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भारत सरकार
GOVERNMENT OF INDIA
भारतीय भूवैज्ञानिक सर्वेक्षण
GEOLOGICAL SURVEY OF INDIA

कर्नाटक के कोडागु जिले के जोडपाल क्षेत्र में मेसो-स्केल (1:10,000) पैमाने में भूस्खलन संवेदनशीलता
मानचित्रण

Meso-scale (1:10,000) Landslide Susceptibility Mapping in Jodpal area, Kodagu district of
Karnataka

टोपशीट सं48Pपी/11/Toposheet No.: 48P/11

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Final report for field season 2020-21

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द्वारा

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सारांश

कार्य सत्र 2020-21 में भूस्खलन अध्ययन परियोजना "मेसो-स्केल (1:10,000) कर्नाटक के कोडागु जिले के जोडपाल क्षेत्र में भूस्खलन संवेदनशीलता मानचित्रण" 20 किमी के क्षेत्र में लिया गया था जो कि मडिकेरी तालुक, कोडागु का एक हिस्सा है। अध्ययन ऐसे क्षेत्र में की गई थी, जहां वर्ष 2018-19 के दौरान कई भूस्खलन और सतही दरारें देखी गई थीं और जहां जोखिम में एक उच्च तत्व शामिल था। अलग-अलग भूस्खलन विफलता डोमेन (रॉक स्लाइड और रॉक फॉल डोमेन, मलबे स्लाइड और अर्थ स्लाइड डोमेन, कट-स्लोप डोमेन) में अध्ययन क्षेत्र के लिए मेसो-स्केल (1:10,000) भूस्खलन संवेदनशीलता मानचित्र तैयार करने के लिए अध्ययन किया गया था। अध्ययन क्षेत्र में पिछले भूस्खलन की घटनाओं के प्रमुख कारक और एक विशेष विफलता डोमेन के लिए प्रासंगिक भू-कारक विषयगत विशेषताओं की भूमिका की जानकारी प्राप्त करने के लिये। सुदूर संवेदन आधारित अध्ययन के अलावा, अध्ययन क्षेत्र विस्तृत रूप से अध्ययन किया गया था, जिसके दौरान अध्ययन क्षेत्र में पिछले भूस्खलन के विभिन्न भू-आकृति संबंधी पहलू, उनकी विफलता तंत्र, मौजूदा भू-कारक विषय, विभिन्न जल निकासी-संबंधी पहलू, ढलान की विशेषताएं, प्राकृतिक और साथ ही साथ मानवजनित ढलान क्षरण प्रक्रियाओं की गहन जांच की गई। अध्ययन क्षेत्र में डेटा के गहन विश्लेषण ने भूस्खलन की संवेदनशीलता का आकलन करने के लिए प्रत्येक भूस्खलन विफलता डोमेन में प्रासंगिक भू-कारक विषयों की गहरी समझ लाई है। संवेदनशीलता मानचित्रण के लिए अनुप्रयुक्त मॉडल के सत्यापन के लिए भूस्खलन सूची तैयार करना आवश्यक था। कुल 20 नग सुदूर संवेदन डेटा स्रोतों और क्षेत्र अध्ययन के इनपुट का उपयोग करके अध्ययन क्षेत्र में भूस्खलन का सीमांकन किया गया है। क्षेत्र के अवलोकन ने सुझाव दिया कि अधिकांश भूस्खलन ओवरबर्डन विफलता डोमेन में हुए हैं और वर्षा से प्रेरित थे। दोनों प्राकृतिक,

साथ ही मानवजनित-संबंधी कारणों को जिम्मेदार पाया गया। प्राकृतिक कारणों में, मध्यम से खड़ी ढलानों पर इन-सीटू मिट्टी की कतरनी ताकत में कमी, जल क्रिया द्वारा धारा तट सामग्री का क्षरण या प्राकृतिक ढलानों का कटाव, और चट्टान के टुकड़ों को अलग करने के लिए अनुकूल संयुक्त हस्तक्षेप पैटर्न की पहचान की गई थी। लगातार बारिश के कारण ये प्राकृतिक उत्प्रेरक भूस्खलन का कारण बने। मानवजनित कारणों में, बुनियादी ढांचे के विकास के लिए प्राकृतिक ढलानों को काटने और खेती के उद्देश्यों के लिए प्राकृतिक ढलानों के संशोधन को जिम्मेदार पाया गया है। प्रत्येक डोमेन में प्रत्येक पिकसेल इकाई की भूस्खलन संवेदनशीलता की भविष्यवाणी के लिए वर्तमान अध्ययन में एक भूस्खलन विफलता डोमेन-आधारित दृष्टिकोण अपनाया जाता है ताकि एक गुणात्मक और भूमि उपयोग प्रबंधन-आधारित भूस्खलन संवेदनशीलता वर्गीकरण किया जा सके। एक वर्गीकृत डोमेन में प्रत्येक भू-कारक विषयगत वर्ग के लिए भूस्खलन संवेदनशीलता मूल्यांकन रेटिंग (एलएसईआर) को अध्ययन क्षेत्र-विशिष्ट स्थितियों और प्रत्येक पिकसेल इकाई के लिए गणना की गई कुल अनुमानित संवेदनशीलता मूल्य (टीईएसवी) पर विचार करके अनुमानी रूप से (ज्ञान-संचालित दृष्टिकोण) निर्धारित किया गया था। योग विधि द्वारा रॉक स्लाइड और रॉक फॉल डोमेन में 0.50 वर्ग किमी क्षेत्र के लिए रॉकस्लाइड और रॉकफॉल के लिए भूस्खलन की संवेदनशीलता का आकलन किया गया है। रॉक स्लाइड डोमेन में, गुणात्मक रूप से अपनाए गए मॉडल ने उच्च संवेदनशीलता में 5.35 प्रतिशत नक्शा क्षेत्र और प्रभावकारिता के साथ कम संवेदनशीलता में 71.47 प्रतिशत नक्शा क्षेत्र की भविष्यवाणी की है और 23 प्रतिशत नक्शा क्षेत्र में मध्यम अतिसंवेदनशील वर्ग के मामले में कम से कम अनिश्चितता है। जबकि रॉक फॉल डोमेन में, गुणात्मक रूप से अपनाए गए मॉडल ने उच्च संवेदनशीलता में 21.62 प्रतिशत नक्शा क्षेत्र और प्रभावकारिता के साथ कम संवेदनशीलता में 49.84 प्रतिशत नक्शा क्षेत्र की भविष्यवाणी की है और 28.54 प्रतिशत नक्शा क्षेत्र में मध्यम अतिसंवेदनशील वर्ग के मामले में कम से कम अनिश्चितता है। उच्च संवेदनशीलता वर्ग ने उन क्षेत्रों को बरकरार रखा है जो रॉक स्लाइड और रॉकफॉल से अधिक प्रवण हैं। मलबे स्लाइड और अर्थ स्लाइड डोमेन में 18.95 वर्ग किमी क्षेत्र में मलबे की स्लाइड और पृथ्वी स्लाइड के लिए भूस्खलन की संवेदनशीलता का आकलन किया गया है। गुणात्मक रूप से अपनाए गए मॉडल ने उच्च संवेदनशीलता में 29.05 प्रतिशत नक्शा क्षेत्र और कम संवेदनशीलता में 45.35 प्रतिशत नक्शा क्षेत्र की भविष्यवाणी की है और 25.59

प्रतिशत नक्शा क्षेत्र में मध्यम अतिसंवेदनशील वर्ग के मामले में कम से कम अनिश्चितता है। 0.0362 वर्ग किमी क्षेत्र के कट-स्लोप डोमेन में, गुणात्मक रूप से अपनाए गए मॉडल ने उच्च संवेदनशीलता में 66.85 प्रतिशत नक्शा क्षेत्र और प्रभावकारिता के साथ कम संवेदनशीलता में 18.51 प्रतिशत नक्शा क्षेत्र की भविष्यवाणी की है और 14.64 से अधिक मध्यम अतिसंवेदनशील वर्ग के संदर्भ में कम से कम अनिश्चितता है। प्रतिशत नक्शा क्षेत्र। कुछ असाधारण भूस्खलनों में रेंगना और सबसिडेंस विफलता तंत्र होने के बावजूद, जहां सतह विषयक विशेषताएं विफलता का पक्ष नहीं लेती हैं, भूस्खलन सूची द्वारा लागू मॉडल भविष्यवाणी का सत्यापन 65% (उच्च): 10% (मध्यम): 25% (कम) मलबे में पाया जाता है। स्लाइड और अर्थ स्लाइड डोमेन; कट-स्लोप डोमेन में 100% (उच्च)। चूंकि अध्ययन क्षेत्र में किसी भी रॉक स्लाइड का सीमांकन नहीं किया गया था, जिसके द्वारा सत्यापन किया जा सकता था, लेकिन एक रॉक स्लाइड (पच्चर की विफलता) बाद में सितंबर 2021 में अब्बीकोली झरने में एक चट्टानी ढलान पर हुई है, जिसकी भविष्यवाणी रॉक स्लाइड में अतिसंवेदनशील क्षेत्र में की गई है। कार्यक्षेत्र उपयोगकर्ता के अनुकूल दृष्टिकोण को ध्यान में रखते हुए, सामान्य अनुशंसाओं के अलावा, भूस्खलन प्रबंधन मानचित्रण और क्षेत्र-विशिष्ट अनुशंसाओं को विस्तृत चित्रण के साथ उच्च संवेदनशीलता क्षेत्र में पड़ने वाले पहाड़ी ढलानों के स्थिरीकरण के लिए सुझाव दिया गया है।

Meso-scale (1:10,000) Landslide Susceptibility Mapping in Jodpal area, Kodagu district of Karnataka

