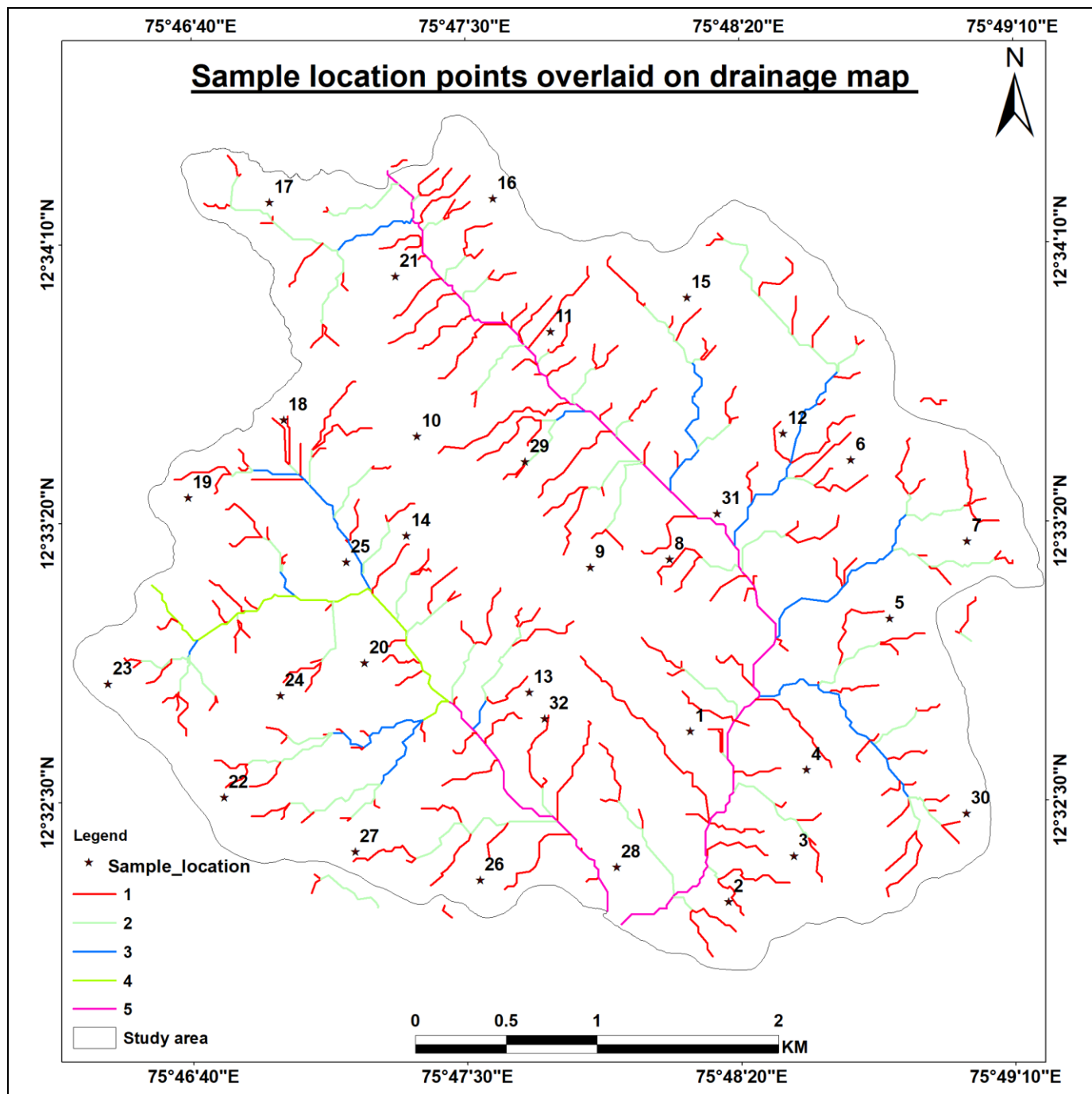


Figure-4.18: Location and distribution of 32 nos. of UDS samples collected from overburden

4.4.7 Overlay Analysis for TESV Calculation in Overburden Domain

A landslide susceptibility map is a representation of the Total Estimated Susceptibility Values (TESV) of each mapping unit in an area in terms of different susceptibility classes (Ghoshal et al., 2013). The total estimated susceptibility value over an area of investigation would remain below or equal to 10 as per the opinion of the workers. The ratings for each geo-factor class were given as per their role in changing the slope stability as assessed during field mapping. The field generated geo-factor themes such

as land use/land cover, and slope forming material which was later on converted to a geotechnical map after assigning the cohesion and angle of internal friction matrix values and CartoDEM 10m derived SPI, Landform and drainage were considered for TESV calculation. In the case of a geotechnical map of the overburden domain in particular, there were two corrections made in its LSER attribute after assigning the cohesion and angle of internal friction matrix values which includes the role of incompetent litho-units fragile for erosion and sliding and mean slope angle. The landslide susceptibility score map which contains TESV has been generated by the overlay method in which the summation of LSER of all geo-factor themes has been performed in the ArcGIS platform.

Total estimated susceptibility value (TESV) for overburden domain = $\sum(\text{LSER}_{\text{Landuse map}} + \text{LSER}_{\text{Landform map}} + \text{LSER}_{\text{Geo-technical map}} + \text{LSER}_{\text{Stream Power Index map}} + \text{LSER}_{2^{\text{nd}} \& 3^{\text{rd}} \text{ Order Drainage map}})$.

Table-4.22: Classified landslide susceptibility map attributes of overburden domain

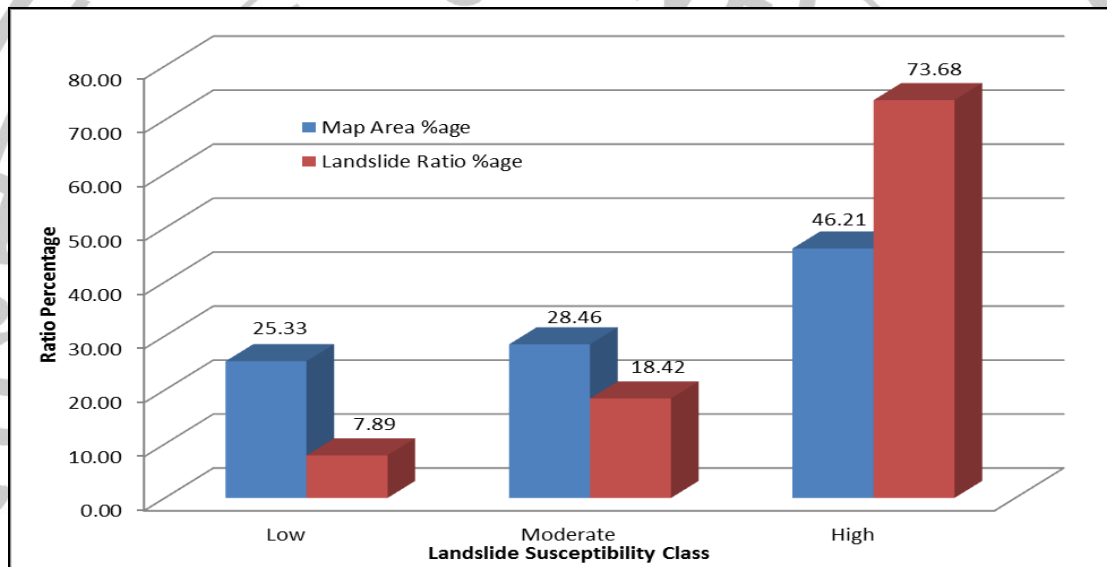
Value	Pixel Count	TESV Break	Susceptibility Class	Map Area Percentage	Landslide Ratio
1	38103	1.75	Low	25.33	3
2	42811	2.1	Moderate	28.46	7
3	69522	4.2	High	46.21	28
Total	150436			100%	38 nos.

4.4.8 Mesoscale Landslide Susceptibility Map of the Overburden Domain

The landslide susceptibility in the overburden domain has been assessed over a 15.59 sq. km area and the total estimated susceptibility value (TESV) ranges from 0.6 to 4.2 which was later reclassified into three classes of landslide susceptibility as mentioned in the table- 4.22. The landslide susceptibility map of the overburden domain (figure- 4.19) is derived through a knowledge-driven heuristic method and can be used to understand the relative stability of natural slopes in the study area. The map would provide a fair idea of the susceptibility to debris and/or earth failures on natural slopes in response to the complex interaction of the considered geo-factor themes. It is worth stating that the impact of external forces particularly rainfall water action was not taken into consideration and it may change the resulting susceptibility scenario of overburden in the study area at any period.

A total of 38 nos. of landslides were recorded in the overburden domain in the study area which has been validated with the resulted susceptibility map area percentage in which landslide ratio remains 3

(low): 7 (moderate): 28 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to debris and/or earth slide failures. Maximum landslides 28 nos. fall in the high susceptibility zone which signifies that the validation of applied model prediction by existing landslides is 74%. Whereas moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 28.46 percent. This signifies that qualitatively the adopted model has predicted 72 percent map area with efficacy and there is the least uncertainty in terms of moderate susceptibility over the 28 percent map area. The below-shown graph depicts the satisfactory ratio between susceptibility map area percentage and landslides in the overburden domain.



Geographically the susceptibility map of the overburden domain shows high susceptibility of natural slopes to debris and/or earth slide failures in northern and south-western parts of Kalladi and Kirdale villages where there can be seen several landslide incidences in the past. Besides the far southern parts of Thakeri and Biligeri villages also shows high susceptibility to debris and/or earth slide failures. However, there are a few isolated parts in and around the Garwale, Sherangali and Biligeri villages that show high susceptibility to natural slope failures. Moderate susceptible slope facets are widespread in the area and represent areas that are relatively stable but can initiate landslides under the interactions of dynamic geo-environmental factors, particularly during intensive rainfall. The low susceptible slope facets are considered stable under the given set of geo-environmental conditions considered in the study. However, the adverse anthropogenic interference and intensive incessant rainfall as a trigger may still initiate landslides in a low susceptible area. The present susceptibility map in the overburden domain is valid only under the given set of geo-environmental conditions taken as input in the susceptibility modeling. Any change in the spatial distribution of the geo-environmental factors considered in the modelling would change the susceptibility of the area over a period of time.

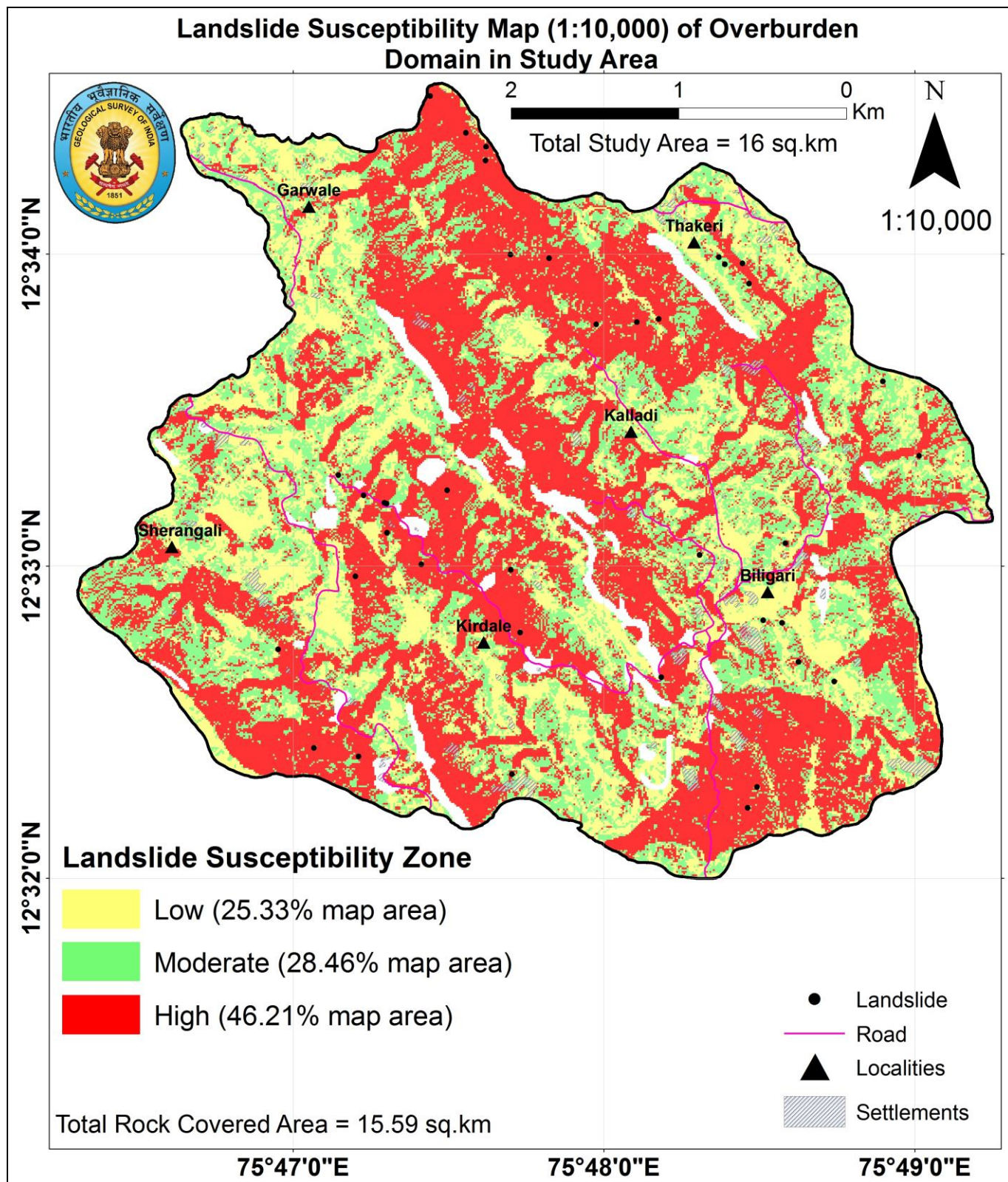


Figure-4.19: Landslide susceptibility map of overburden domain in the study area

4.5 Cut-slope Domain

Cut-slopes are mostly the results of anthropogenic activities performed on the earth's surface for road & railway line construction, settlement building construction, and mining of useful mineral commodities. However, the cut-slopes are also naturally occurring due to stream or river erosional processes. Cut-slopes are found as isolated stress-released windows in both rock and overburden-covered slopes where the probability of movement of slope material to downslope increases under the action of various factors responsible for decreasing resisting forces. In macro-scale (1:50,000) landslide susceptibility mapping the cut-slopes were mapped as a feature class in the land use/landcover map but in the present study, the cut-slopes have been analyzed as a separate domain. It has been observed that a cut slope with a moderate to high upslope angle is highly susceptible to failure and if cut-slope height increases then the susceptibility to failure also increases for the same cut slope. Therefore, relative relief, cut-slope height, and upslope angle have been selected to evaluate the landslide susceptibility in the cut-slope domain. There is only a 0.24 sq. km area covered by the cut-slope domain in the study area.