Item no.: M4LSSM/NC/SR/SU-KG/2020/32438

By

Aijaz Ahmad Bhat, Senior Geologist & Senthilkumar K, Geologist

ABSTRACT

A Landslide investigation project/field season programme titled “Meso-scale (1:10,000) Landslide Susceptibility Mapping in Jodpal area, Kodagu district of Karnataka” was taken up in field season 2020-21 covering an area of about 20 km² in parts of Madikeri taluk, Kodagu. The investigation was carried out in an area that had experienced several landslides and surface cracks during the year 2018-19 involving high element at risk (EatR). The investigation was carried out to generate landslide failure domain wise meso-scale (1:10,000) landslide susceptibility map for the study area viz., rock slide & rock fall domain, debris slide & earth slide domain, cut-slope domain by understanding the major causative factors of past landslide incidences occurred in the study area and role of relevant geo-factor thematic features for a particular failure domain. Apart from remote sensing based study, the field study was extensively carried out during which various geomorphometric aspects of past landslides in the study area, their failure mechanism, existing geo-factor themes, different drainage-related aspects, slope characteristics, natural as well as anthropogenic slope degradation processes were investigated thoroughly. The field study observations and thorough analysis of field data have brought a deep understanding of relevant geo-factor themes in each landslide failure domain to assess their landslide susceptibility. It was necessary to prepare a landslide inventory for validation of the applied model for susceptibility mapping. Total 20 nos. of landslides have been demarcated in the study area using inputs of remote sensing data sources and field study. Field observations suggested that most of the landslides have occurred in overburden failure domains and were rainfall-induced. Both natural, as well as anthropogenic-related causes, were found responsible. 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 were identified. These natural causes came into work by incessant rainfall trigger. In anthropogenic causes, cutting of natural slopes for infrastructure development and modification of natural slopes for cultivation purposes is found responsible. A landslide failure domain-based approach is adopted in the present investigation for predicting landslide susceptibility of each pixel unit in each domain so that a qualitative and land use management-based

landslide susceptibility classification would be done. The landslide susceptibility evaluation ratings (LSER) to each geo-factor thematic class in a categorized domain were determined heuristically (knowledge-driven approach) by considering the study area-specific conditions and the total estimated susceptibility value (TESV) calculated for each pixel unit by summation method. The landslide susceptibility to the rockslide and rockfall has been assessed for 0.50 sq. km area in the rock slide & rock fall domain. In the rock slide domain, qualitatively the adopted model has predicted 5.35 percent map area in high susceptibility and 71.47 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 23 percent map area. Whereas in the rock fall domain, qualitatively the adopted model has predicted 21.62 percent map area in high susceptibility and 49.84 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 28.54 percent map area. The high susceptibility class has retained those areas which are more prone to rock slides and rockfall. The landslide susceptibility to debris slide and earth slide has been assessed in 18.95 sq. km area in debris slide and earth slide domain. Qualitatively the adopted model has predicted 29.05 percent map area in high susceptibility and 45.35 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 25.59 percent map area. In the cut-slope domain of 0.0362 sq. km area, qualitatively the adopted model has predicted 66.85 percent map area in high susceptibility and 18.51 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 14.64 percent map area. Despite few exceptional landslides having creep and subsidence failure mechanisms where surface thematic features do not favor failure, the validation of applied model prediction by landslide inventory is found as 65% (high): 10% (moderate): 25% (low) in debris slide & earth slide domain; 100% (high) in the cut-slope domain. As such no rock slide was demarcated in the study area by which validation could be done but one rock slide (wedge failure) has later occurred in September 2021 on a rocky slope in Abbikolli waterfalls which is predicted into the high susceptible zone in the rock slide domain. Keeping the user-friendly approach in consideration, apart from general recommendations, the landslide management mapping and area-specific recommendations have been suggested for stabilization of hill slopes falling in high susceptibility zone along with detailed illustrations.

CHAPTER-1

INTRODUCTION

1.1 General

In pursuance of project FSP titled “Meso-scale (1:10,000) Landslide Susceptibility Mapping in Jodpal area, Kodagu district of Karnataka” with item code: M4LSSM/NC/SR/SU-KG/2020/32438 of field season 2020-21, the landslide investigation has been carried in 20 km² area which is a part of Madikeri taluk, Kodagu. This investigation was taken up in view of the implementation of the Ministry of Mines approved Landslide Vision and Strategy Document 2020-2030 by the Geological Survey of India in the landslide-prone area of the country. As per the Standard Operating Procedure (SOP) of Meso-scale (10,000) Landslide Susceptibility Mapping project, the following changes in the present investigation were brought to achieve quality product; (1) the field data density is higher; (2) the validation of geo-factor maps is upscaled with higher accuracy; (3) the landslide susceptibility has modeled as per the types of slope failures; (4) the final landslide susceptibility map would be user-friendly and contain 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. Besides, the earlier geological map (1:50,000) of the study area has been updated on 1:10,000 scale with due care. Most importantly the kinematic analysis has been done for each rock outcrop in the study area by which the different rock failures and topographic evolutionary changes have been revealed.

1.2 Location, Communication, and Physiography

The study area of 20 km² is situated in the Kodagu/Coorg district of Karnataka (*see fig. 1.1*) and it lies in SOI toposheets no. 48P/11. The study area is bound between latitudes 12°25'58" N and 12°27'52" N and longitudes 75°36'26"E and 75°38'26" E respectively in which parts of Jodpal, 2nd Monannageri, 10th Mail, Devarakolli and Bettaturu villages of Madikeri Taluk, Kodagu District, Karnataka are situated.

The Coorg district is bordered by the Dakshina Kannada district of Karnataka in the north, the Mysore district of Karnataka in the east, and Kasargod district of Kerala state on the west and south. The study area is about 18 km away from Madikeri town and is about 262 km away from Bangaluru (Karnataka State Capital), 128 km from Mysuru, and 130 km from Mangaluru, respectively. The nearest railway stations to visit Madikeri are in Hassan and Mysore towns. The nearest airport to Madikeri is located at a distance of about 131 km in Mysuru city and second nearest is in Mangaluru city at a distance of about 139 km. The Bangaluru-Mangaluru Highway (NH275) passes through the study area. In general, a fairly good network of roads exists in the Coorg district which are connecting almost every part of rural and urban areas.

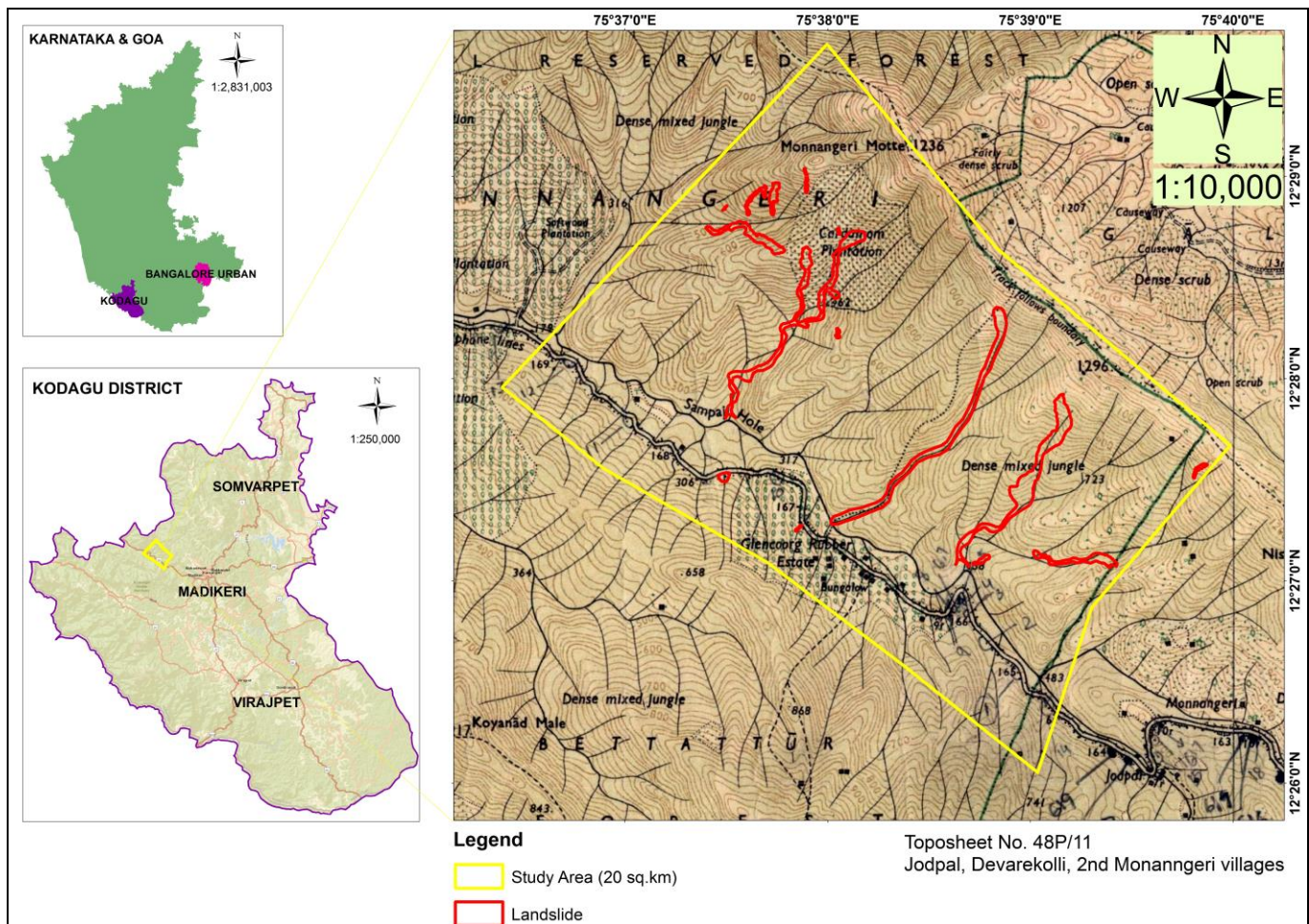


Figure-1.1: Location map of the study area

The study area lies in the vicinity of Western Ghat 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 Coorg district is located in the high precipitation zone with picturesque topography occupying the eastern and western slopes of the Western Ghats. The Western Ghats represents a hilly range with steep slopes and escarpments parallel to the west coast of India. The study area is having lowly to moderately dissected hill slopes with gently dipping pediment slopes. The study area is a part of the 6th stream order-level watershed with a 62.58 Sq. km area which has well-defined drainage patterns. The elevation range varies from 1330m to 427m and the slope angle ranges from 0°-52° in the study area.

1.3 Climate and Rainfall

The Coorg district is having a tropical climate characterized by slight to medium humidity due to proximity to the coast (about 32km). It is known to be quite a pleasant and healthy place in south India by its unique climate, weather conditions, and rainfall patterns. The area receives rainfall during monsoon period starting in June and lasts till the end of September. Even during the post-monsoon months of

October and November certain parts of the district receive a significant amount of rainfall. The climate is dominated by SW monsoon starting from June end. Because of the cloudy weather, the day would be quite sultry during October and it is only during the second half of November that the weather becomes very clear. The period from December to February is the cold season marked by bright weather, foggy mornings, and cool nights. The day temperature begins to rise sharply during March and marks the commencement of the summer season, which lasts till the end of May. The highest maximum temperature recorded at Madikeri is 35°C on the 11th of May 1902 and the lowest minimum temperature ever recorded is 8.9°C on the 20th of February 1936.

The Coorg district has recorded average annual normal rainfall of 2903.1 mm and average annual actual rainfall of 2539.4 mm for the period 2016-2018 (KSNDMC). While the Madikeri taluk (where the present study area lies) of the Coorg district has recorded average annual normal rainfall of 4078.6 mm and average annual actual rainfall of 3416 mm for the period 2016-2018 (KSNDMC). The southwest monsoon reaches usually during early June. Generally, June-September is the month of heavy rainfall (see fig. 1.3) and the precipitation in July is incessant and very heavy. The analysis of rainfall data (from KSNDMC) shows a continuous increasing trend in annual actual rainfall pattern from the year 2016 in Madikeri taluk (see fig. 1.2) and the highest average actual rainfall has been recorded here during the June-September months of the year 2018 (KSNDMC; see fig. 1.3). Further detailed analysis of rainfall data of July and August 2018 has been done station wise. Madikeri, Galibidu and sampaje rainfall stations

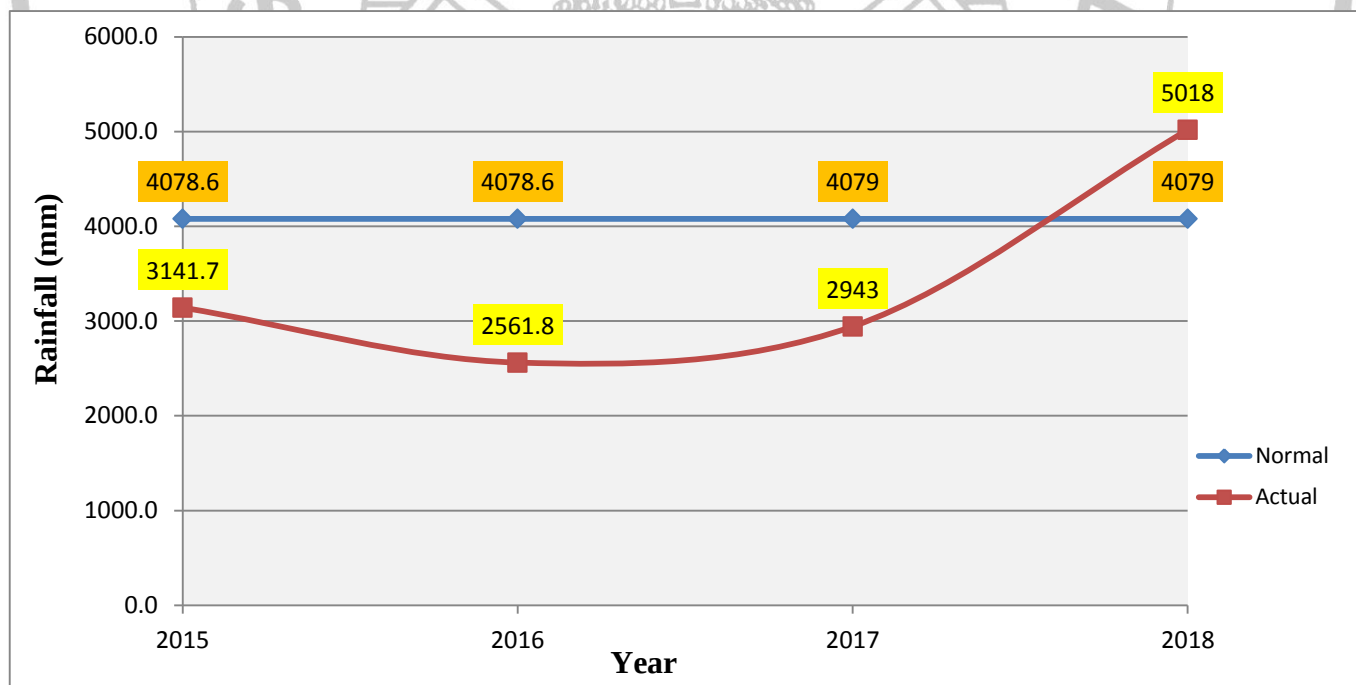


Figure-1.2: Trend of average annual normal and actual rainfall pattern in Madikeri taluk, Coorg recorded for 2015-2018 period. (Source: KSNDMC)

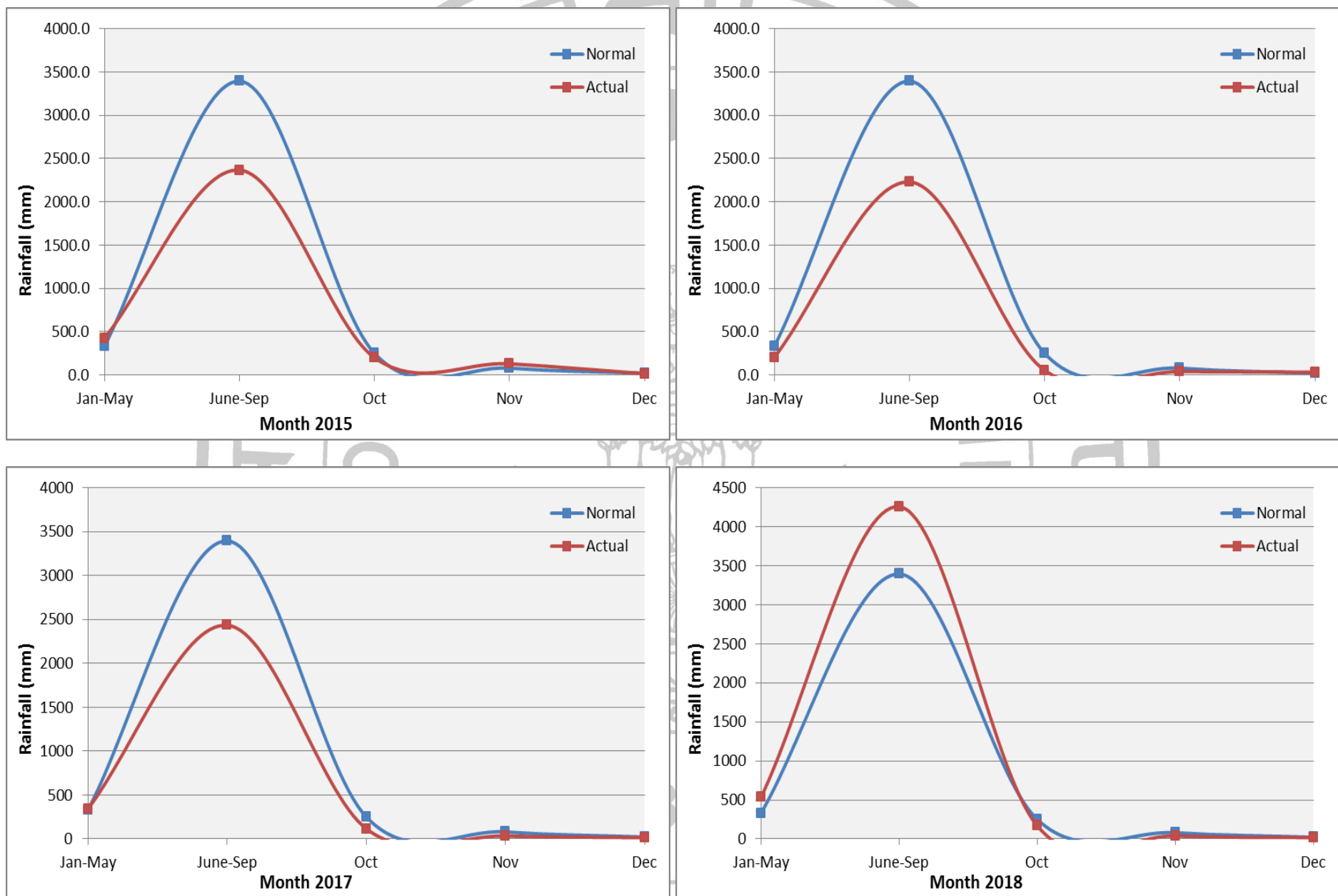


Figure-1.3: Trend of monthly average normal and actual rainfall pattern in Madikeri taluk, Coorg for years 2015-2018