4.5.1 Relative Relief

The relative relief represents the actual variation of altitude in a unit area with respect to its local base level, in other words, the difference in height between the highest and the lowest points in a specified area. Relative relief is directly related to the degree of dissection in an area; that is the area with high relative relief would experience high intensity of dissection and more will be the movement of material down the slope. In the present study, the relative relief has been calculated for a slope facet in which cut-slope exists and it ranges from 0-150 respectively.

4.5.2 Cut-Slope Failure Tendency

Although cut-slope failures are initiated mostly by anthropogenic activities but their failure tendency depends more or less on cut-slope height and upslope angle. In the present study, the impact of these two factors (cut-slope height and upslope angle) has been evaluated and it has been observed that a cut slope with moderate to high upslope angle is highly susceptible to failure, and if cut-slope height increases then the susceptibility to failure accelerated for the same cut slope. The cut-slope height range for each portion of the cut-slope is measured on the ground and the upslope angle range on each slope facet with cut-slope is derived from CartoDEM 10m as shown in table-4.23. The cut-slope failure tendency map has been prepared by giving failure tendency value based on the increase in cut-slope height and upslope angle as shown in the table below;

Table-4.23: Cut-Slope failure tendency map attributes

Sl. No.	Cut-Slope Height	Cut-Slope Material	Upslope Angle	Cut-Slope Height/Upslope Angle LSER	Modified LSER	Area_sqkm
1	3-6m	Immature soil (Debris)	16-35	0.6	0.6	0.0029
2	3-6m	Loose weathered rock (deformed)	0-15	0.2	0.4	0.0017
3	<3m	Loose weathered rock (deformed)	16-35	0.4	0.6	0.0029
4	7-10m	Weathered rock (Debris)	16-35	0.8	0.9	0.0097
5	7-10m	Immature soil (Debris)	16-35	0.8	0.8	0.0055
6	3-6m	Loose weathered rock (deformed)	36-45	0.8	1.0	0.0061
7	7-10m	Weathered rock (Debris)	16-35	0.8	0.9	0.0065
8	3-6m	Colluvium (Debris)	16-35	0.6	0.7	0.0018
9	3-6m	Weathered rock (Debris)	16-35	0.6	0.7	0.0045
10	<3m	Immature soil (Debris)	16-35	0.4	0.4	0.0054
11	7-10m	Weathered rock (Debris)	0-15	0.3	0.4	0.0080
12	3-6m	Outcrop (Rock)	16-35	0.6	0.2	0.0066
13	3-6m	Loose weathered rock (deformed)	16-35	0.6	0.8	0.0062
14	3-6m	Immature soil (Debris)	0-15	0.2	0.2	0.0118
15	3-6m	Immature soil (Debris)	36-45	0.8	0.8	0.0058
16	7-10m	Weathered rock (Debris)	16-35	0.8	0.9	0.0169
17	<3m	Immature soil (Debris)	0-15	0.1	0.1	0.0099
18	3-6m	Mature soil (Earth)	16-35	0.6	0.5	0.0174
19	3-6m	Immature soil (Debris)	36-45	0.8	0.8	0.0022
20	3-6m	Immature soil (Debris)	0-15	0.2	0.2	0.0035
21	<3m	Immature soil (Debris)	16-35	0.4	0.4	0.0036
22	7-10m	Mature soil (Earth)	16-35	0.8	0.7	0.0034
23	3-6m	Immature soil (Debris)	16-35	0.6	0.6	0.0018
24	3-6m	Mature soil (Earth)	36-45	0.8	0.7	0.0034
25	7-10m	Immature soil (Debris)	16-35	0.8	0.8	0.0106
26	3-6m	Immature soil (Debris)	36-45	0.8	0.8	0.0083
27	3-6m	Immature soil (Debris)	16-35	0.6	0.6	0.0052
28	7-10m	Immature soil (Debris)	16-35	0.8	0.8	0.0046
29	7-10m	Mature soil (Earth)	16-35	0.8	0.7	0.0046
30	7-10m	Weathered rock (Debris)	0-15	0.3	0.4	0.0158
31	7-10m	Loose weathered rock (deformed)	16-35	0.8	1.0	0.0106
32	3-6m	Mature soil (Earth)	16-35	0.6	0.5	0.0054
33	3-6m	Weathered rock (Debris)	16-35	0.6	0.7	0.0210
34	3-6m	Outcrop (Rock)	0-15	0.2	0.5	0.0025
35	3-6m	Outcrop (Rock)	36-45	0.8	0.2	0.0017
36	3-6m	Outcrop (Rock)	16-35	0.6	0.2	0.0001
37	7-10m	Outcrop (Rock)	16-35	0.8	0.2	0.0004
38	3-6m	Immature soil (Debris)	16-35	0.6	0.6	0.0002

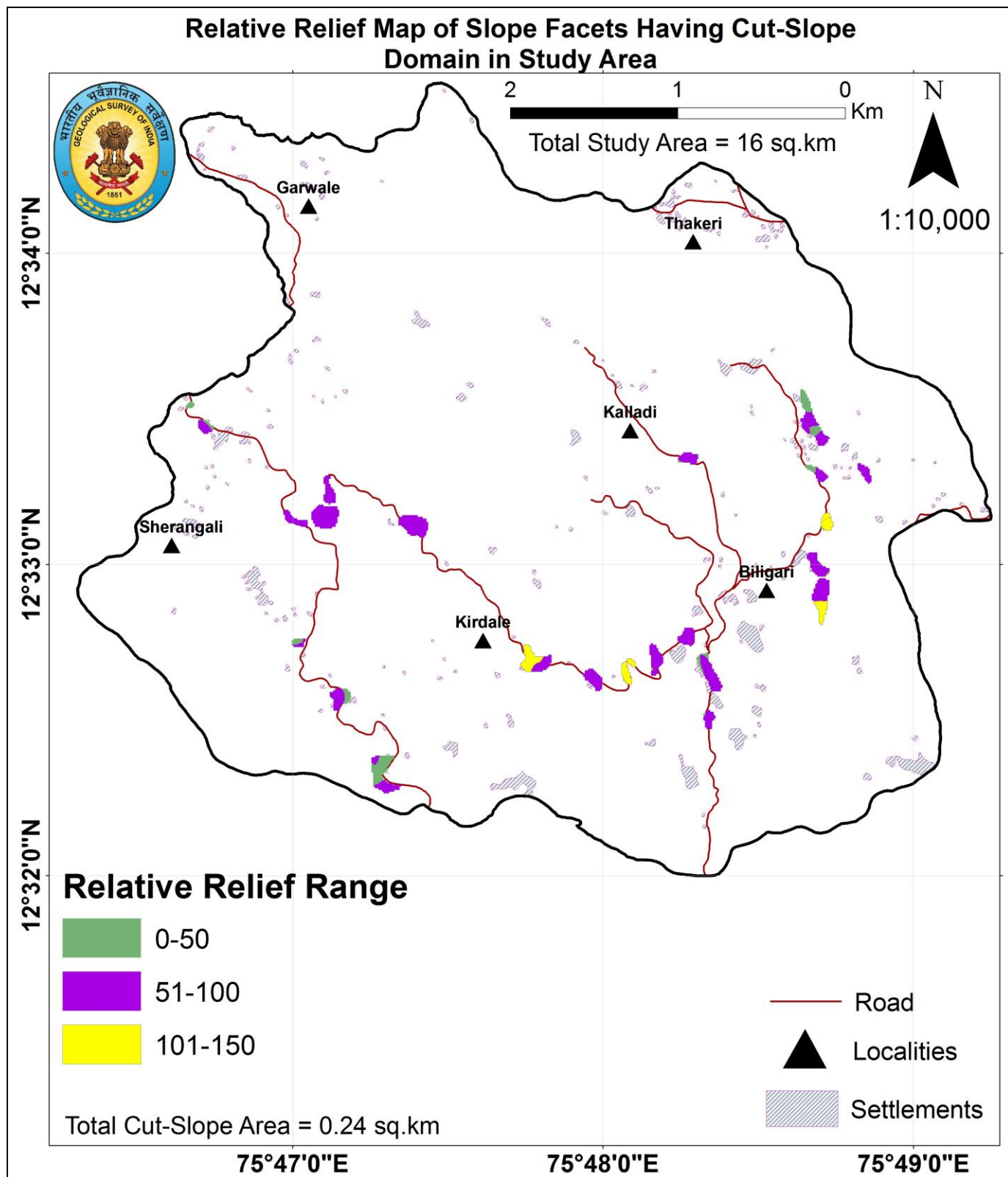


Figure-4.20: Relative relief map of slope facets having cut-slopes in the study area

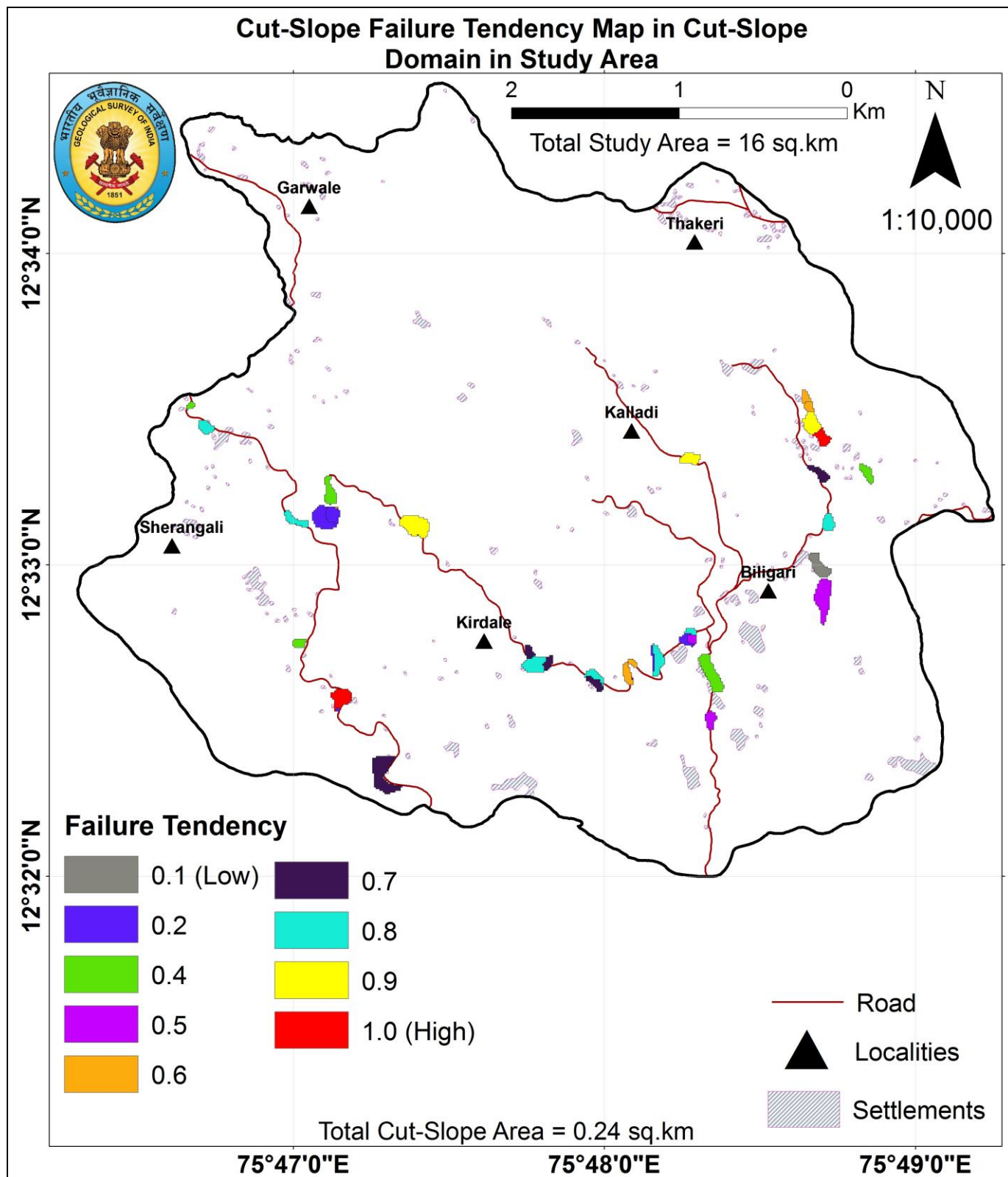


Figure-4.21: Cut-slope failure tendency map of slope facets having cut-slopes in the study area

4.5.3 Ratings and Integration of Geo-Factor Maps

In the cut-slope domain, the slope facets with cut-slopes were studied thoroughly to find out the most relevant factors which accelerate failures. Apart from the relative relief of each slope facet, the impact of the cut-slope height range and upslope angle range has been analyzed in a combined way of correlation matrix. The external forces, mostly rainfall which increases the unit mass of slope material were not accounted for in this study. That is why the LSER value has not been kept as 0 (zero) because, under the effect of external forces at any period, the minimum LSER value to any factor class may show a tendency towards increasing vulnerability. The landslide susceptibility evaluation rating (LSER) is determined heuristically (knowledge-driven approach) as per the current SOP. The landslide susceptibility evaluation ratings were taken for each factor class that exists in the cut-slope domain in the study area from the given rating system as follows;

Table-4.24: Landslide susceptibility evaluation rating (LSER) for relative relief map

Relative Relief Range	LSER
0-25m	0.2
26-50m	0.4
51-75m	0.6
76-100m	0.8
>100m	1.0

Table-4.25: Landslide susceptibility evaluation rating (LSER) for cut-slope failure tendency map

Correlation Matrix					
Upslope Angle (Degree)		0-15	16-35	36-45	>45
Cut-Slope Height	<3m	0.1	0.4	0.7	1
	3-6m	0.2	0.6	0.8	1
	7-10m	0.3	0.8	0.9	1
	>10m	0.4	1	1	1

The heuristically determined landslide susceptibility evaluation ratings (LSER) mentioned in table-4.6, 4.7, 4.21, 4.24 & 4.25 were given to each thematic class of factor maps selected for the preparation of landslide susceptibility map in the cut-slope domain. In addition, the worker has also considered the compactness of slope-forming material and incompetent rock mass in giving LSER in the cut-slope failure tendency map and has increased LSER by 0.2 over the correlation matrix class ratings. The landslide

susceptibility evaluation ratings (LSER) for each factor class were integrated. The landslide susceptibility evaluation ratings (LSER) for each factor class have been deliberately put below 1 so that the total estimated susceptibility value (TESV) remains below or equal to 10. The calculation of the total estimated susceptibility value (TESV) was performed in the GIS platform by using the below-mentioned calculation (Aijaz Ahmad & Senthilkumar, 2021);

Total estimated susceptibility value (TESV) for overburden cut-slopes = $\sum(\text{LSER_Relative Relief map} + \text{LSER_Cut-slope Failure Tendency map} + \text{Geotechnical map})$

Total estimated susceptibility value (TESV) for rock cut-slopes = $\sum(\text{LSER_Relative Relief map} + \text{LSER_Cut-slope Failure Tendency map} + \text{Kinematic maps (planar, wedge, topple)})$

Table-4.26: Maximum LSER of factor maps selected for preparation of landslide susceptibility map in the cut-slope domain (overburden and rock) other than geotechnical and kinematic maps

Factor Map	Factor Class		Maximum LSER	
Relative relief map	0-50		0.4	
	51-100		0.8	
	101-150		1.0	
Cut-slope failure tendency map	Cut-slope Height (m)	Upslope Angle (Degree)	LSER	After Corrections by cut-slope material (Overburden) & RMR (Rock)
	<3	0-15	0.1	0.1
	3-6	0-15	0.2	0.2-0.5
	7-10	0-15	0.3	0.4
	<3	16-35	0.4	0.4-0.6
	3-6	16-35	0.6	0.2-0.8
	3-6	36-45	0.8	0.2-1.0
	7-10	16-35	0.8	0.2-1.0

4.5.4 Landslide Susceptibility Map of Cut-Slope Domain

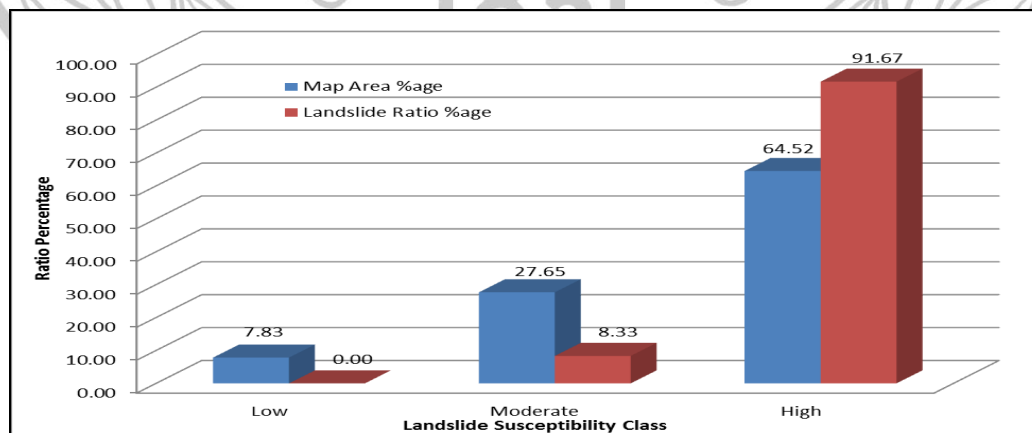
A landslide susceptibility map is a picture of the total estimated susceptibility value (TESV) calculated for each mapping unit (facet or pixel). The total estimated susceptibility value over an area of investigation would remain below or equal to 10 as per the opinion of the worker. The landslide susceptibility map has been generated by the overlay method in which the summation of LSER of all factor maps has been done in the GIS platform. The landslide susceptibility in the cut-slope domain has

been assessed over a 0.24 sq. km area. The total estimated susceptibility value (TESV) ranges from 1 to 2.9 and it was reclassified into three classes of landslide susceptibility as mentioned in table- 4.27.

Table-4.27: Classified landslide susceptibility map attributes for cut-slope domain

Value	Pixel Count	TESV Break	Susceptibility Class	Map Area Percentage	Landslide Ratio
1	180	1.6	Low	7.83	0
2	636	1.8	Moderate	27.65	1
3	1484	2.9	High	64.52	11
Total	2300			100%	12 nos.

A total of 12 nos. of landslides were recorded in cut-slopes in the study area which have been validated with the susceptibility map area percentage in which landslide ratio is 0 (low): 1 (moderate): 11 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to upslope failures. Maximum landslides 11 nos. fall in the high susceptibility zone of the cut-slope. It signifies that the validation of applied model prediction by existing landslides is 92%. Whereas moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 27.65 percent. This signifies that qualitatively the adopted model has predicted 72 percent map area with efficacy and there is the least uncertainty in terms of moderate susceptibility over the 28 percent map area. Most importantly the model has predicted more than 60 percent map area in the cut-slope domain in high susceptibility which proves physical observation of certain failures on slope facets with cut-slopes because most of the cut-slopes enhance the probability of slope failures. It is worth stating that the impact of external forces particularly rainfall water action was not taken into consideration and it may change the resulting susceptibility scenario of cut-slopes in the study area at any period. The below-shown graph depicts the satisfactory ratio between susceptibility map area percentage and landslides in the cut slope domain.



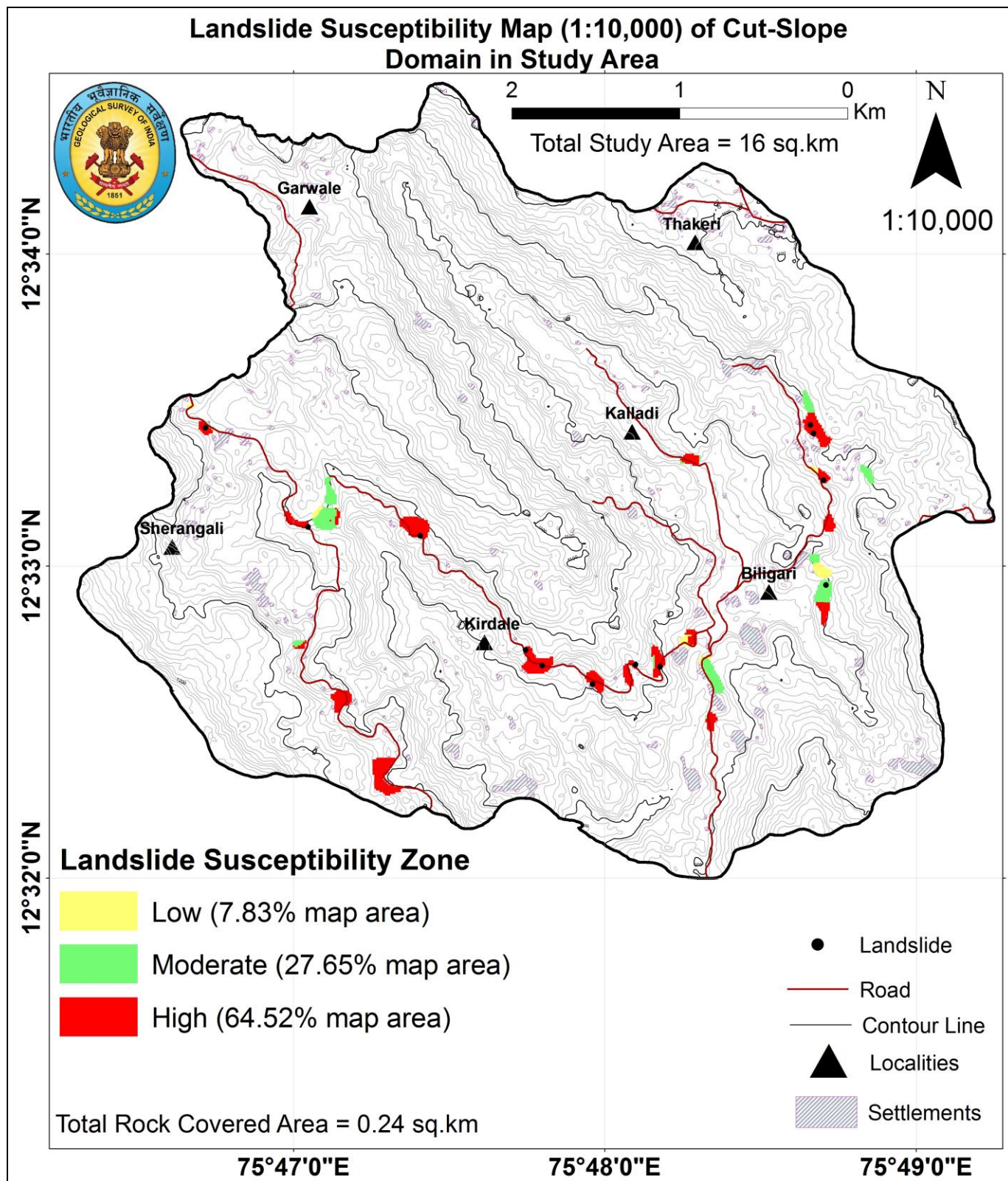


Figure-4.22: Landslide susceptibility map of the cut-slope domain in the study area

CHAPTER – 5

CONCLUSIONS AND RECOMMENDATIONS

The conclusions and recommendations thereon were made after having thorough discussions on the field observations, analysed geotechnical parameters of the overburden material, kinematic failure analysis and output landslide susceptibility in the study area.

5.1 Conclusions

- ❖ The study area of 16 sq. km is a part of the hilly terrain in Western Ghat and contains overburden material covering over 15.59 sq. km area whereas the rock-covered area is only 0.44 sq. km area.
- ❖ The study area is a part of the 7th stream order-level watershed with a 102 sq. km area which has well-defined drainage patterns. The morphometric drainage parameters of the watershed suggest that it is in the immaturity phase of evolution wherein there are more chances of surface erosion, particularly along 2nd and 3rd-order streams.
- ❖ Several deformed and highly sheared thin litho-units have been reported in the study area with in Granite Gneiss. These deformed and highly sheared litho-units are some times associated with Pegmatite veins and are evolved into mylonite fabric. These deformed and highly sheared litho-units are witnessed frequent failures on slopes where these litho-units are oriented parallel to the slope dip.
- ❖ At several places in the study area, the Amphibolite rock type occurs in large dimensions in association with complex dyke systems wherein the litho-contact of Amphibolite with host rock (Granite Gneiss) has been observed very vulnerable to slope failures.
- ❖ The rock types in the study area are having well-developed foliation oriented at an average trend of 325^o and dipping in the SW direction at an average dip amount of 55^o. Four joint sets (J1, J2, J3, J4) are recorded in the study area, among these the NW-SE trending joint set (J2) traversing parallel to the foliation and the other three joint sets (J1, J3, J4) is trending NE-SW and dipping in different directions. These four joint sets along with foliation are making different interference patterns in the study area by which the rock types are breaking down (physical weathering) even into smaller orthogonal pieces. However joint set J1 is closely spaced, mostly having a perpendicular relationship with the foliation and it would be the cleavage plane of the regional fold structure in the area.
- ❖ It is observed that these four joint sets along with foliation are playing a prominent role in the evolution of hilly terrains and the development of different geomorphological features in the area. The NE-SW oriented joint sets J1, J3 and J4 are found the most responsible factors for developing, evolving, and orientation of lower-order drainage systems (1st, 2nd, 3rd, 4th & 5th) in the area.

The stream segments up to the 5th order in the area are following similar geological structures (J1, J3, J4) and there onwards the stream segments of higher orders are following the regional foliation plane in the area.

- ❖ At several places in the study area, the interference of these geological structures is found one major cause for occurring landslide incidences. The Kinematic analysis of these geological structures revealed three different conditions of interference, among which joint interference between foliation+J1+J4 is found the most favourable condition to dislocate the rock blocks/fragments from the outcrop which later moves down on south-west direction slopes. The result of this joint interference has evolved the regional topography of the area by forming long ridges and valleys trending in the NW-SE direction and steep slopes in the SW direction. Besides the three different conditions of interference that were revealed in the study area thorough kinematic analysis are making the rock domain slopes day-lighted (vulnerable) for planer, wedge, and topple failures at several places where all eligible conditions meet w.r.t slope angle and direction.
- ❖ Among the reported landslides in the study area, 38 nos. are debris and/or earth slides that occurred on natural slopes in the overburden domain, 02 nos. are rock slides that occurred in the rock domain, and the rest 12 nos. occurred in the cut-slope domain comprising both debris & rock slides. Most of these landslides were initiated during the 2018 monsoon and almost all landslides that occurred in the study area were triggered by rainfall. Both natural, as well as anthropogenic-related causes, were found responsible for landslide occurrences in the study area. In natural causes, the decrease in shear strength of overburden material on moderate to steep slopes on saturation, erosion of stream bank material or toe cut of natural slopes by water action, favorable joint interference patterns for detachment of rock fragments, fragile contact between hard rock and overlying weathered material and deformed and highly sheared litho-units associated with Pegmatite veins within Granite Gneiss are included. In anthropogenic causes, cutting of natural slopes for road construction & settlement buildings for both domestic as well as commercial use and modification of natural slopes for cultivation purposes are included.
- ❖ The demarcated landslides in the study area have occurred mostly during the 2018 rainfall period as per the local inhabitants. After analyzing the rainfall data from 2015-2020, the conclusion made by Aijaz Ahmad Bhat and Dr. Zameer Ahmad Shah., 2019 has been found quite relevant that the Somwarpet taluk in which the present study area lies, received more than 2400mm of actual rainfall during June-September period 2018 which accounts more than 700mm rise over 1700mm normal rainfall intensity in previous three years record. The 700mm rise in actual rainfall intensity

not annually but in a particular event (June-September) has resulted in several landslides, particularly in the overburden domain and subsequent stream channel erosion by landslide debris material along the runout distance. The daily rainfall analysis of rainfall data from Somwarpet taluk shows that there were multiple rainfall events above 100mm rainfall recorded between June-August 2018 among which two longer events (5 days) of rainfall above 100mm in July and August 2018 would have been triggered most of the landslide incidences in the study area.

- ❖ As such rainfall threshold analysis was not done presently but indirectly it may be concluded that >100mm rainfall is the threshold limit and whenever the said threshold limit would be achieved over a period of 5 or >5 days, the hill slopes which have some inherent weaknesses in overburden material, day-lighted rocky slopes, and the hill slopes on which cut-slopes have been given would be considered as most susceptible for landslides.
- ❖ In the present study, the upscaled mapping methodology (domain-specific modeling) adopted for the preparation of various generic-based geo-factor feature classes and their role in causing a landslide has proved a good model for predicting landslide susceptibility in each failure domain with defined responsible causative factors.
- ❖ There are four failure/landslide domains identified in the study area viz; rock slide/fall domain, debris slide/flow domain, earth slide/flow domain and cut-slope domain. For each failure domain, the landslide susceptibility mapping is done separately by rating and integrating their relevant geo-factor maps as per study area-specific conditions.
- ❖ In the rockslide domain, qualitatively the adopted model has predicted a 7.67 percent map area in high susceptibility and 68.95 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 23.37 percent map area. A total of 2 nos. of rock slides was recorded in the study area which has been validated with the susceptibility map area percentage in which the rock slide ratio is 0 (low): 2 (moderate): 0 (high) which is a satisfactory ratio. Whereas in the rockfall domain, qualitatively the adopted model has predicted 8.92 percent map area in high susceptibility and 74.06 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 17.01 percent map area. A total of 2 nos. of rock slides were recorded in the study area which has been validated with the susceptibility map area percentage in which the rock slide ratio is 0 (low): 1 (moderate): 1 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to rock slides and rockfall in the study area.
- ❖ In the overburden domain, qualitatively the adopted model has predicted 46.21 percent map area in high susceptibility and 25.33 percent map area in low susceptibility with efficacy and there is the

least uncertainty in terms of moderate susceptible class over 28.46 percent map area. A total of 38 nos. of landslides were recorded in the overburden domain in the study area which has been validated with the resulted susceptibility map area percentage in which landslide ratio remains 3 (low): 7 (moderate): 28 (high) which is a satisfactory ratio. The high susceptibility class has retained those areas which are more prone to debris and/or earth slide failures.