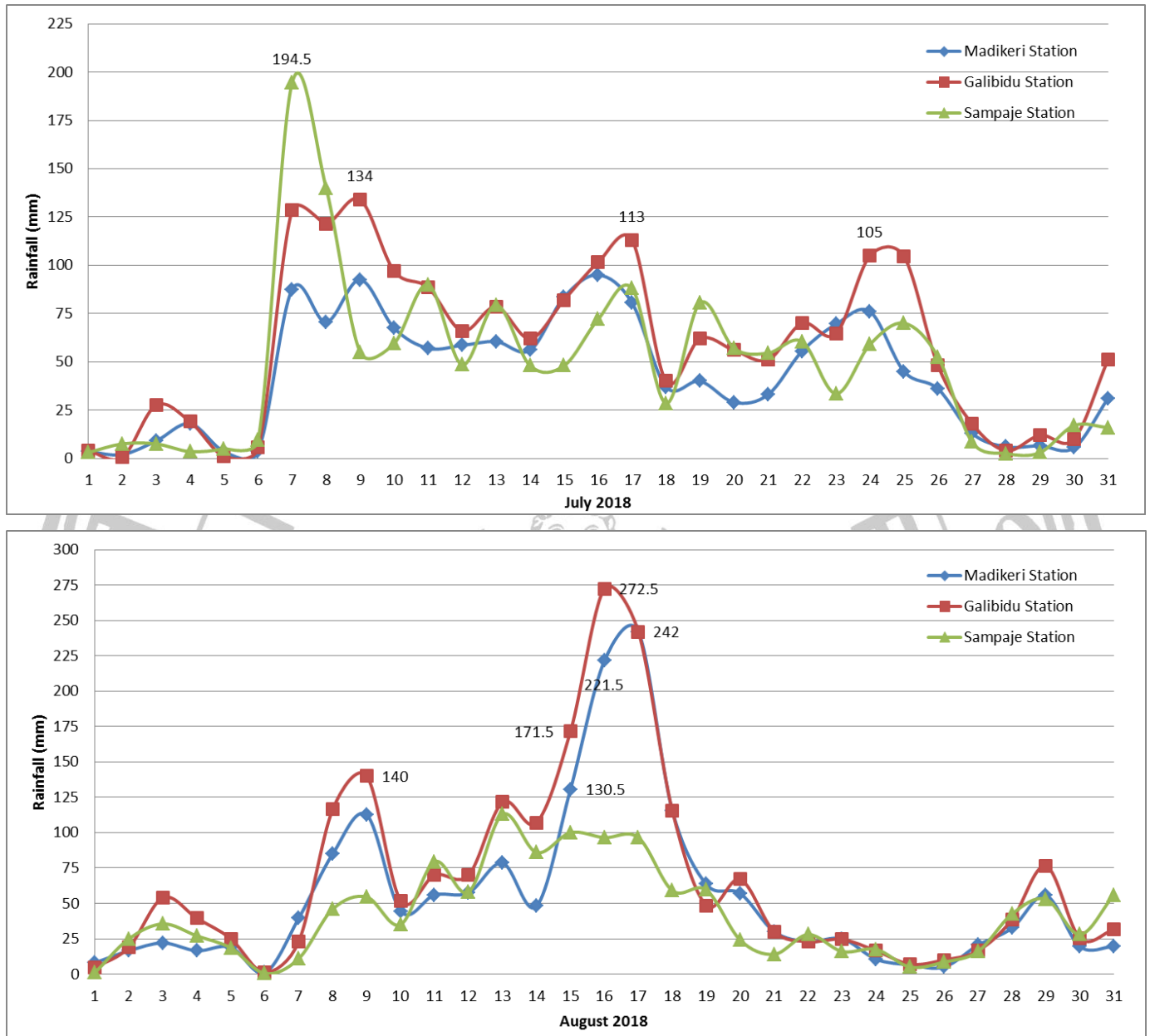


Figure-1.4: Trend of daily rainfall data in July & August 2018 at Madikeri, Galibidu and Sampaje rainfall stations

are nearest to the study area and as per the local inhabitants in the study area, most of the landslide incidences occurred during July-August 2018 period in which maximum rainfall were recorded in the area in year 2018 (see figure-1.4). The daily rainfall data recorded in July & August 2018 at Madikeri, Galibidu and Sampaje rainfall stations shows considerable variations but the daily rainfall data recordings in above said months at Madikeri & Galibidu rainfall stations are almost parallel as shown by graph. It is revealed from the analysis of daily rainfall data recorded in July & August 2018 over the area in which study area lies that the surrounding areas of Madikeri, Galibidu and Sampaje rainfall stations have received rainfall above 150mm in two rainfall events; one event on 7th July 2018 and second event from

15th to 17th August 2018. Although few local people were witnessed that most large scale landslide incidences occurred in second event in the study area and its adjoining places. Their witness is supported by the conclusion drawn from analysis of daily rainfall data recorded in July & August 2018 at Madikeri, Galibidu and Sampaje rainfall stations. Therefore indirectly it may be concluded that for the study area and its adjoining area, the 150mm rainfall is the threshold limit and whenever the said threshold limit would achieve, the hill slopes which have some inherent weaknesses in overburden material or the hill slopes on which cut-slopes are given, would be considered most susceptible for landslides.

1.4 Previous and Present Work

In Coorg district Geological Survey of India has carried out landslide studies since 2007 by A. K. Mishra *et al.*, 2008; K.V. Maruthi *et al.*, 2012, 2013, 2010, 2014; and A.K. Srivastava *et al.*, 2016 & 2017. Among these A. K. Mishra *et al.*, K.V. Maruthi *et al.*, have done landslide inventory, landslide hazard zonation, and post-disaster landslide studies in past years. 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. The areas classified as a high and moderate zone of landslide susceptibility by A.K. Srivastava *et al.*, 2016 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. 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 1 km buffer on both sides. This work has been carried out on macro-scale (1:25,000) level in 85 sq. km area in parts of toposheet no. 48P/11/NE and 48P/15/NW quadrants. In this work, the majority of slides have been classified as debris slumps and earth slumps mainly due to toe cutting of slope during road construction. The area was classified as low, moderate, and highly susceptible. The recommendations include construction of a drainage system on the slopes to reduce the pore pressure, construction of retaining wall, stone pitching and gabions, the 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 have carried 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 for geometrical modification of the slope by grading and benching, bio-technical measures of slope protection, and proper drainage arrangements. Besides post landslide hazard studies have been carried out from time to time as per necessity in the area. These include post-disaster studies in and around Madikeri town, Coorg district, Karnataka in July 2013 where workers have reported several landslides, ground subsidence, and surface cracks around Madikeri town. The surface cracks were about

10-15 cm wide and extending for about 600-700 m in Mannageri village of Madikeri taluk lies in toposheet no. 48P/11. The earlier workers have found that these surface cracks were caused mainly due to an increase in pore water pressure subsequent to the infiltration of rainwater. In this study, the workers have mentioned in their report that unplanned expansion of habitation along with modified land-use patterns has disturbed the natural equilibrium of the area which resulted in the occurrence of such events. The workers in this study have recommended the removal of loose and hanging boulders, slope gradation, and proper drainage arrangements on natural slopes as mitigation measures.

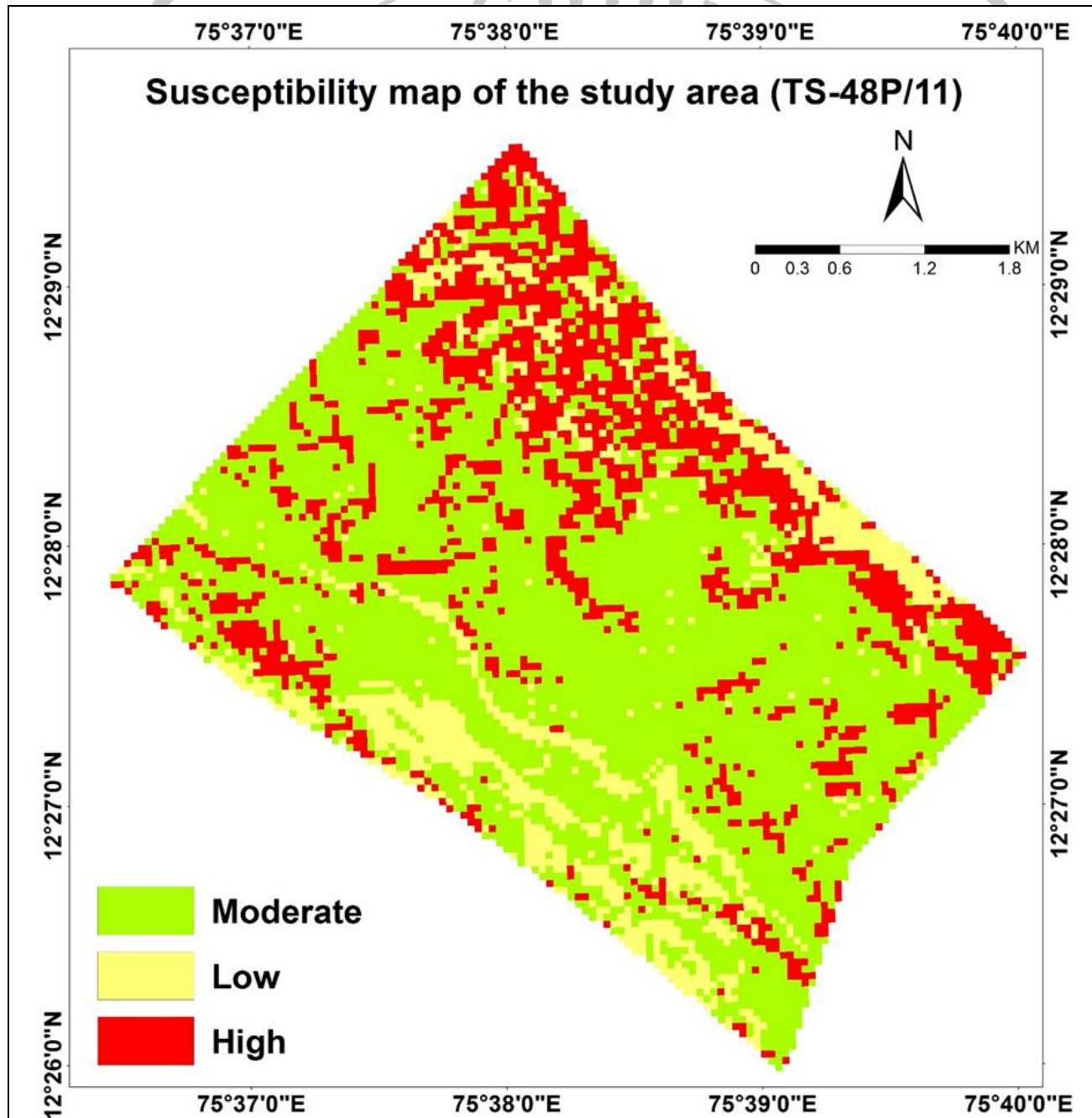


Figure-1.5: Extract of 1:50000 scale Landslide Susceptibility map (NLSM) of present study area

Ankur Kumar Srivastava and Neha Kumari in the year 2016-17 have carried out macro-scale (1:50,000) landslide susceptibility mapping in parts of toposheet no. 48P/07, 11 & 12, Kodagu district, Karnataka in 1317 sq. km area in which present study area of 20 sq. km have also taken into account. This work was part of the national programme for generating a seamless landslide susceptibility map under NLSM. The workers in this study have prepared various thematic factor maps by utilizing remote sensing datasets and field inputs. These factor maps include geomorphology map, land use/land cover 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 landslide susceptibility map has been created for the present study area. It has been worked out from this subset that 5 sq. km area falls under high landslide susceptible zone, 12 sq. km area falls under moderate landslide susceptible zone and 3 sq. km area falls under low landslide susceptible zone (*see figure-1.5*). 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 construction of retaining walls as preventive measures. Besides they have recommended shifting of residential areas to geologically stable places and pursuance of detailed geological study for some areas.