- ❖ In the cut-slope domain, it is observed during the field study that places, where cut-slopes have been given and were left untreated, are more prone to landslides and efficiently the high susceptibility class has retained those areas in the study area. Qualitatively the adopted model has predicted 64.52 percent map area in high susceptibility and 7.83 percent of map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 27.65 percent map area.

5.2 General Recommendations

The recommendations have been given in general for the whole study area for taking precautionary measures as and when required. However, specific recommendations for critical areas have been given in the landslide management map. The general recommendations are as follows:

1. Since the watershed configuration is a naturally controlled thing that can evolve with time depending on climate, lithology, and tectonic activity and each watershed can perform as per the natural conditions applied, the only way to minimize the risk is that the natural streams should not be blocked by any means and all human developmental activities particularly settlements should be adopted away from natural streams.
2. The settlement activities should be avoided within the flooding areas of higher-order streams or main draining streams which receives waters from all lower hierarchy stream orders during heavy rainfall period.
3. There is a need to construct properly lined drainage network arrangements on natural slopes having societal importance and along roads so that runoff waters during rainfall periods would be easily drained out.
4. The areas which fall in the high susceptibility zone and their zone of influence on the downslope side should be given the utmost priority for reinforcement by appropriate stabilization measures. There is a need to consult the given landslide susceptibility map in each domain at the preliminary stage before going to perform any type of developmental activities in the study area.
5. The anthropogenic activities including modifications and cutting of natural slopes should be avoided but if given for any purpose should not be left untreated. Besides the untreated cut-slopes

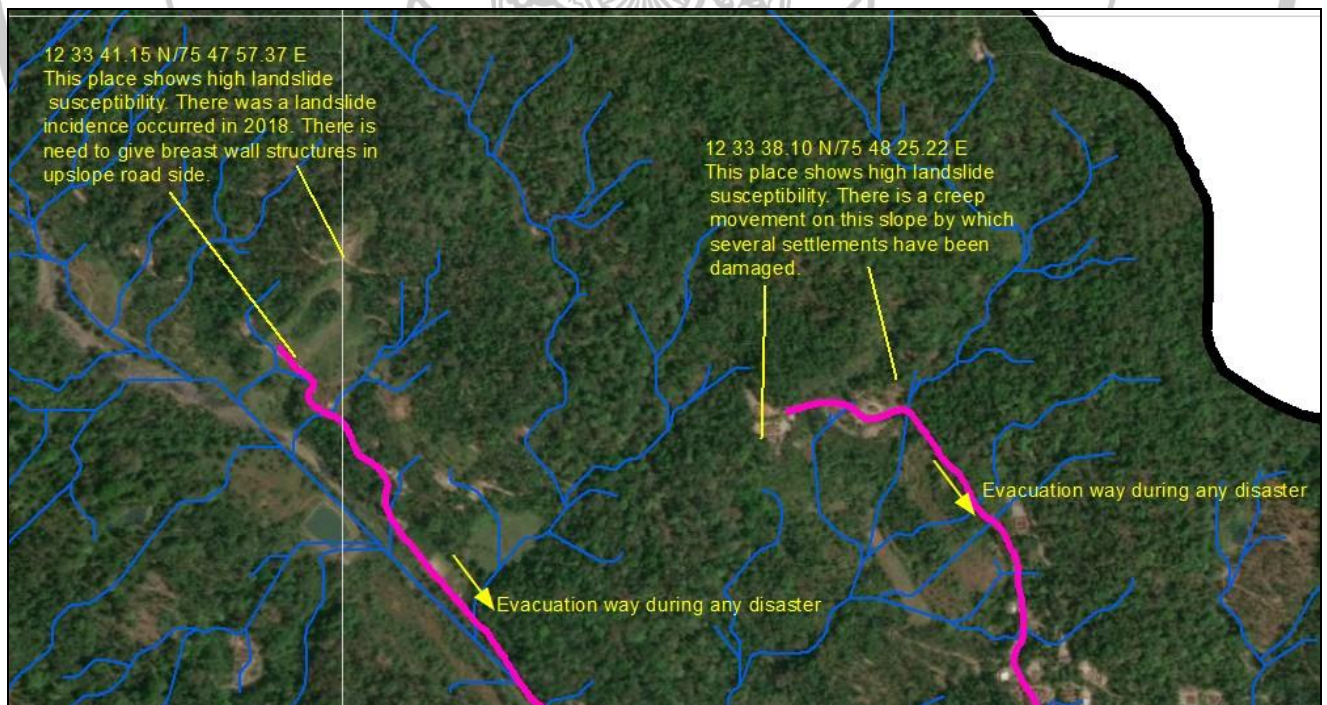
showing high susceptibility should be immediately reinforced by appropriate stabilization measures.

6. The given landslide susceptibility map of the study area would be fruitful for the Kodagu district administration for further necessary arrangements under the Kodagu district disaster management plan.
7. It is suggested that whenever the rainfall threshold limit (as concluded in the present study) will achieve, the district administration authorities should remain on high alert to evacuate the public from hill slopes that are falling in high to moderate landslide susceptibility in and surrounding areas of Somwarpet taluk as per the investigations carried out by GSI under NLSM and Meso-scale landslide susceptibility programs.

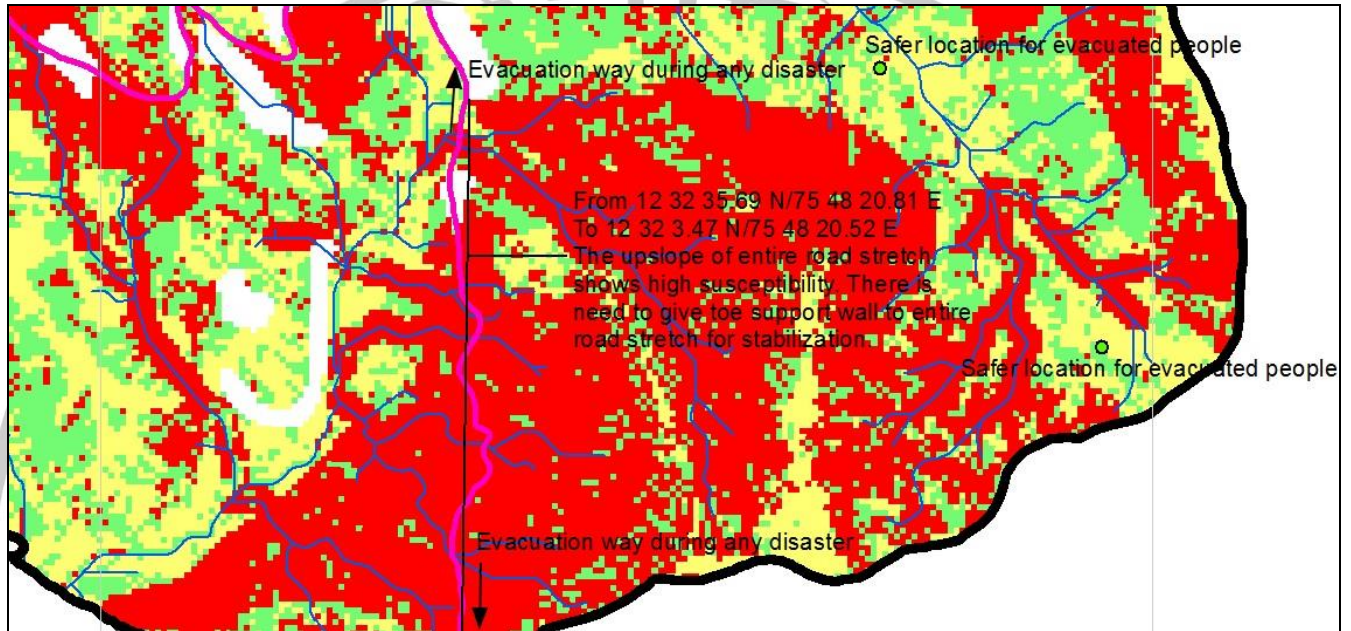
5.3 Landslide Management Mapping and Area-Specific Recommendations

Overburden Slopes

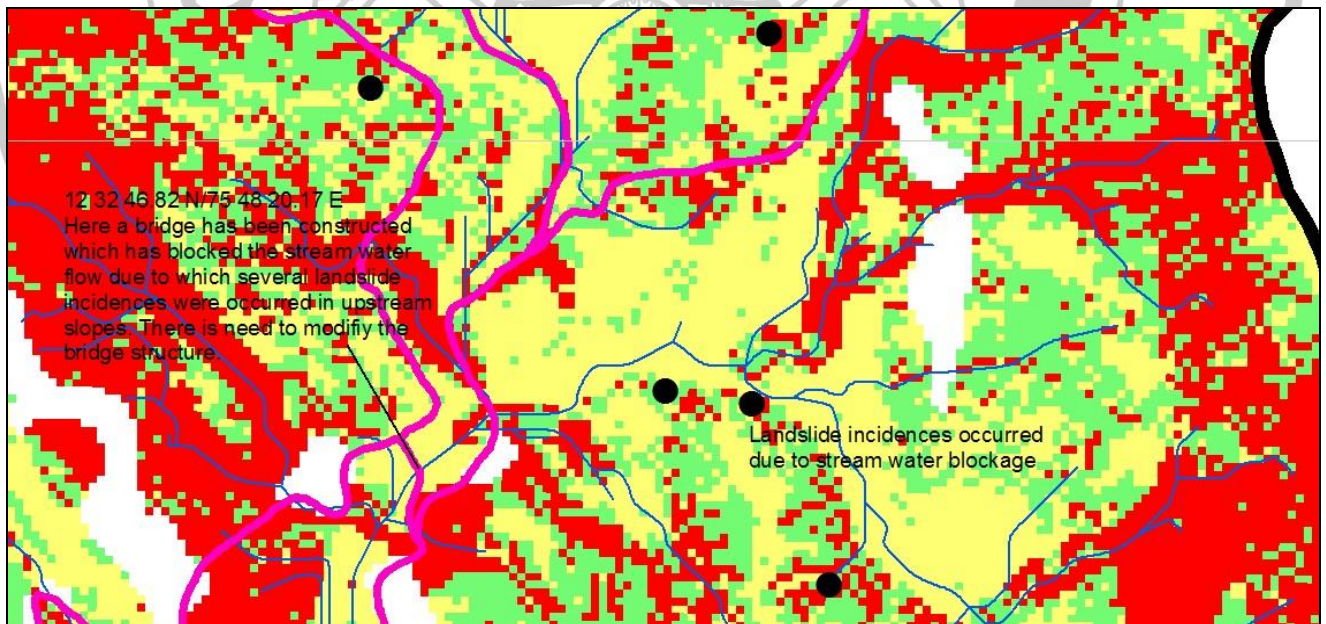
1. In Biligeri village at $12^{\circ} 33' 38.10''$ N/ $75^{\circ} 48' 25.22''$ E as shown below in the map, there is a creep movement that occurs on south-west dipping slopes by which several settlement houses have been damaged. The place falls under the high susceptibility zone. There is a need to shift the settlements to safer places until the movement would be stopped by taking appropriate stabilization measures. While in the same village at $12^{\circ} 33' 41.15''$ N/ $75^{\circ} 47' 57.37''$ E as shown below in the map a landslide incidence occurred in 2018 by which road stretches at two different contour levels were damaged. There is a need to construct breast wall structures to stabilize the road stretches immediately.



2. Along the road from Biligeri to Madapur the road stretch from $12^{\circ} 32' 35.69''$ N/ $75^{\circ} 48' 20.81''$ E to $12^{\circ} 32' 3.47''$ N/ $75^{\circ} 48' 20.52''$ E shows high landslide susceptibility. The said road stretch needs immediate attention and a toe support wall to the entire road stretch as shown below in the map is suggested for stabilizing the upslope material.



3. In Billigeri village a bridge has been constructed on a stream at $12^{\circ} 32' 46.82''$ N/ $75^{\circ} 48' 20.17''$ E as shown below in the map which blocks the stream water flow during rainfall due to which the upstream slopes collapsed. There is a need to modify the structure of the bridge immediately.



4. In Shirangali village at $12^{\circ} 32' 48.92''$ N/ $75^{\circ} 46' 56.66''$ E, there would be several underground water flow channels due to which the ground surface has been subsided at several places in the settlement

zone. There is a need to give immediate attention and shift the settlements at high risk to safer places until a permanent solution would be suggested after a detailed investigation.

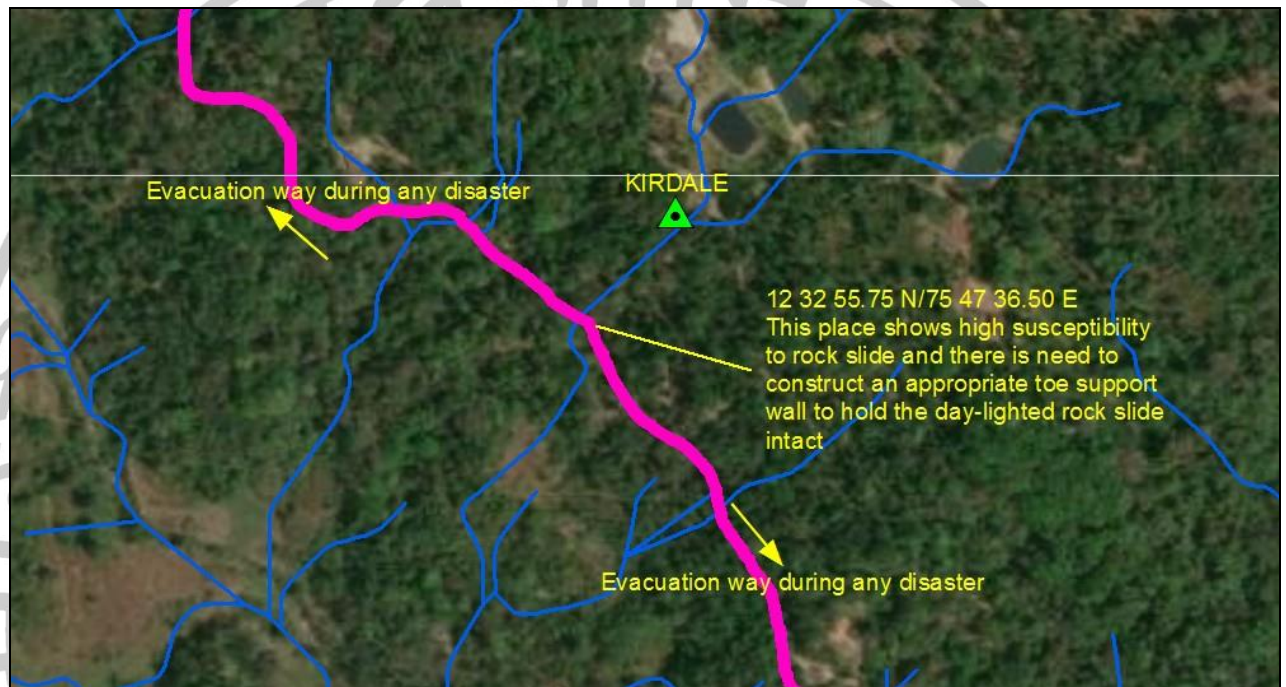


Rocky Slopes

- It has been found that the below-mentioned rocky slope in the Biligeri area has high susceptibility to a rock slide. Therefore it is suggested that an appropriate toe support wall may be constructed to hold these vulnerable rocky slopes. If any disaster situation arises then people may be evacuated towards the north and can be shifted to a safer place as shown in the map below;