The present study was taken up in view of the implementation of the Ministry of Mines approved Landslide Vision and Strategy Document 2020-2030 by the Geological Survey of India in the landslide-prone areas of the country. The present 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 to minimize the risk factor by adopting up scaled approach in geo-factor mapping, sampling of overburden material for geotechnical analysis to achieve a quality product. Besides, the workers have identified the probability high risk (PHR) zones and suggested the generic mitigation measures which would be prove a helpful contribution to the Kodagu district disaster management plan in case of any landslide and/or flood event in the area, although it was not a part of work objectives but was done on the advise of supervisory officer. Extensive fieldwork has been carried out to make the best possible observations and to understand the failure mechanism, landslide material involved, causative factors, and prevailing geological conditions. The present assignment was one year programme with given nature, quantum, and target (NQT) details (*see table-1.1*). The concerned field officers have successfully achieved all assigned targets and given mandatory field days (*see table-1.2*).

1.5 Objectives of Work

The objectives were: (i) to generate Meso-scale (1:10,000) landslide susceptibility zonation; (ii) to identify causative factors related to landslides; (iii) to suggest generic mitigation measures for unstable slopes; (iv) to update the existing landslide inventory.



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

Nature of Work	Target (km ²)	Achievement (km ²)
1.Pre – field studies Preparation of thematic maps from remote sensing data (ortho rectified CartoDEM 10m) & CartoPAN image 2.5m on 1:10,000 scale	20	20
i. Landuse/Landcover map		
ii. Drainage map		
iii. Geomorphology/Landform map		
iv. Slope Morphometry (Slope Angle, Slope Aspect, Slope Curvature and Relative Relief)		
2. Field – based studies	20	20
i. Geological-Slope Forming Material Mapping (1:10,000 scale)		
ii. Geotechnical Mapping (Shear parameters of overburden and rock mass characterization of slope) on 1: 10,000 scale		
iii. Field validation of all pre-field thematic maps		
iv. Updation of existing landslide inventory with detailed assessment as per 42 point geo-parametric datasheet	45 Nos.	45 Nos.
v. Sample collection for determination of geo- technical parameters		
3. Post-field studies & modeling	20	20
i. Updation and finalization of thematic maps and landslide inventory in GIS platform		
ii. Preparation of landslide susceptibility map in GIS platform		
4.Collection of rainfall data	As per availability	Collected from 2015-2018

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

Name of the field officers	Field days mandatory	Total field days spent
Aijaz Ahmad Bhat, Sr. Geologist	80 days	91 days
Senthilkumar K, Geologist	80 days	94 days

1.6 Acknowledgement

The authors wish to thank Additional Director General and HOD, GSI (SR), and Dy. Director-General, GSI, SU: K&G for giving us an opportunity to work on this project. The authors are thankful to the Supervisory Officers (R.Sajeev & KV Maruthi) for providing technical guidance, support, and valuable suggestions during the entire project work. The authors are very grateful to Director (TC), & Director & HO, SU: K&G for all the logistic support during work. Besides, the authors are thankful to the Kodagu district administration and local people who have rendered immense help and cooperation in various ways for the successful completion of this project.

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 Mercara shear zone traverses through the investigated area which is bound on the north by Western Dharwar Craton of Indian shield and to the south by Coorg Block. The Coorg Block is welded with Dharwar craton to the north by 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 of degree sheet 48P prepared by various workers of GSI from 1949-1986 and published the second edition *Geological Quadrangle Map* in 2013. The regional stratigraphic set-up is shown in *table-2.1*. This GQM reveals rocks of Sargur Group as oldest in the area having Archean age and is equivalent to Wyand 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	
			Gneiss/Garnet-Biotite-Silliminite	Graphite
			Kyanite Cordierite Gneiss/Quartzite	

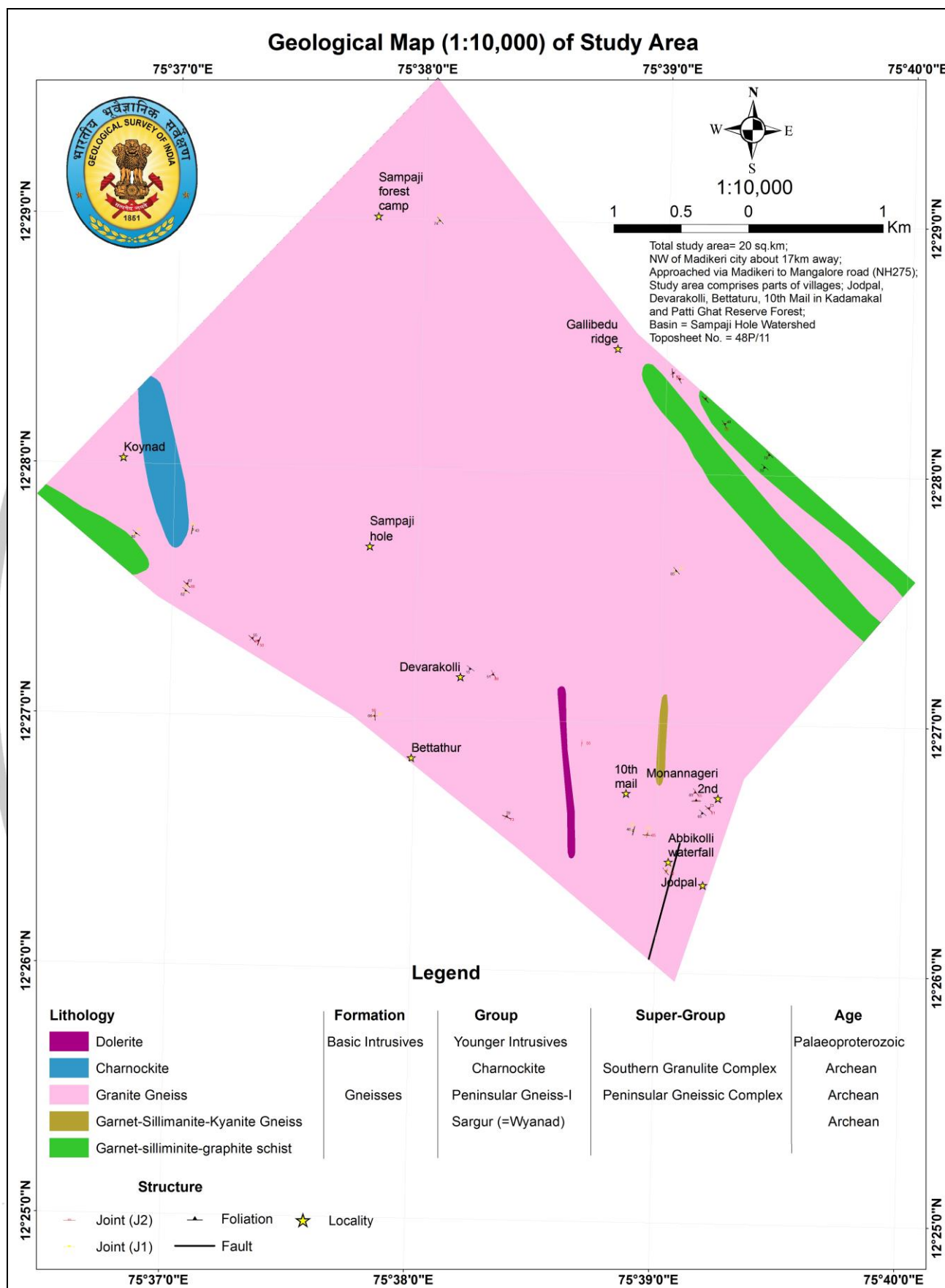


Figure-2.1: Upscaled Geological Map of study area on 1:10K scale (after Aijaz & Senthilkumar)

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

Supergroup	Group	Formation	Lithology	Age
			Alluvium/Overburden	Recent
	Younger Intrusives	Basic Intrusives	Dolerite	Palaeoproterozoic
Southern Granulite Complex	Charnockite		Charnockite	Archaean
Peninsular Gneissic Complex	Peninsular Gneiss-I	Gneisses	Granite Gneiss	Archean
	Sargur (=Wyanad)		Garnet-Sillimanite-kyanite Gneiss Garnet-Silliminite-Graphite Schist	Archean

2.2 Geology of the Study Area

The investigated area of 20 sq. km is occupied by rocks of 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 oldest (*GQM Second edition, 2013, Geological Survey of India*). In the present study up scaled geological mapping (1:10,000) has been done in an area of about 18 sq. km based on field-based studies without petrographic studies. Few changes or modifications have been done in the previous geological map on 1:50k by GSI.

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*). The Sargur Group comprises the rock types as mentioned in table-3.1. Garnet-Silliminite-Graphite Schist is the dominant rock type of Sargur Group exposed in the present investigated area which is described as follows:

Garnet-Silliminite-Graphite Schist: This rock type is highly metamorphosed seen as narrow and discontinues patches and/or bands enclaved within Granite Gneiss (Biotite Gneiss) essentially made of quartzite, garnet, and sillimanite with few flakes of graphite whereas apatite and magnetite are the accessory minerals present (*B.R.C. Iyengar, 1954*). This rock type is exposed along the Galibedu ridge and in the Koynad area. Foliation is trending in NW-SE direction and dipping at 40°-70° both in south-westerly and north-easterly direction because of the folding pattern. This rock type is highly prone to weathering. As observed in field its weathering pattern varies from III to IV grade in the study area. Many landslides have occurred in the proximity of this rock type. The weathered portions of this rock type are showing light pink to light red colour.



Figure-2.2: Garnet-Silliminite-Graphite Schist rock outcrops in Galibedu ridge, Madikeri, Kodagu

2.2.2 Peninsular Gneissic Complex (PGC)

The recent studies on rock types of different ages occurring in the Indian peninsula have gained a lot 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-Trondjemite-Granodiorite (TTG) composition while Younger Gneiss Complex is having largely reworked and mobilized gneisses of around 2600 m.y. The rock types occurring in PGC are shown in table-3.1. In the present investigated area, rock types of Older Gneissic Complex have been only observed, mostly Granite Gneiss.

Granite Gneiss: This rock type is commonly known as Granite Gneiss which belongs to Peninsular Gneiss-I or PGC. This rock type is coarse-grained, leucocratic to mesocratic consisting of quartz, plagioclase, and minor amounts of mafic minerals (*T.S.S. Murthy et al., 1979, GSI*) 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. In the present study, various discontinuous amphibolite patches and/or bands up to a few meters thickness (<5m) have been observed occurring parallel to regional foliation NNW-SSE direction of Granite Gneiss. These amphibolite bands are resistant to weathering and are standing alone running parallel to the regional foliation direction of Granite Gneiss in the area.



Figure-2.3: Granite Gneiss rock outcrops observed in the study area along Sampaji nala section, Madikeri Kodagu.

2.3 Geological Structure in the Study Area

Two minor fold types were observed in the study area which is localised in distribution. One fold is observed in Granite Gneiss which is tight, plunging vertically and its axial plane is parallel to the regional foliation strike. However second fold is observed in Garnet Schist of Sargur Group which is open, also plunging vertically and its axial plane is perpendicular to the regional foliation strike. This signifies that these two minor folds have developed in different folding phases under different stress regimes applied in the study area. Two to three joint sets are recorded in the study area. Among these, the NE-SW trending joint sets (J2 and J4) are observed frequently in the study area. These joint sets are closely spaced and have a dependent relationship with the regional foliation in the area. Joint set J2 would be the cleavage plane of the regional fold in the area. These joint sets play a prominent role in the evolution of hilly terrains and the development of different geomorphological features in the area. The southwestern side of Galibido ridge has torn out under the orthogonal relationship of these joint sets with regional foliation. The small sized broken rock fragments fall in the opposite direction of dip of regional foliation under gravity effect which leads to the formation of small to large size escarpments on Galibido ridge. The barren hill tops in the area would be the result of the same phenomenon. The small sized broken rock fragments on these barren hilltops frequently washed out to downslope side during the rainfall periods. This factor has minimized the chances of natural plant growth on barren hilltops in the area. Most importantly, the barren hilltops have developed convex slopes under the same phenomenon. These convex slopes are most vulnerable for slope movement under gravity effect. The second possibility is the dislocation of wedge blocks by the interference of J1, J2 joint sets, and foliation plane (see stereonet-9).



Figure-2.4: Two types of folds observed in the study area; (left) one fold in which axial plane is parallel to regional foliation observed in Sampaji nala section, Madikeri Kodagu; (right) second fold type in which axial plane is in orthogonal relationship with regional foliation observed in Galibedu ridge, Madikeri Kodagu.



Figure-2.5: Different joint sets observed in the study area are among major factors that control the regional topographic changes



Figure-2.6: Different fault-related geomorphological and lithological evidence observed along a particular zone in the study area including; (from top left); lithological displacement in Granite Gneiss in Sampaji nala section near Abbikolli waterfalls; shifting of stream confluence point near Abbikolli waterfalls; and high stream density along the faulted zone on the south western face of Galibedu ridge, Madikeri Kodagu

These blocks are susceptible to move on slopes that are open to the atmosphere in NE direction preferably within 20° slope window/slope orientation. This possibility of the vulnerability of wedge failure is witnessed in the Devarakolli village area where a wide colluvium zone has evolved by this phenomenon. The joint data analysis and their stereo-net plots predict the two possibilities of dislocation of rock blocks from an intact rock outcrop in the study area.

Some fault-related geomorphological and lithological evidence have been observed along a zone in the NE and SW direction of Abbikolli waterfalls. The displacement of litho-units in this zone shows both sinistral and dextral sense of movement. Along this zone, drainage density is high resulted by headward erosion of hilly terrains at a high rate, detached rock fragments with overburden cover have moved down

the stream frequently, stream confluence point of 5th and 6th order has shifted from the original position. Besides, a waterfall has been developed on a steep escarpment face which is locally known as Abbikolli waterfall. Few surface cracks trending almost in EW direction were observed along this zone in overburden cover and one among these is traversing across a ridge which is exceptionally seen in block movement scenarios along a faulted zone. These pieces of evidence suggested that a fault is traversing through the area wherein there would be more chances of mass movement in the future.

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

Joint Set (J1)					
Location No.	Lat	Long	Strike	Dip	Azimuth
1	12.450122	75.630578	360	66	90
2	12.460156	75.650908	335	40	65
3	12.458172	75.617572	290	35	20
4	12.461928	75.614111	300	83	30
5	12.440181	75.650714	306	51	36
6	12.442825	75.648322	295	90	0
7	12.442592	75.649358	285	85	15
8	12.462283	75.618033	360	90	0
9	12.483214	75.634342	280	21	10
Mean			312.33	62.33	27.67
Joint Set (J2)					
Location No.	Lat	Long	Strike	Dip	Azimuth
1	12.450122	75.630578	85	90	0
2	12.4436	75.639758	32	73	122
3	12.453017	75.638581	50	88	140
4	12.444417	75.653517	36	81	153
5	12.473403	75.650506	50	82	140
6	12.472997	75.650947	65	90	0
7	12.455169	75.622228	45	53	135
8	12.440181	75.650714	27	72	117
9	12.442011	75.655678	45	90	0
10	12.442592	75.649358	15	65	105
11	12.444936	75.652633	30	90	0
12	12.445431	75.652503	30	55	120
13	12.458714	75.617725	30	68	120
14	12.454975	75.622581	60	50	150
15	12.448597	75.644794	5	55	95
16	12.471739	75.652731	35	44	125
17	12.470064	75.654097	75	50	165
18	12.468036	75.657083	20	43	110
19	12.461269	75.666161	43	51	133

20	12.464628	75.661906	43	52	133
Mean			41.05	67.1	103.15
Joint Set (J3)					
Location No.	Lat	Long	Strike	Dip	Azimuth
1	12.438556	75.652117	290	54	200
2	12.453017	75.638581	290	59	200
3	12.458172	75.617572	360	90	0
4	12.440464	75.651175	306	51	215
5	12.442825	75.648322	315	85	225
6	12.442592	75.649358	305	33	215
7	12.444936	75.652633	300	16	210
8	12.458714	75.617725	335	34	245
9	12.448597	75.644794	323	32	233
10	12.462283	75.618033	290	23	200
Mean			311.4	47.7	194.3
Joint Set (J4)					
Location No.	Lat	Long	Strike	Dip	Azimuth
1	12.4436	75.639758	42	54	312
2	12.444417	75.653517	45	72	315
3	12.460156	75.650908	57	70	327
4	12.461928	75.614111	50	88	320
5	12.440464	75.651175	35	83	305
6	12.445431	75.652503	50	73	320
7	12.448597	75.644794	75	59	345
8	12.470064	75.654097	60	80	330
9	12.483214	75.634342	64	58	334
Mean			53.11	70.78	323.11

CHAPTER – 3

LANDSLIDE INVENTORY

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, 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 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 pre-field-based landslide inventory. It is worthy to utilize freely available satellite images through Google Earth for landslide boundary demarcation but there were 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

In the present study a total of 20 nos. of landslides have been demarcated using inputs of remote sensing data sources and field study. Landslides demarcated from remote sensing sources have been checked and validated during field study and were found existing on the ground. All 20 nos. of landslide, sites were accessible and were studied thoroughly during the field study. The relevant attributes/information (geo-parametric attributes) were recorded for each landslide incidence for future

reference (*see annexure-I*). During the field investigation, the workers have given thrust upon landslide classification, causative factors for the occurrence of landslides, 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 overburden failure domains and were found rainfall-induced landslides. Rainfall-induced landslides occur in a particular rainfall period and depend on rainfall intensity, saturation limits, and geotechnical parameters in various earth surface domains, slope morphometry behavior, and drainage morphometric parameters. Both natural, as well as anthropogenic related causes, were found responsible for landslide occurrences in the area and the multiple causative factors in both natural as well as anthropogenic have acted in landslide occurrences in the study area. 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 did not run proportionately as observed in field without any field test, due to which the pore water pressures decrease the in-situ soil's effective stress, and then low shear strength material with low tensile strength slide down the slope in the form of either debris flow or earth flow. The debris flow or earth flow then evolved to long-distance channel flow and impacted both natural as well as man-made surface features. Under this phenomenon, if the overburden material does have high tensile strength, the surface cracks would have developed before any slope failure. However, some surface cracks have developed in the overburden material with high clay mineral content in the study area. The streams with large catchment areas received runoff waters in large quantities and the resulted accumulated stream waters flown with high speed due to which stream bank material eroded. The erosion of stream bank material which always forms the base of the uprising slope created instability to 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. This phenomenon in rock surface domains has evolved many hill slopes and led to the development of a few large pediment slopes in the study area whose slope gradient decreases gradually from top to foot.