6. Along the Biligeri to Kirdale road stretch below mentioned rocky outcrop shows high susceptibility to a rock slide. Therefore it is also suggested that an appropriate toe support wall may be constructed to hold these vulnerable rocky slopes. If any disaster situation arises then people may be evacuated towards the north and can be shifted to a safer place as shown in the map below;



7. Along the Shirangali to Madapur road stretch below mentioned rocky outcrops show high susceptibility to rock slides & rock falls. Therefore it is also suggested that at $12^{\circ} 32' 44.7''$ N/ $75^{\circ} 48' 16.36''$ E where there is moderate to high susceptibility for rock slide, there is a need to give an appropriate reinforcement to hold the day-lighted rock slide intact & drain the stream water through lined drainage so that rocky slope remains dry. At $12^{\circ} 32' 25.16''$ N/ $75^{\circ} 47' 25.03''$ E a steep rock slope shows high susceptibility to rock fall. Since it is a difficult hilly slope to access but the identified joint planes susceptible to rock fall may be kept intact by rock bolting cum shotcrete measures. If any disaster situation arises then people may be evacuated towards north-west and east directions and can be shifted to a safer place as shown in the map below;



LOCALITY INDEX

Locality Name	Longitude (DMS)	Latitude (DMS)	Elevation (m)
KIRDALE	75° 47' 36.756" E	12° 32' 45.304" N	900
BILIGARI	75° 48' 31.588" E	12° 32' 55.019" N	860
GARWALE	75° 47' 3.046" E	12° 34' 9.130" N	1040
THAKERI	75° 48' 17.363" E	12° 34' 2.255" N	1120
SHERANGALI	75° 46' 36.561" E	12° 33' 3.669" N	1080
KALLADI	75° 48' 5.226" E	12° 33' 25.827" N	840

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Annexure-I: Geotechnical results of undisturbed overburden samples (UDS)

Sample No.	X	Y	Moisture Content (%)	Specific Gravity	Density (gm/cm3)	Void ratio (e)
SUKG/33515/G1	75.779333	12.541917	19.4	2.48	1.89	0.31
SUKG/33515/G2	75.785972	12.539194	18.96	2.63	2.06	0.28
SUKG/33515/G3	75.792306	12.537778	14.35	2.6	2.1	0.24
SUKG/33515/G4	75.804889	12.536667	15.65	2.48	1.97	0.26
SUKG/33515/G5	75.808194	12.538917	19.89	2.67	1.97	0.36
SUKG/33515/G6	75.773472	12.547583	11.84	2.64	1.91	0.38
SUKG/33515/G7	75.782194	12.547	14.25	2.69	2.24	0.2
SUKG/33515/G8	75.786472	12.548611	16.57	2.6	1.61	0.61
SUKG/33515/G9	75.794806	12.547111	11.27	2.53	2.04	0.24
SUKG/33515/G10	75.802972	12.545167	17.83	2.57	1.91	0.35
SUKG/33515/G11	75.808861	12.543222	16.11	2.49	1.71	0.46
SUKG/33515/G12	75.777556	12.556861	13.1	2.48	1.54	0.61
SUKG/33515/G13	75.788611	12.554944	16.25	2.62	1.67	0.57
SUKG/33515/G14	75.797917	12.553333	22.44	2.58	1.48	0.74
SUKG/33515/G15	75.801944	12.553722	14.03	2.46	1.66	0.48
SUKG/33515/G16	75.813083	12.55075	11.45	2.5	1.72	0.45
SUKG/33515/G17	75.817028	12.554583	15.32	2.51	1.63	0.54
SUKG/33515/G18	75.782417	12.560722	21.13	2.49	1.57	0.59
SUKG/33515/G19	75.789167	12.559889	18.79	2.49	1.49	0.67
SUKG/33515/G20	75.795944	12.565083	13.01	2.45	1.47	0.67
SUKG/33515/G21	75.807722	12.559972	16.78	2.47	1.69	0.46
SUKG/33515/G22	75.811139	12.558639	17.7	2.61	1.53	0.71
SUKG/33515/G23	75.781722	12.571556	9.63	2.55	1.34	0.9
SUKG/33515/G24	75.788083	12.567861	12.45	2.6	1.61	0.61
SUKG/33515/G25	75.793028	12.571722	6.38	2.41	1.43	0.69
SUKG/33515/G26	75.802861	12.56675	16.44	2.57	1.65	0.56
SUKG/33515/G3A	75.799222	12.538389	12.91	2.55	1.69	0.51
SUKG/33515/G5A	75.816944	12.541028	16.85	2.62	1.67	0.57

SUKG/33515/G9A	75.795583	12.545806	13.41	2.56	1.69	0.51
SUKG/33515/G13A	75.785556	12.553639	22.07	2.69	1.55	0.74
SUKG/33515/G15A	75.804361	12.556	18	2.64	1.66	0.59
SUKG/33515/G20A	75.794639	12.558611	12.23	2.67	1.6	0.67

Sample No.	X	Y	Porosity (n)	Gravel (%)	Sand (%)	Silt (%)	Clay (%)	Cohesion (kgf/cm ²)	Angle of Internal friction (Ø)
SUKG/33515/G1	75.77933	12.54192	0.24	50	18	25	7	0.19	25
SUKG/33515/G2	75.78597	12.53919	0.22	64	18	0	18	0.22	20
SUKG/33515/G3	75.79231	12.53778	0.19	42	24	2	32	0.23	20
SUKG/33515/G4	75.80489	12.53667	0.21	25	37	13	25	0.21	22
SUKG/33515/G5	75.80819	12.53892	0.26	40	20	4	36	0.3	23
SUKG/33515/G6	75.77347	12.54758	0.28	13	41	12	34	0.38	20
SUKG/33515/G7	75.78219	12.547	0.17	28	29	22	21	0.26	22
SUKG/33515/G8	75.78647	12.54861	0.38	5	32	53	10	0.22	21
SUKG/33515/G9	75.79481	12.54711	0.19	9	47	5	40	0.28	22
SUKG/33515/G10	75.80297	12.54517	0.26	7	28	37	28	0.29	23
SUKG/33515/G11	75.80886	12.54322	0.31	21	27	32	20	0.19	20
SUKG/33515/G12	75.77756	12.55686	0.38	11	39	39	11	0.41	25
SUKG/33515/G13	75.78861	12.55494	0.36	41	29	23	7	0.36	28
SUKG/33515/G14	75.79792	12.55333	0.43	48	16	22	14	0.29	27
SUKG/33515/G15	75.80194	12.55372	0.33	39	26	10	25	0.41	21
SUKG/33515/G16	75.81308	12.55075	0.31	2	46	43	9	0.39	22
SUKG/33515/G17	75.81703	12.55458	0.35	33	35	27	5	0.48	28
SUKG/33515/G18	75.78242	12.56072	0.37	2	31	65	2	0.25	25
SUKG/33515/G19	75.78917	12.55989	0.4	16	36	33	15	0.32	23

SUKG/33515/G20	75.79594	12.56508	0.4	7	39	48	6	0.28	24
SUKG/33515/G21	75.80772	12.55997	0.32	1	54	32	13	0.21	22
SUKG/33515/G22	75.81114	12.55864	0.41	8	44	45	3	0.34	27
SUKG/33515/G23	75.78172	12.57156	0.47	17	62	18	3	0.25	26
SUKG/33515/G24	75.78808	12.56786	0.38	12	30	56	2	0.28	28
SUKG/33515/G25	75.79303	12.57172	0.41	53	11	33	3	0.27	26
SUKG/33515/G26	75.80286	12.56675	0.36	1	28	70	1	0.33	24
SUKG/33515/G3A	75.79922	12.53839	0.34	52	19	24	5	0.41	23
SUKG/33515/G5A	75.81694	12.54103	0.36	0	29	70	1	0.26	25
SUKG/33515/G9A	75.79558	12.54581	0.34	6	49	41	4	0.24	22
SUKG/33515/G13A	75.78556	12.55364	0.42	2	38	58	2	0.33	27
SUKG/33515/G15A	75.80436	12.556	0.37	42	33	21	4	0.35	25
SUKG/33515/G20A	75.79464	12.55861	0.4	10	47	36	7	0.27	26

Annexure-II: Geo-parametric attributes of 52 nos. of landslides recorded in the study area

Sl. No.	1
Landslide No.	ls3
Deg.	12°
Min.	32'
Sec.	40.6"
Y	12.54461111
Deg.	75°
Min.	48'
Sec.	10.6"
X	75.80294444
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	3m
Area	450m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, pepper, silver oak
Hydrological Condition	Dripping
Element at Risk	Settlement, road and cultivation

Geo-scientific Cause	Unplanned cutting of slope for road construction; steep slope; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (rock cum debris)



Sl. No.	2
Landslide No.	ls4
Deg.	12°
Min.	32'
Sec.	38.6"
Y	12.54405556
Deg.	75°
Min.	48'
Sec.	11"
X	75.80305556
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	3m
Area	450m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2019
Lithology	Not visible
Landuse/Landcover	Coffee, silver oak

Hydrological Condition	Wet
Element at Risk	Road, Settlements
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Overburden domain
	

Sl. No.	3
Landslide No.	ls5
Deg.	12°
Min.	32'
Sec.	41.04"
Y	12.54473333
Deg.	75°
Min.	48'
Sec.	5.85"
X	75.801625
Locality Name	Kirdale village, Kodagu, Karnataka
Length	10m
Width	12m
Height	4m
Area	480m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2019
Lithology	Not visible
Landuse/Landcover	Forest vegetation

Hydrological Condition	Wet
Element at Risk	Road
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (overburden)



Sl. No.	4
Landslide No.	ls6
Deg.	12°
Min.	32'
Sec.	37.22"
Y	12.54367222
Deg.	75°
Min.	47'
Sec.	57.6"
X	75.79933333
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	6m
Area	900m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational deep
History	2018
Lithology	Not visible
Landuse/Landcover	House court yard, coffee with mixed hhp

Hydrological Condition	Dry
Element at Risk	Road, cultivation, power line
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate toe support; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (overburden)



Sl. No.	5
Landslide No.	ls7
Deg.	12°
Min.	32'
Sec.	40.81"
Y	12.54466944
Deg.	75°
Min.	47'
Sec.	47.87"
X	75.79663056
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	4m
Area	600m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee with mixed high height plantation

Hydrological Condition	Wet
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (overburden)
	

Sl. No.	6
Landslide No.	ls8
Deg.	12°
Min.	32'
Sec.	43.8"
Y	12.5455
Deg.	75°
Min.	47'
Sec.	44.7"
X	75.79575
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	60m
Width	30m
Height	15m
Area	27000m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational deep
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, silver oak, nandi wood

Hydrological Condition	Wet
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (overburden)
	

Sl. No.	7
Landslide No.	ls9
Deg.	12°
Min.	32'
Sec.	58"
Y	12.54944444
Deg.	75°
Min.	47'
Sec.	12"
X	75.78666667
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	150m
Width	15m
Height	60m
Area	135000m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational deep
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, banana, jungle trees

Hydrological Condition	Wet
Element at Risk	Road, cultivation
Geo-scientific Cause	Toe erosion by stream, steep slope angle, thick overburden cover, reduction of material strength on saturation
Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion; need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material
Alert	II
Remarks	Overburden domain
	

Sl. No.	8
Landslide No.	ls10
Deg.	12°
Min.	33'
Sec.	5.8"
Y	12.55161111
Deg.	75°
Min.	47'
Sec.	24.4"
X	75.79011111
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	30m
Height	6m
Area	1800m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, banana, jungal trees

Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Cut-slope domain (overburden)
	

Sl. No.	9
Landslide No.	ls11
Deg.	12°
Min.	33'
Sec.	6.4"
Y	12.55177778
Deg.	75°
Min.	47'
Sec.	18.1"
X	75.78836111
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	5m
Area	750m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, orange, green elaichi

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Unplanned cutting of slope for settlement; increase in unit mass by water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate reinforcement measure; need to give proper lined drainage for safe passage of runoff waters
Alert	III
Remarks	Overburden domain



Sl. No.	10
Landslide No.	ls12
Deg.	12°
Min.	33'
Sec.	13.6"
Y	12.55377778
Deg.	75°
Min.	47'
Sec.	13.6"
X	75.78711111
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	70m
Width	20m
Height	30m
Area	42000m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational deep
History	Old slide and reactivated in 2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, papaya, jungal wood

Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope; loose debris (colluvium) material on slope; steep slope angle; poor drainage network; blockage of stream waters for irrigation purpose
Remedial Measures	Avoid cut-slopes and blockage of stream waters; need to give appropriate breast wall structure for toe support at road level
Alert	I
Remarks	Overburden domain



Sl. No.	11
Landslide No.	ls13
Deg.	12°
Min.	33'
Sec.	12.14"
Y	12.55337222
Deg.	75°
Min.	47'
Sec.	17.6"
X	75.78822222
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	150m
Width	30m
Height	50m
Area	225000m ³
Type of Material	Debris
Type of Movement	Flow
Failure Mechanism	Translational deep
History	2018
Lithology	Granite gneiss; pegmatite vein; basic dyke
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dripping
Element at Risk	Road, cultivation

Geo-scientific Cause	Unplanned cutting of slope; fragile disintegrated/weathered loose overburden material; excess water influx into overburden material during rainfall; reduction of material strength in saturation; slope angle direction parallel to the dip direction of litho-contact; material got pulverised under high strain condition
Remedial Measures	Need to strengthen the already given breast wall structure at road level; need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	I
Remarks	Overburden domain
	

Sl. No.	12
Landslide No.	ls14
Deg.	12°
Min.	33'
Sec.	12"
Y	12.55333333
Deg.	75°
Min.	47'
Sec.	18"
X	75.78833333
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	6m
Area	600m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by rainfall water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Overburden domain
	

Sl. No.	13
Landslide No.	ls15
Deg.	12°
Min.	32'
Sec.	59.3"
Y	12.54980556
Deg.	75°
Min.	47'
Sec.	42"
X	75.795
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	4m
Area	600m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Not known
Lithology	Not visible
Landuse/Landcover	Coffee, silver oak

Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope; loose debris dumped material; increase in unit mass by rainfall water saturation
Remedial Measures	Avoid cut-slopes; need to give appropriate reinforcement measure; need to give proper lined drainage for safe passage of runoff waters
Alert	III
Remarks	Overburden domain



Sl. No.	14
Landslide No.	ls17
Deg.	12°
Min.	32'
Sec.	47.2"
Y	12.54644444
Deg.	75°
Min.	47'
Sec.	43.8"
X	75.7955
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	5m
Area	750m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Granite gneiss
Landuse/Landcover	Forest vegetation

Hydrological Condition	Dry
Element at Risk	Settlement house
Geo-scientific Cause	Unplanned cutting of slope; lack of proper reinforcement to cut-slope; increase in unit mass by rainfall water saturation
Remedial Measures	Avoid cut-slopes; landslide has been already stabilized
Alert	I
Remarks	Overburden domain



Sl. No.	15
Landslide No.	ls18
Deg.	12°
Min.	33'
Sec.	14.6"
Y	12.55405556
Deg.	75°
Min.	47'
Sec.	29.7"
X	75.79158333
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	4m
Area	400m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide
Lithology	Not visible
Landuse/Landcover	Forest vegetation

Hydrological Condition	Wet
Element at Risk	Nil
Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material; steep slope gradient
Remedial Measures	Slide has been stabilized
Alert	III
Remarks	Overburden domain



Sl. No.	16
Landslide No.	ls19
Deg.	12°
Min.	33'
Sec.	0.3"
Y	12.55008333
Deg.	75°
Min.	47'
Sec.	24.7"
X	75.79019444
Locality Name	kirdale village
Length	10m
Width	15m
Height	5m
Area	750m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, orange
Hydrological Condition	Dry
Element at Risk	Settlement house court yard

Geo-scientific Cause	Unplanned cutting of slope; lack of proper reinforcement to cut-slope; increase in unit mass by rainfall water saturation; fragile disintegrated/weathered loose overburden material; material got pulverised under high strain condition
Remedial Measures	Avoid cut-slopes; need to give appropriate reinforcement measure; need to give proper drainage network for safe passage of runoff waters; do not remove the slid material
Alert	II
Remarks	Overburden domain



Sl. No.	17
Landslide No.	ls20
Deg.	12°
Min.	33'
Sec.	16.5"
Y	12.55458333
Deg.	75°
Min.	48'
Sec.	42.1"
X	75.81169444
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	15m
Width	10m
Height	8m
Area	1200m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	15th Aug 2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, silver oak, nandi wood

Hydrological Condition	Damp
Element at Risk	Cultivation
Geo-scientific Cause	Unplanned cutting of slope; loose and incompetent debris
Remedial Measures	Need to plant vertiver grass; need to give appropriate reinforcement measure; need to give proper drainage network for safe passage of runoff waters
Alert	II
Remarks	Cut-slope domain (overburden)



Sl. No.	18
Landslide No.	ls21
Deg.	12°
Min.	33'
Sec.	25.5"
Y	12.55708333
Deg.	75°
Min.	48'
Sec.	40.2"
X	75.81116667
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	10m
Width	20m
Height	7m
Area	1400m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	16th Aug 2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Cultivation, school ground
Geo-scientific Cause	Unplanned cutting of slope; loose and incompetent debris material
Remedial Measures	Need to give appropriate reinforcement measure; need to give proper drainage network for safe passage of runoff waters; do not remove the slided material
Alert	I
Remarks	Cut-slope domain (overburden); School premises



Sl. No.	19
Landslide No.	ls22
Deg.	12°
Min.	33'
Sec.	27.1"
Y	12.55752778
Deg.	75°
Min.	48'
Sec.	39.6"
X	75.811
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	15m
Width	10m
Height	10m
Area	1500m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Not known
Lithology	Not visible
Landuse/Landcover	Coffee, silver oak

Hydrological Condition	Damp
Element at Risk	Road
Geo-scientific Cause	Unplanned cutting of slope; modified slope by cultivation activities
Remedial Measures	Avoid to give cut-slopes; need to give appropriate reinforcement measure; need to give proper drainage network for safe passage of runoff waters;
Alert	I
Remarks	Cut-slope domain (overburden)



Sl. No.	20
Landslide No.	ls23
Deg.	12°
Min.	34'
Sec.	20.6"
Y	12.57238889
Deg.	75°
Min.	47'
Sec.	37.2"
X	75.79366667
Locality Name	Garwale village, Kodagu district, Karnataka
Length	15m
Width	10m
Height	10m
Area	1500m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	16th Aug 2018
Lithology	Granite granite
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Modified slope by cultivation activities
Remedial Measures	Slide has been stabilized
Alert	III
Remarks	Overburden domain



Sl. No.	21
Landslide No.	ls24
Deg.	12°
Min.	34'
Sec.	18"
Y	12.57166667
Deg.	75°
Min.	47'
Sec.	37.1"
X	75.79363889
Locality Name	Kuramotte, Kodagu district, Karnataka
Length	10m
Width	15m
Height	7m
Area	1050m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	16th Aug 2018
Lithology	Amhibolite
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material
Remedial Measures	Need to give appropriate reinforcement measure at the toe; need to give proper drainage network for safe passage of runoff waters
Alert	III
Remarks	Overburden domain



Sl. No.	22
Landslide No.	ls25
Deg.	12°
Min.	34'
Sec.	23.3"
Y	12.57313889
Deg.	75°
Min.	47'
Sec.	33.3"
X	75.79258333
Locality Name	Thakeri village, Kodagu district, Karnataka
Length	12m
Width	12m
Height	10m
Area	1440m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide
Lithology	Amhibolite
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material; steep slope angle
Remedial Measures	Need to give appropriate reinforcement measure; need to give proper drainage network for safe passage of runoff waters;
Alert	III
Remarks	Overburden domain



Sl. No.	23
Landslide No.	ls26
Deg.	12°
Min.	34'
Sec.	30.4"
Y	12.57511111
Deg.	75°
Min.	47'
Sec.	26.4"
X	75.79066667
Locality Name	Thakeri village, Kodagu district, Karnataka
Length	150m
Width	50m
Height	20m
Area	150000m ³
Type of Material	Debris
Type of Movement	Flow
Failure Mechanism	Translational deep
History	2018
Lithology	Granite gneiss, pegmatite vein, basic dyke
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Damp
Element at Risk	Road, cultivation
Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material; excess water influx into overburden material during rainfall; reduction of material strength in saturation; slope angle direction parallel to the dip direction of litho-contact; material got pulverized under high strain condition

Remedial Measures	Need to give breast wall structure at road level; need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	I
Remarks	Overburden domain
	

Sl. No.	24
Landslide No.	ls27
Deg.	12°
Min.	33'
Sec.	7.5"
Y	12.55208333
Deg.	75°
Min.	47'
Sec.	2.8"
X	75.78411111
Locality Name	Garwale village, Kodagu district, Karnataka
Length	10m
Width	15m
Height	5m
Area	750m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	15th & 16th Aug 2018
Lithology	Charnockite
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cutting of slope for road construction; increase in unit mass by water saturation;
Remedial Measures	Avoid cut-slopes; need to give appropriate breast wall structure for toe support at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	II
Remarks	Cut-slope domain (Overburden)
	

Sl. No.	25
Landslide No.	ls28
Deg.	12°
Min.	33'
Sec.	17.5"
Y	12.55486111
Deg.	75°
Min.	47'
Sec.	8.7"
X	75.78575
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	20m
Width	15m
Height	10m
Area	3000m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide
Lithology	Charnockite
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Road, cultivation

Geo-scientific Cause	Unplanned cutting of slope for road construction; fragile disintegrated/weathered loose overburden material
Remedial Measures	Avoid cut-slopes; need to strengthen the existing toe support structure at road level; need to give proper lined drainage for safe passage of runoff waters
Alert	I
Remarks	Overburden domain



Sl. No.	26
Landslide No.	ls29
Deg.	12°
Min.	33'
Sec.	26.6"
Y	12.55738889
Deg.	75°
Min.	46'
Sec.	43"
X	75.77861111
Locality Name	Garwale village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	7m
Area	700m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	16th Aug 2018
Lithology	Granite gneiss
Landuse/Landcover	Settlement area
Hydrological Condition	Wet
Element at Risk	Living house, cultivation

Geo-scientific Cause	Unplanned cutting of slope for road construction; fragile disintegrated/weathered loose overburden material; increase in unit mass by water saturation;
Remedial Measures	Avoid cut-slopes; need to strengthen the concrete reinforce structure for toe support; need to give proper drainage network for safe passage of runoff waters; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	I
Remarks	Cut-slope domain (overburden)



Sl. No.	27
Landslide No.	ls30
Deg.	12°
Min.	33'
Sec.	46.9"
Y	12.56302778
Deg.	75°
Min.	48'
Sec.	6.3"
X	75.80175
Locality Name	Kalladi village, Kodagu district, Karnataka
Length	30m
Width	25m
Height	10m
Area	7500m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	18th Aug 2018
Lithology	Not visible
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation land
Geo-scientific Cause	Toe erosion by stream, steep slope angle, thick overburden cover, reduction of material strength in saturation

Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion; need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material
Alert	III
Remarks	Debris domain (overburden)



Sl. No.	28
Landslide No.	ls31
Deg.	12°
Min.	33'
Sec.	59.2"
Y	12.56644444
Deg.	75°
Min.	47'
Sec.	49.4"
X	75.79705556
Locality Name	Kalladi village, Kodagu district, Karnataka
Length	30m
Width	15m
Height	10m
Area	4500m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational deep
History	2018 aug
Lithology	Amhibolite
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation land
Geo-scientific Cause	Toe erosion by stream, steep slope angle, thick overburden cover, litho-contact dipping parallel to slope direction

Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion; need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material
Alert	III
Remarks	Overburden domain
	

Sl. No.	29
Landslide No.	ls32
Deg.	12 ⁰
Min.	33'
Sec.	59.9"
Y	12.56663889
Deg.	75 ⁰
Min.	47'
Sec.	41.9"
X	75.79497222
Locality Name	Kalladi village, Kodagu district, Karnataka
Length	60m
Width	30m
Height	15m
Area	27000m ³
Type of Material	Debris
Type of Movement	Flow
Failure Mechanism	Translational shallow
History	2018 aug
Lithology	Amhibolite, deformed and sheared granite gneiss
Landuse/Landcover	Forest vegetation
Hydrological Condition	Dry
Element at Risk	Forest land

Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material; excess water influx into overburden material during rainfall; reduction of material strength in saturation; slope angle direction parallel to the dip direction of litho-contact; material got pulverized under high strain condition
Remedial Measures	Need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	III
Remarks	Overburden domain
	

Sl. No.	30
Landslide No.	ls33
Deg.	12°
Min.	32'
Sec.	23.4"
Y	12.53983333
Deg.	75°
Min.	47'
Sec.	12.6"
X	75.78683333
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	100m
Width	70m
Height	40m
Area	280000m ³
Type of Material	Soil
Type of Movement	Flow
Failure Mechanism	Translational deep
History	16th Aug 2018
Lithology	Deformed and sheared granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation land

Geo-scientific Cause	Fragile disintegrated/weathered loose overburden material; excess water influx into overburden material during rainfall; reduction of material strength in saturation; slope angle direction parallel to the dip direction of litho-contact; material got pulverized under high strain condition
Remedial Measures	Need to give multiple wooden walls at equal contour intervals across the length of slide to check the eroded soft material; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	I
Remarks	Overburden domain
	

Sl. No.	31
Landslide No.	ls34
Deg.	12°
Min.	32'
Sec.	31.5"
Y	12.54208333
Deg.	75°
Min.	47'
Sec.	22.7"
X	75.78963889
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	30m
Width	40m
Height	20m
Area	24000m ³
Type of Material	Rock
Type of Movement	Fall
Failure Mechanism	Wedge failure
History	Old
Lithology	Not visible
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Road and cultivation land

Geo-scientific Cause	Unplanned cutting of slope for road construction; favorable joint interference
Remedial Measures	Need to strengthen toe of slope by appropriate concrete, sand bags or wooden structure; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	II
Remarks	Rock domain
	

Sl. No.	32
Landslide No.	ls35
Deg.	12°
Min.	32'
Sec.	12.5"
Y	12.53680556
Deg.	75°
Min.	47'
Sec.	31"
X	75.79194444
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	35m
Width	10m
Height	30m
Area	10500m ³
Type of Material	Rock
Type of Movement	Fall
Failure Mechanism	Topple failure
History	Old
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation land
Geo-scientific Cause	Steep slope gradient; favorable joint conditions for topple (day-lighted slope for topple and planar failure)

Remedial Measures	Need to strengthen toe of slope by appropriate concrete, sand bags or wooden structure; need to plant the water consumable and erosion resistant plantation across the slide zone
Alert	III
Remarks	Rock domain



Sl. No.	33
Landslide No.	ls36
Deg.	12°
Min.	32'
Sec.	20"
Y	12.53888889
Deg.	75°
Min.	47'
Sec.	42.2"
X	75.79505556
Locality Name	Moovathokalu village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	5m
Area	500m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	18th Aug 2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Wet
Element at Risk	Cultivation land
Geo-scientific Cause	Toe erosion by stream; modified stream

Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	III
Remarks	Overburden domain



Sl. No.	34
Landslide No.	ls37
Deg.	12°
Min.	32'
Sec.	44"
Y	12.54555556
Deg.	75°
Min.	46'
Sec.	57.1"
X	75.78252778
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	10m
Width	12m
Height	8m
Area	960m ³
Type of Material	Debris
Type of Movement	Flow
Failure Mechanism	Translational shallow
History	16th Aug 2018
Lithology	Deformed and sheared granite gneiss
Landuse/Landcover	Forest vegetation
Hydrological Condition	Dry
Element at Risk	Forest land

Geo-scientific Cause	Incompetent lithology, deformed and sheared granite gneiss; excess water influx during rainfall; reduction of material strength in saturation; unplanned cut-slope
Remedial Measures	Need to strengthen the upslope by suitable breast wall structure; need to give proper lined drainage
Alert	I
Remarks	Overburden domain



Sl. No.	35
Landslide No.	ls38
Deg.	12°
Min.	32'
Sec.	25"
Y	12.54027778
Deg.	75°
Min.	47'
Sec.	4"
X	75.78444444
Locality Name	Shirangalli village, Kodagu district, Karnataka
Length	10m
Width	3m
Height	8m
Area	240m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Forest vegetation

Hydrological Condition	Dry
Element at Risk	Forest
Geo-scientific Cause	Steep slope; thin overburden cover over hard rock
Remedial Measures	Need to plant the erosion resistance grasses and plants
Alert	III
Remarks	Overburden domain
<i>Photograph got corrupted</i>	



Sl. No.	36
Landslide No.	ls39
Deg.	12°
Min.	32'
Sec.	13.5"
Y	12.53708333
Deg.	75°
Min.	48'
Sec.	27.7"
X	75.80769444
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	60m
Width	20m
Height	15m
Area	18000m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide/date and year not known
Lithology	Granite gneiss and amphibolite in co-relation
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cut-slope for road construction; steep upslope gradient; sparse vegetation