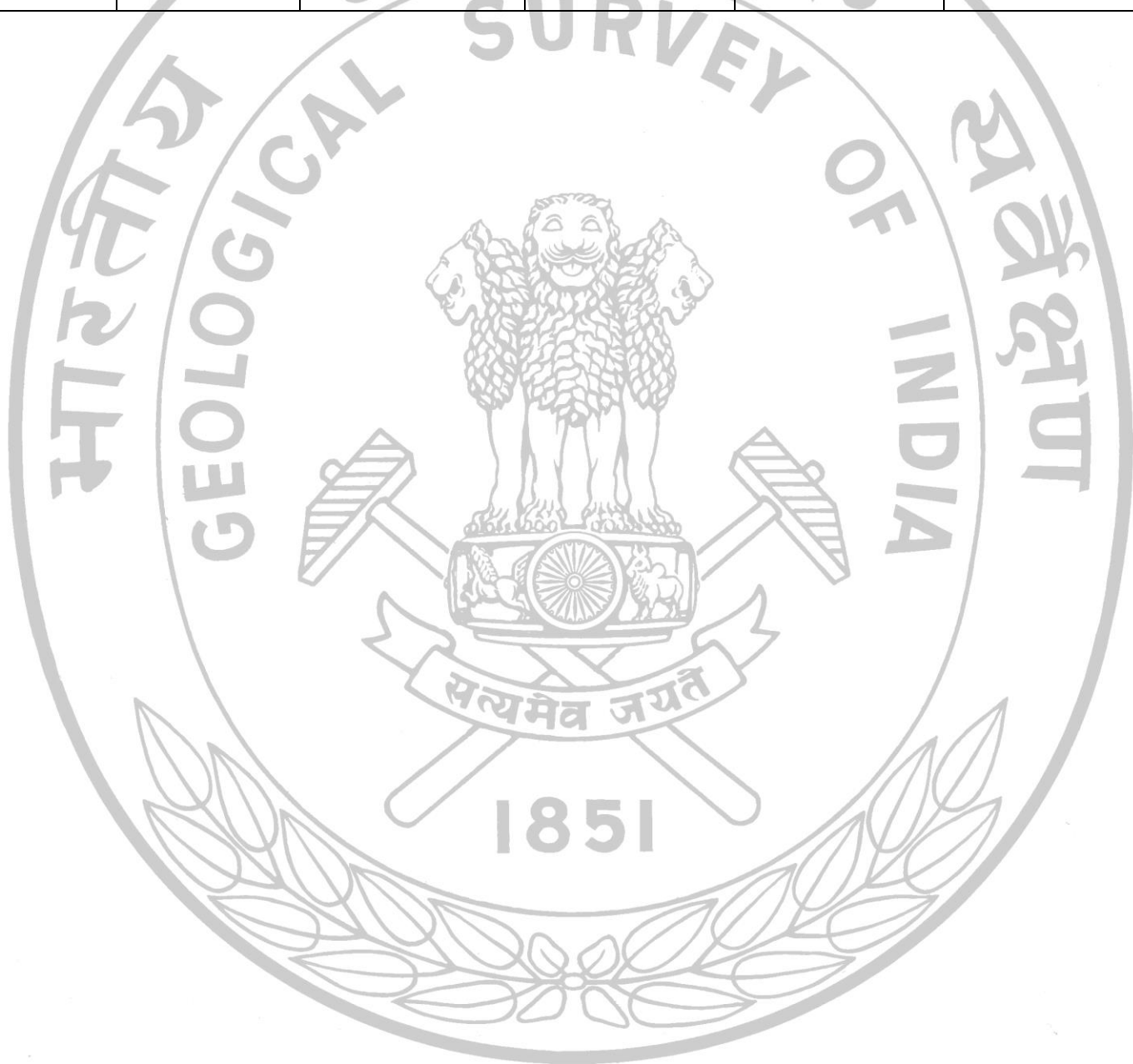
In anthropogenic causes, cutting of natural slopes for road construction & settlement buildings for both domestic as well as commercial use and modification of natural slopes for cultivation purposes are included. Although it is found that most small dimensional landslides have occurred by anthropogenic

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 gravity effect in under-saturated conditions. This process leads to occur 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 surface along the existing slip plane, large dimensional and deep surface landslides have occurred under the same conditions. This type of landslide occurred near a temple in Devarakolli village in the study area.

Table-3.1: Details of landslide incidences studied in the present work.

Sl. No.	Landslide No.	Longitude (DMS)	Latitude (DMS)	Toposheet No.	Area (sq. meter)
1	ls9	75°39' 15.712" E	12°27' 9.128" N	48P/11	34030
2	ls10	75°38' 55.117" E	12°27' 36.787" N	48P/11	157900
3	ls12	75°37' 47.949" E	12°28' 22.540" N	48P/11	109200
4	ls14	75°37' 34.469" E	12°28' 46.407" N	48P/11	40720
5	ls4	75°39' 17.158" E	12°26' 38.504" N	48P/11	911.10
6	ls7	75°39' 9.468" E	12°26' 43.879" N	48P/11	491.70
7	ls8	75°39' 3.930" E	12°26' 42.749" N	48P/11	488.10
8	ls6	75°39' 9.529" E	12°26' 45.605" N	48P/11	641.90
9	ls2	75°38' 23.875" E	12°27' 2.374" N	48P/11	665.70
10	ls18	75°38' 35.909" E	12°27' 0.675" N	48P/11	1070
11	ls17	75°38' 42.358" E	12°26' 55.158" N	48P/11	12790
12	ls16	75°38' 41.432" E	12°26' 52.041" N	48P/11	686
13	ls1	75°38' 8.081" E	12°27' 18.797" N	48P/11	1857
14	ls3	75°37' 48.003" E	12°27' 21.249" N	48P/11	2690
15	ls5	75°37' 49.955" E	12°27' 32.965" N	48P/11	2463

16	ls19	75°36' 40.068" E	12°28' 5.316" N	48P/11	4487
17	ls11	75°38' 10.263" E	12°28' 24.044" N	48P/11	2545
18	ls13	75°37' 50.102" E	12°28' 34.864" N	48P/11	30330
19	ls15	75°38' 46.180" E	12°28' 17.568" N	48P/11	35400
20	ls20	75°39'03.24" E	12°26'26.32" N	48P/11	600m ³



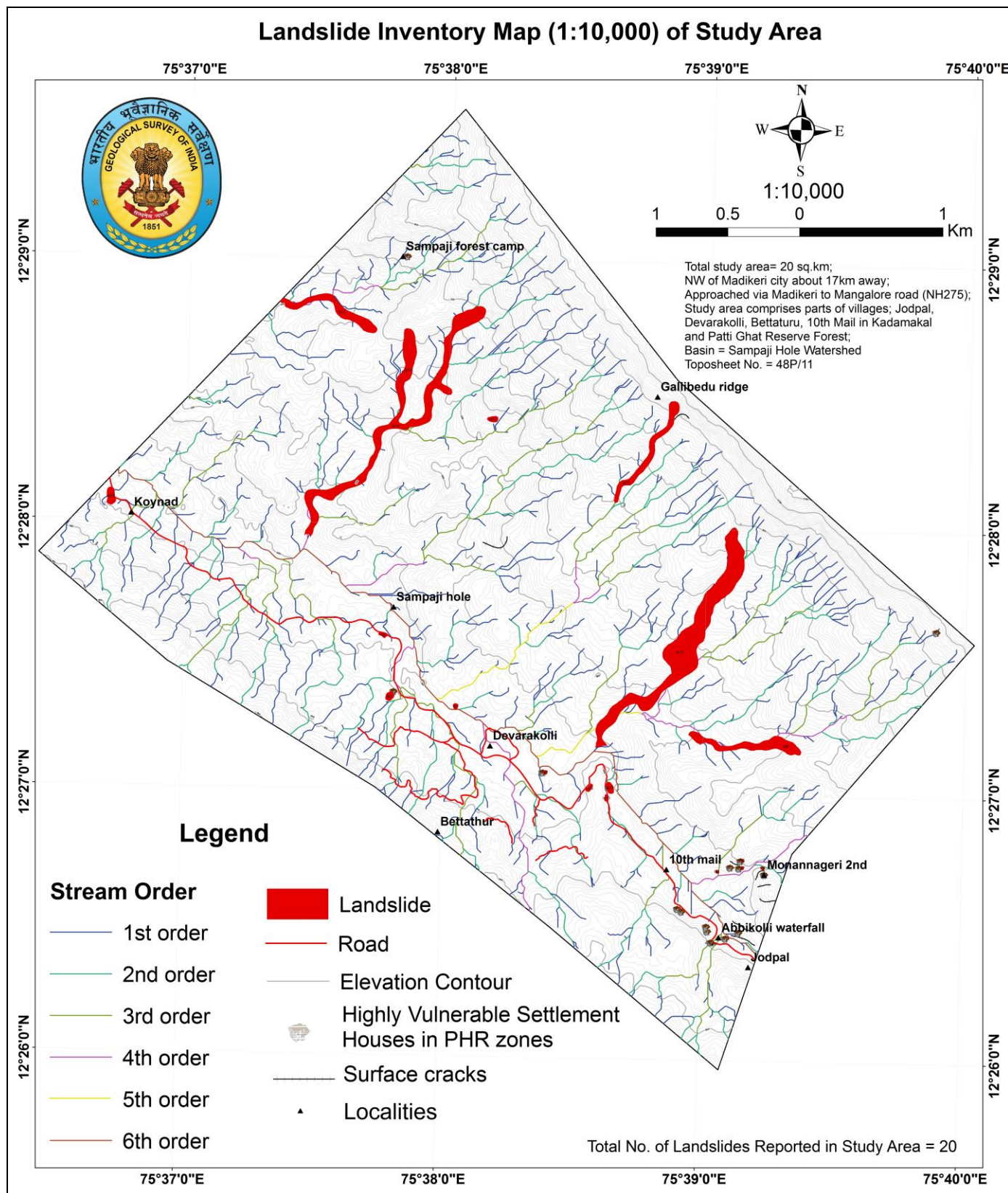


Figure-3.1: Landslide inventory map of the study area



(a) Debris slide occurred on a moderate slope which was cut for settlement purpose in Monannageri 2nd village, Madikeri Kodagu (12°26' 45.605" N/75°39' 9.529" E)



(b) Debris slide occurred moderate slope in Monannageri 2nd village, Madikeri Kodagu (12°26' 43.879" N/75°39' 9.468" E)



(c) Earth slide occurred on right stream bank (sompaji hole) near Devarakolli village Madikeri Kodagu.



(d) Debris flow occurred on SW side steep slope of Galibedu ridge Madikeri Kodagu



(e) Rock slide occurred on a steep slope in Kadamakal R. Forest Madikeri Kodagu



(f) Earth flow occurred on a moderate slope in Kadamakal R. Forest Madikeri Kodagu



(g) Creep movement observed on a gentle slope with multiple surface cracks in Monannageri 2nd village Madikeri Kodagu



(h) 2nd order stream which has the potential to carry boulder material downstream during high water conditions exists in the upslope side of Abbikolli waterfalls where high drainage density is observed.