Remedial Measures	Need to strengthen the upslope by suitable breast wall structure; need to make sufficient deep rooted plantation across the slide at the road level
Alert	II
Remarks	Overburden domain
	

Sl. No.	37
Landslide No.	ls40
Deg.	12°
Min.	32'
Sec.	17.5"
Y	12.53819444
Deg.	75°
Min.	48'
Sec.	29.5"
X	75.80819444
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	5m
Area	500m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Not known
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Road, cultivation
Geo-scientific Cause	Unplanned cut-slope for road construction; steep upslope gradient

Remedial Measures	Need to strengthen the upslope by suitable breast wall structure; need to make sufficient deep rooted plantation across the slide at the road level
Alert	I
Remarks	Cut-slope domain (overburden)



Sl. No.	38
Landslide No.	ls41
Deg.	12°
Min.	33'
Sec.	35.5"
Y	12.55986111
Deg.	75°
Min.	48'
Sec.	53.8"
X	75.81494444
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	50m
Width	20m
Height	10m
Area	10000m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational deep
History	2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Excess water influx during rainfall; reduction of material strength in saturation; blockage of drainage course
Remedial Measures	Avoid blockage of drainage course; need to give wooden walls at regular contour intervals to stop erosion of loose earth material and strengthen the base of slope
Alert	II
Remarks	Overburden domain
	

Sl. No.	39
Landslide No.	ls42
Deg.	12°
Min.	33'
Sec.	21.2"
Y	12.55588889
Deg.	75°
Min.	49'
Sec.	0.8"
X	75.81688889
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	6m
Area	600m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide and reactivated in 2018
Lithology	Granite gneiss
Landuse/Landcover	Settlement, coffee, silver oak

Hydrological Condition	Flowing
Element at Risk	Settlement, cultivation
Geo-scientific Cause	Toe erosion by 2nd order stream; blockage of drainage course
Remedial Measures	Avoid blockage of drainage course; need to strengthen the stream bank by gabion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	I
Remarks	Overburden domain



Sl. No.	40
Landslide No.	ls43
Deg.	12°
Min.	32'
Sec.	37.8"
Y	12.54383333
Deg.	75°
Min.	48'
Sec.	44.4"
X	75.81233333
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	15m
Width	30m
Height	6m
Area	2700m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational deep
History	15th Aug 2018
Lithology	Granite gneiss with amphibolite
Landuse/Landcover	Settlement, coffee, silver oak

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Toe erosion by 4th order stream; shifting of natural drainage course towards stream bank
Remedial Measures	Avoid shifting of natural drainage course; need to strengthen the stream bank by gabion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	I
Remarks	Overburden domain



Sl. No.	41
Landslide No.	ls44
Deg.	12°
Min.	32'
Sec.	41.6"
Y	12.54488889
Deg.	75°
Min.	48'
Sec.	37.5"
X	75.81041667
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	15m
Width	10m
Height	6m
Area	900m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide/year not known
Lithology	Granite gneiss
Landuse/Landcover	Coffee, silver oak

Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Toe erosion by stream
Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	III
Remarks	Overburden domain



Sl. No.	42
Landslide No.	ls45
Deg.	12°
Min.	32'
Sec.	49.1"
Y	12.54697222
Deg.	75°
Min.	48'
Sec.	34.3"
X	75.80952778
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	8m
Area	800m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Old slide/year not known
Lithology	Granite gneiss
Landuse/Landcover	Coffee, paddy
Hydrological Condition	Flowing
Element at Risk	Cultivation
Geo-scientific Cause	Toe erosion by 4th order stream; shifting of natural drainage course towards stream bank

Remedial Measures	Avoid shifting of natural drainage course; need to strengthen the stream bank by gabion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	II
Remarks	Overburden domain
	

Sl. No.	43
Landslide No.	ls46
Deg.	12°
Min.	32'
Sec.	49.6"
Y	12.54711111
Deg.	75°
Min.	48'
Sec.	30.7"
X	75.80852778
Locality Name	Kirdale village, Kodagu district, Karnataka
Length	10m
Width	30m
Height	8m
Area	2400m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Aug-18
Lithology	Deformed and sheared granite gneiss
Landuse/Landcover	Settlement, coffee, jungal wood
Hydrological Condition	Flowing
Element at Risk	Settlement, cultivation
Geo-scientific Cause	Toe erosion by 4th order stream; shifting of natural drainage course towards stream bank; blockage of drainage course

Remedial Measures	Avoid shifting and blockage of natural drainage course; need to strengthen the stream bank by gabbion wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	I
Remarks	Overburden domain
	

Sl. No.	44
Landslide No.	ls47
Deg.	12°
Min.	32'
Sec.	56.3"
Y	12.54897222
Deg.	75°
Min.	48'
Sec.	42.6"
X	75.81183333
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	10m
Width	20m
Height	5m
Area	1000m ³
Type of Material	Debris
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	18th Aug 2018
Lithology	Deformed and sheared granite gneiss
Landuse/Landcover	Settlement, road
Hydrological Condition	Flowing
Element at Risk	Settlement, road
Geo-scientific Cause	Toe erosion by 3rd order stream
Remedial Measures	Need to strengthen the stream bank by gabion wall structure to stop further erosion;

	need to make sufficient deep rooted plantation across the slide at the toe of the slope; need to give appropriate reinforcement measure for cut-slope; need to give proper drainage network for safe passage of runoff waters;
Alert	I
Remarks	Cut-slope domain (overburden)
	

Sl. No.	45
Landslide No.	ls48
Deg.	12°
Min.	33'
Sec.	4.4"
Y	12.55122222
Deg.	75°
Min.	48'
Sec.	35"
X	75.80972222
Locality Name	Biligeri village, Kodagu district, Karnataka
Length	10m
Width	10m
Height	5m
Area	500m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	2018
Lithology	Not visible
Landuse/Landcover	Coffee, banana trees
Hydrological Condition	Flowing
Element at Risk	Cultivation

Geo-scientific Cause	Toe erosion by 4th order stream; shifting of natural drainage course towards stream bank
Remedial Measures	Need to shift the drainage course through mid-way; need to strengthen the stream bank by wooden wall structure to stop further erosion; need to make sufficient deep rooted plantation across the slide at the toe of the slope
Alert	II
Remarks	Overburden domain
Photograph not available	

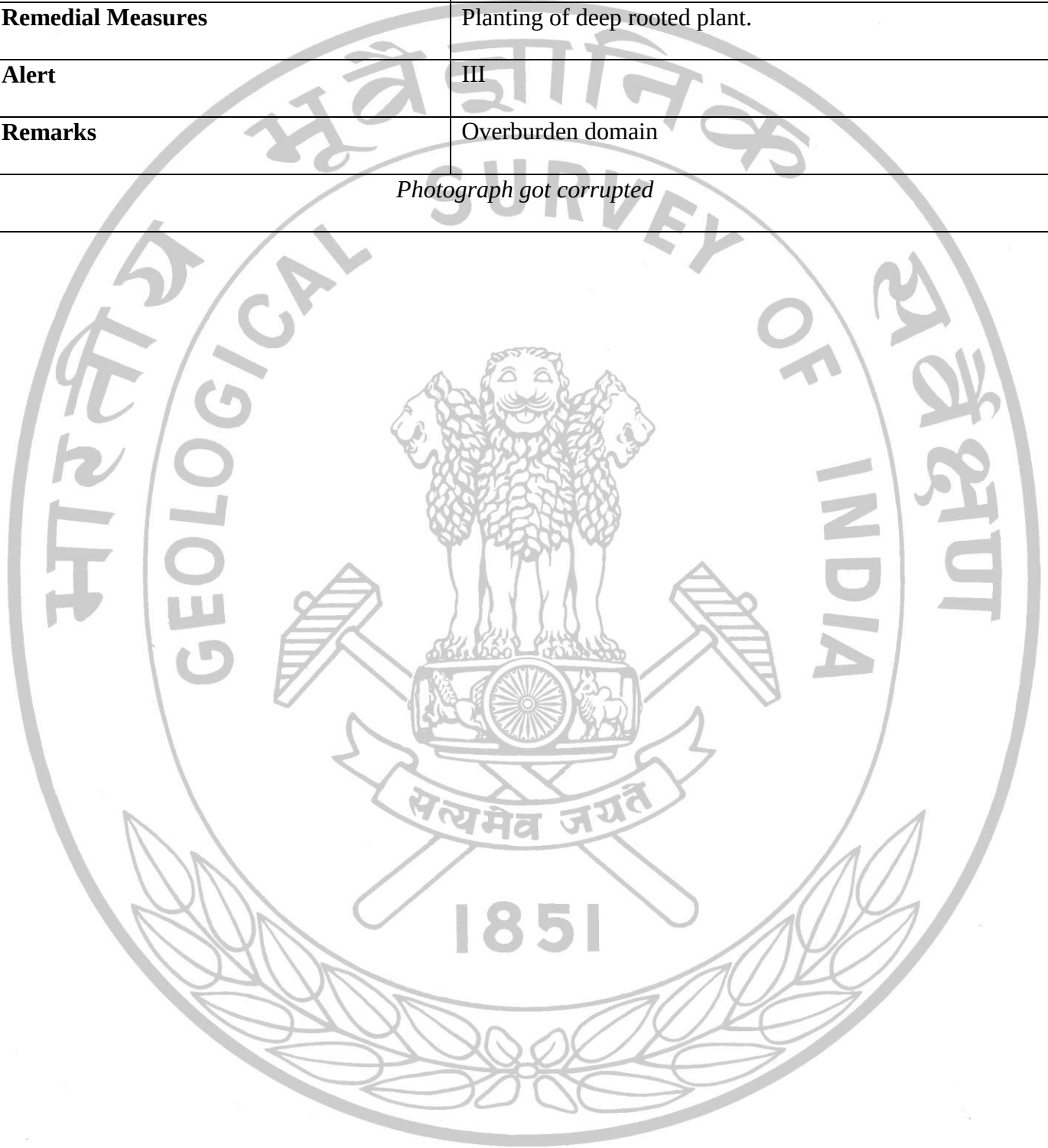
Sl. No.	46
Landslide No.	ls49
Deg.	12°
Min.	33'
Sec.	58.23"
Y	12.566175
Deg.	75°
Min.	48'
Sec.	26.7"
X	75.80741667
Locality Name	Gubbanamane village, Kodagu district, Karnataka
Length	5m
Width	5m
Height	4m
Area	100m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Shallow translational
History	2018
Lithology	Deformed and sheared granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Poor slope forming material (highly weathered granite gneiss)

Remedial Measures	Planting of deep rooted plant.
Alert	III
Remarks	Overburden domain



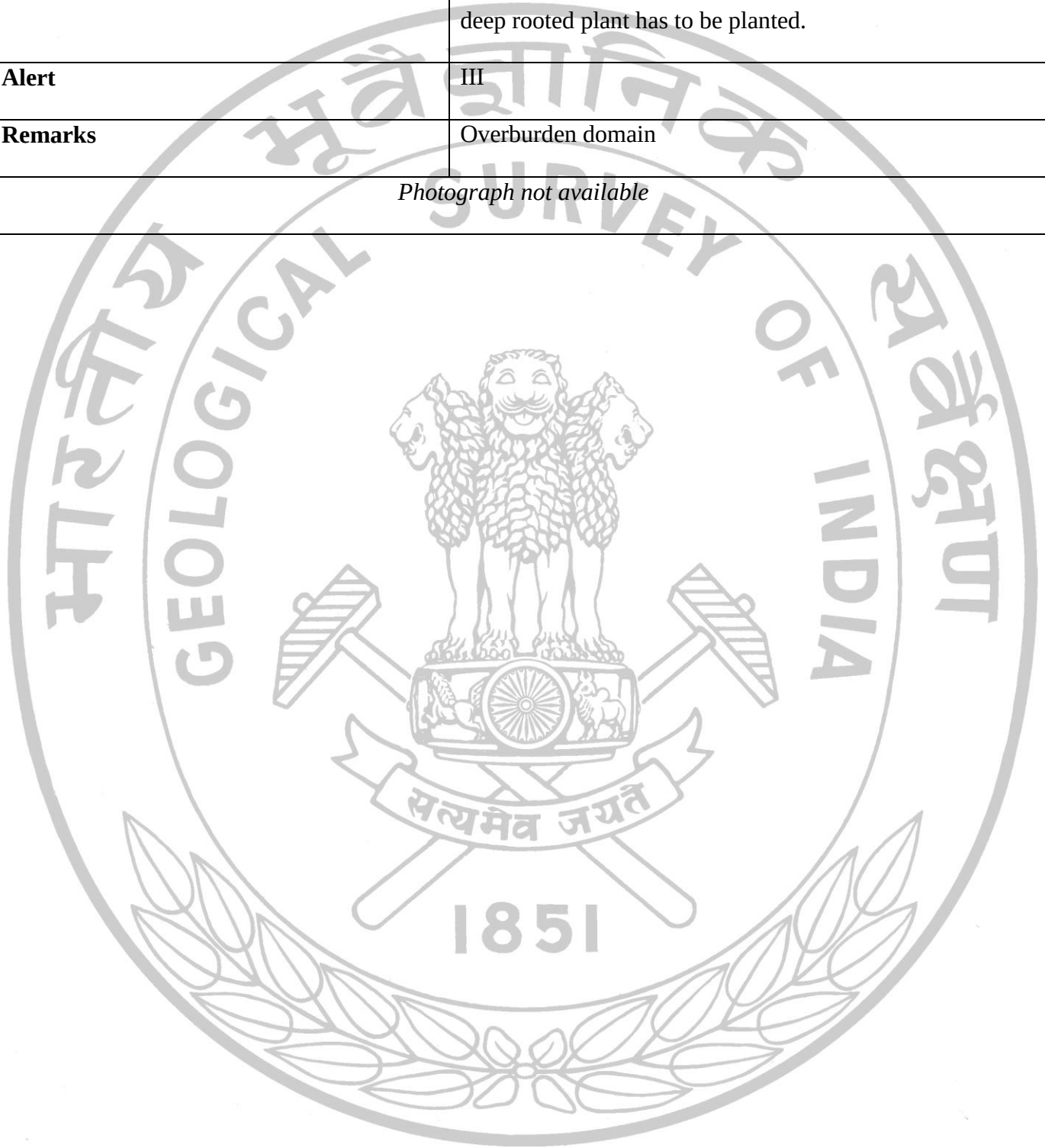
Sl. No.	47
Landslide No.	ls50
Deg.	12°
Min.	33'
Sec.	54.34"
Y	12.56509444
Deg.	75°
Min.	48'
Sec.	27.96"
X	75.80776667
Locality Name	Gubbanamane, Kodagu district, Karnataka
Length	4m
Width	10m
Height	3m
Area	120m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Shallow translational
History	2018
Lithology	Granite gneiss
Landuse/Landcover	Coffee, silver oak, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation

Geo-scientific Cause	Excess water influx during rainfall; reduction of material strength in saturation.
Remedial Measures	Planting of deep rooted plant.
Alert	III
Remarks	Overburden domain
<i>Photograph got corrupted</i>	



Sl. No.	48
Landslide No.	ls51
Deg.	12°
Min.	33'
Sec.	58.06"
Y	12.56612778
Deg.	75°
Min.	48'
Sec.	23.3"
X	75.80647222
Locality Name	Gubbanamane village, Kodagu district, Karnataka
Length	25m
Width	20m
Height	20m
Area	10000m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Shallow translational
History	Unknown
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Toe erosion by nala, reduction of material strength in

	saturation.
Remedial Measures	Avoid shifting and blockage of natural drainage course; deep rooted plant has to be planted.
Alert	III
Remarks	Overburden domain
<i>Photograph not available</i>	



Sl. No.	49
Landslide No.	ls52
Deg.	12°
Min.	33'
Sec.	59.39"
Y	12.56649722
Deg.	75°
Min.	48'
Sec.	22.14"
X	75.80615
Locality Name	Gubbanamane village, Kodagu district, Karnataka
Length	15m
Width	10m
Height	10m
Area	1500m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Shallow translational
History	Unknown
Lithology	Granite gneiss
Landuse/Landcover	Coffee, jungal wood
Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Reduction of material strength in saturation.

Remedial Measures	Deep rooted plant has to be planted.
Alert	III
Remarks	Overburden domain



Sl. No.	50
Landslide No.	ls53
Deg.	12°
Min.	33'
Sec.	2.11"
Y	12.55058611
Deg.	75°
Min.	48'
Sec.	18.4"
X	75.80511111
Locality Name	Gubbanamane village, Kodagu district, Karnataka
Length	12m
Width	15m
Height	10m
Area	1800m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Shallow translational
History	Unknown
Lithology	Granite gneiss
Landuse/Landcover	Coffee, silver oak and jungle wood
Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Reduction of material strength in saturation.

Remedial Measures	Deep rooted plant has to be planted.
Alert	III
Remarks	Overburden domain



Sl. No.	51
Landslide No.	ls54
Deg.	12°
Min.	33'
Sec.	47.51"
Y	12.56319722
Deg.	75°
Min.	48'
Sec.	10.56"
X	75.80293333
Locality Name	Rajandabane village, Kodagu district, Karnataka
Length	15m
Width	5m
Height	12m
Area	900m ³
Type of Material	Earth
Type of Movement	Slide
Failure Mechanism	Translational shallow
History	Unknown
Lithology	Granite gneiss
Landuse/Landcover	Coffee, silver oak and jungle wood
Hydrological Condition	Dry
Element at Risk	Cultivation

Geo-scientific Cause	Steep slope with thick overburden and toe cut by the nala. Reduction of material strength in saturation.
Remedial Measures	Easing of the slope recommended, lining of the stream also recommended
Alert	III
Remarks	Overburden domain



Sl. No.	52
Landslide No.	ls55
Deg.	12°
Min.	33'
Sec.	46.5"
Y	12.56291667
Deg.	75°
Min.	47'
Sec.	58.5"
X	75.79958333
Locality Name	Kalladi village, Kodagu district, Karnataka
Length	30m
Width	30m
Height	25m
Area	22500m ³
Type of Material	Debris
Type of Movement	Flow
Failure Mechanism	Deep translational
History	18th Aug 2018
Lithology	Sheared granite
Landuse/Landcover	Coffee, silver oak and jungle wood
Hydrological Condition	Dry
Element at Risk	Cultivation
Geo-scientific Cause	Weak slope forming material and steep slope, saturation of

	the overburden material.
Remedial Measures	Easing of the slope and maintain the natural flow path, planting of deep rooted plant in the slide area.
Alert	I
Remarks	Overburden domain



Plate-1

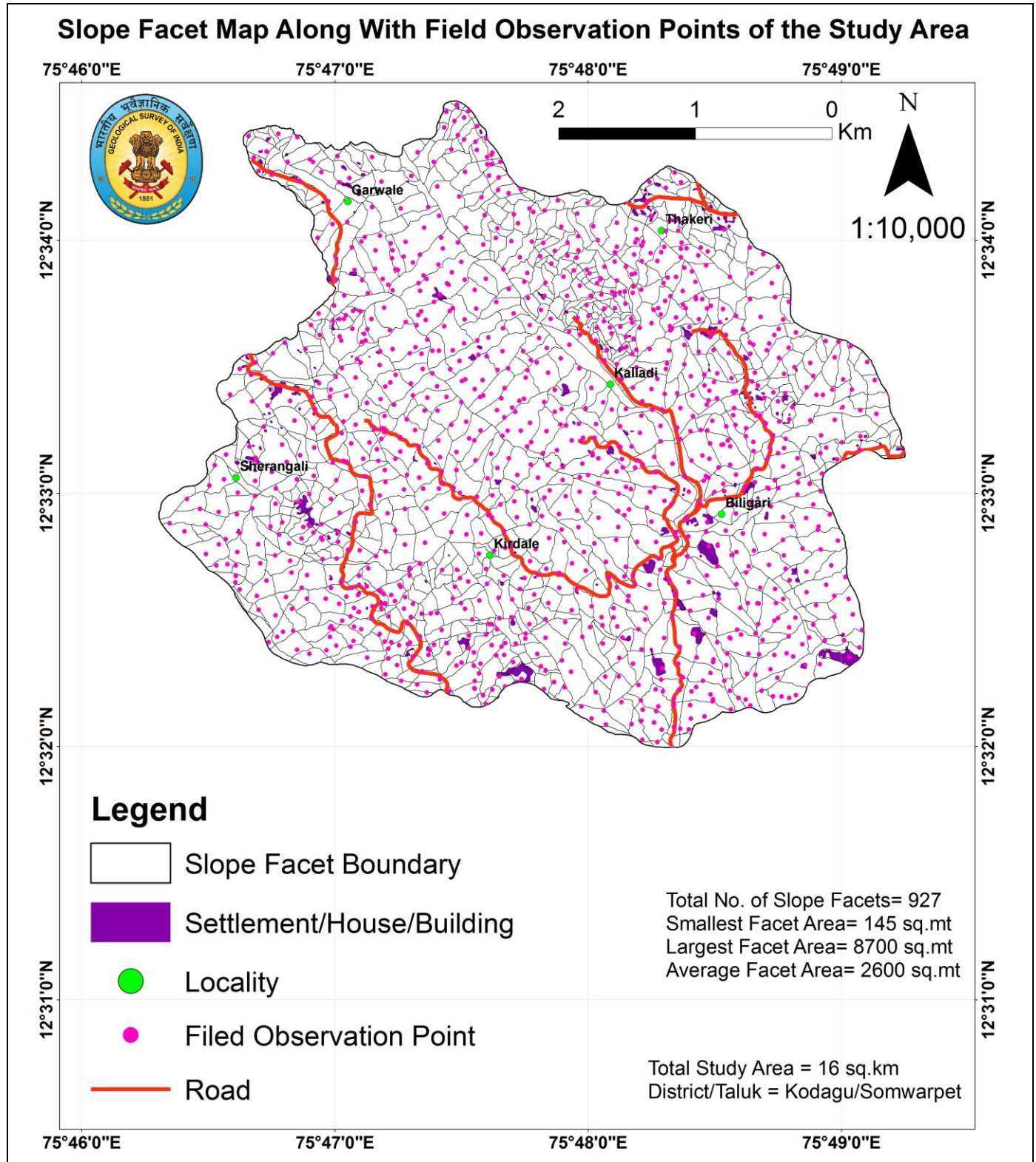


Plate-2

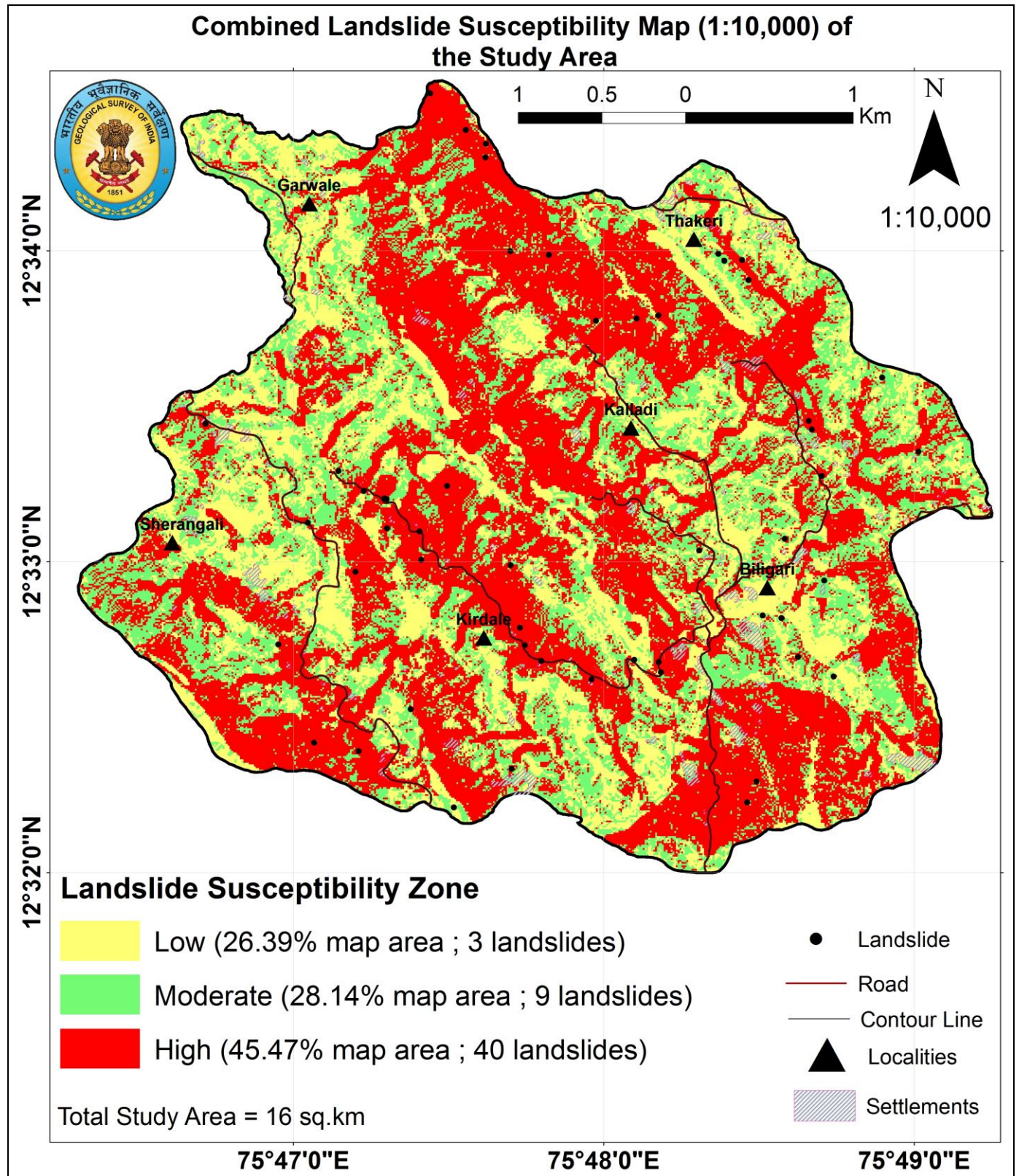
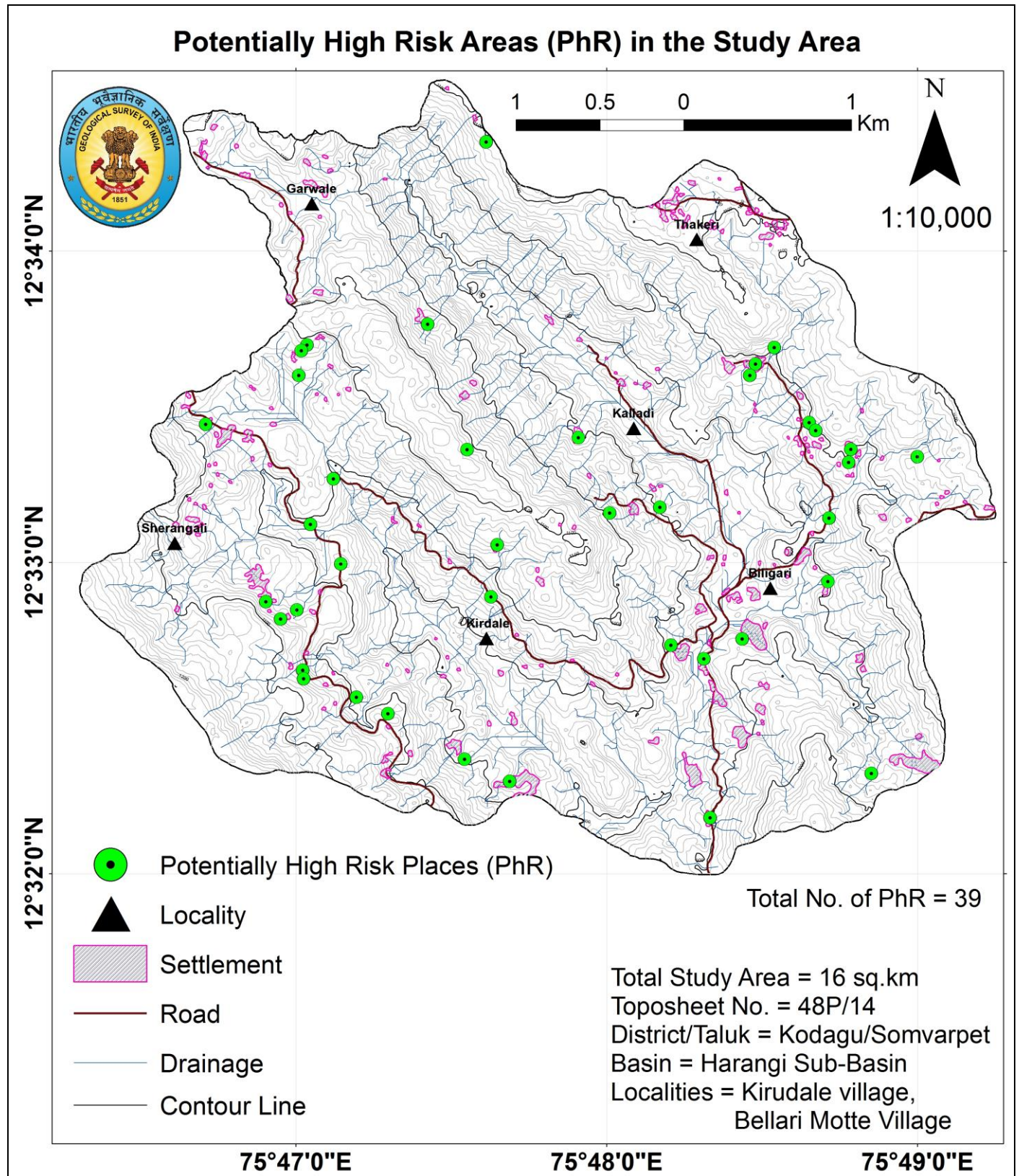


Plate-3







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