(i) Road cut slope along NH 275 near 10th mile village Madikeri Kodagu



(j) Area along NH275 where subsidence of overburden material continuously occurs since 2013 in Koyanad Madikeri Kodagu



(k) Earth slide occurred on a gentle slope near a temple in Devarakolli village Madikeri Kodagu



(l) Streambank erosion by water action along Sampaji hole which has initiated many small slumps in the area

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. 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 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 of 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. 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, slope facet map is used for field mapping use only. The geo-factor thematic maps for each landslide failure domain were prepared by incorporating the; pre-field based inputs from remote sensing sources; field mapping based inputs and laboratory-based inputs. The relevance of each geo-factor thematic map has been 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 of pre-field study has been found satisfactory in-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 has been prepared precisely, initially from multi-temporal satellite images through Google Earth, data from old reports of GSI, other literatures 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. Overburden domain is 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} .

During the post-field study, all the geo-factor thematic maps were finalized after incorporating both the field mapping and 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 has been performed by keeping into consideration the satisfactory level of field visualization assessment of hill slope vulnerability to failure during field observation and the validation of susceptibility score map by landslide inventory.

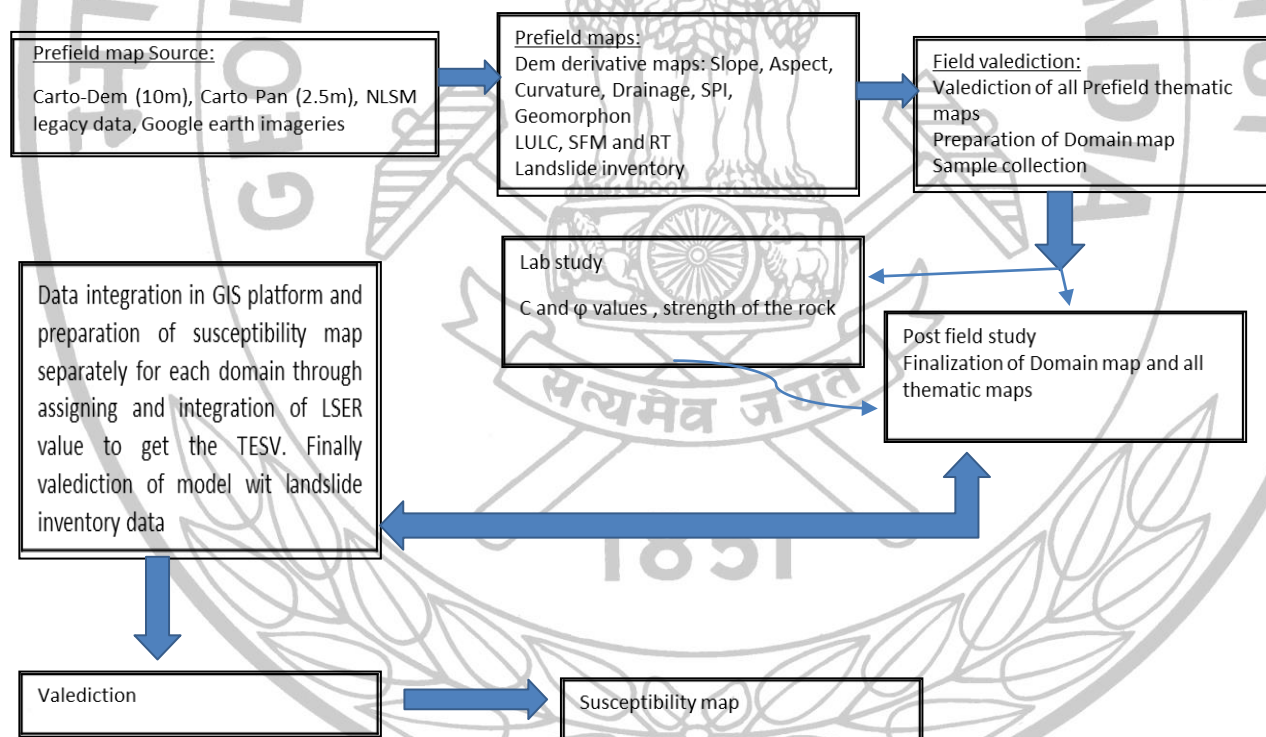


Figure-4.1: Flow chart showing methodology for the preparation of Meso-scale susceptibility map

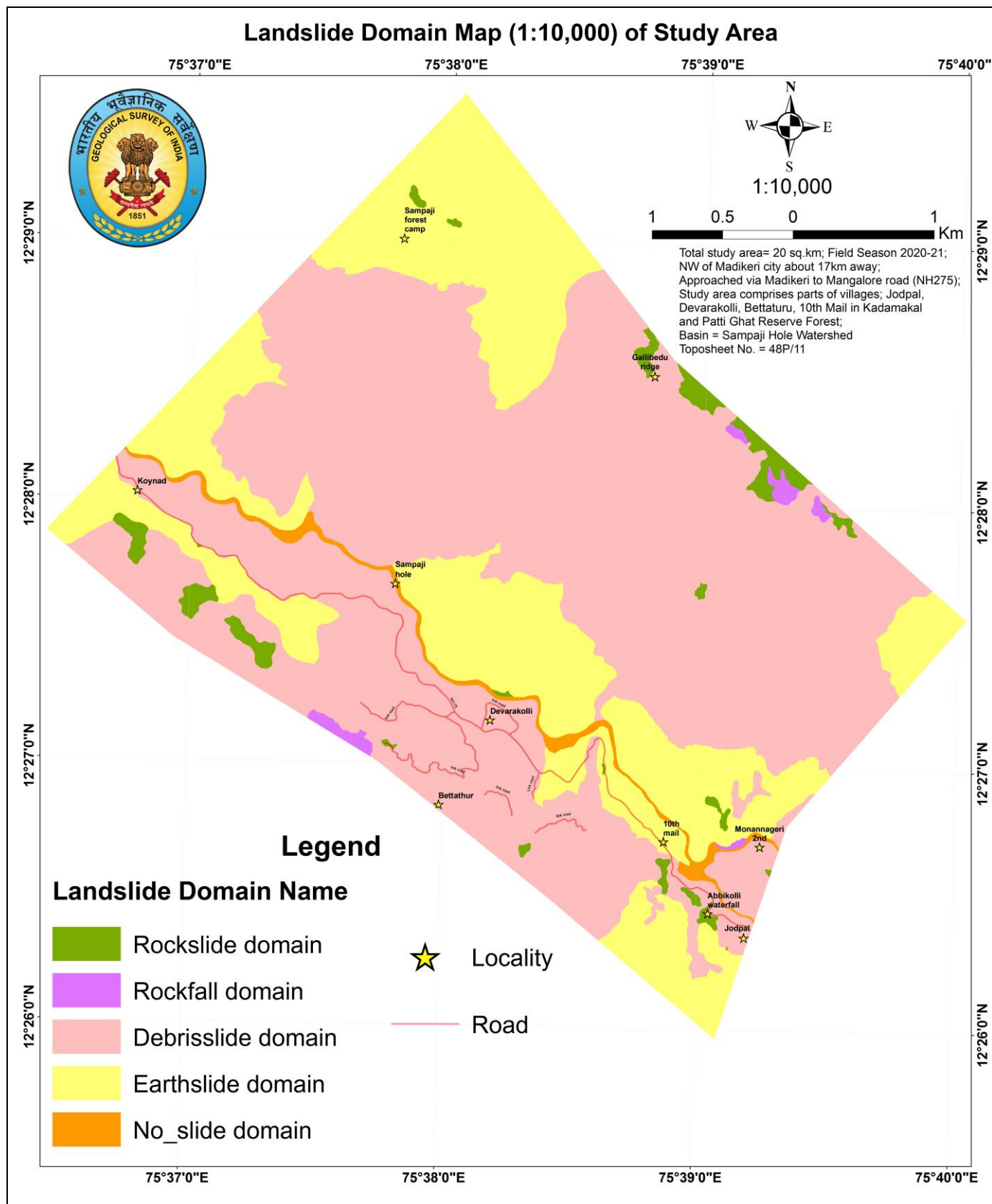


Figure-4.2: Landslide failure domain map of the study area

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. 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. The very purpose to study the rock slide and rockfall domains separately was to select the most relevant variables which will determine the strength of the rock mass. Besides slope angle map, the kinematic failure analysis and rock mass rating (RMR_{basic}) are the two geo-factors that were 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 of orientation of the discontinuities and the slope faces has been recorded in rock slopes through field-based geological mapping techniques. The recorded data were geometrically classified into different sets of discontinuities (*see table-4.2*) 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 was done to identify the potential failures of planar, wedge, and topple by adopting Markland's test for kinematic failures. The data of orientation of different sets of discontinuity planes were fed in GIS using fishnet toolset as 10mX10m 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 generated. The resulting trend and plunge data of each intersection were also fed in GIS using 10mX10m 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.

Table-4.2: Geometrically classified data of different sets of discontinuities (J1, J2, J3, J4 and Foliation) recorded in the study area.

Details of Joint Data Sets J1 and J2														
Sl. No.	Latitude	Longitude	Strike_J1	Dip_J1	Azimuth_J1	Slope direction		Slope angle	Strike_J2	Dip_J2	Azimuth_J2	Slope direction		Slope angle
1	12.450122	75.630578	360	66	73	0-29	NNE	30-35	85	88	175	0-29	NNE	30-35
2	12.443600	75.639758							32	73	122	0-29	NNE	15-20
3	12.438556	75.652117												
4	12.453017	75.638581							50	88	140	299-329	NW	0-5
5	12.444417	75.653517							36	81	153	269-299	WNW	35-40
6	12.460156	75.650908	335	40	65	149-179	SSE	15-20						
7	12.473403	75.650506							50	82	140	179-209	SSW	40-45
8	12.472997	75.650947							65	90	0	239-269	WSW	25-30
9	12.458172	75.617572	290	35	20	0-29	NNE	10-15						
10	12.461928	75.614111	300	83	30	29-59	NE	20-25						
11	12.455169	75.622228							45	53	135	29-59	NE	20-25
12	12.440464	75.651175												
13	12.440181	75.650714	306	51	36	0-29	NNE	25-30	27	72	117	0-29	NNE	25-30
14	12.442825	75.648322	295	84	25	0-29	NNE	35-40						
15	12.442592	75.649358	285	85	15	29-59	NE	30-35	15	65	105	29-59	NE	30-35
16	12.444936	75.652633							30	82	300	329-360	NNW	20-25
17	12.445431	75.652503							30	55	120	209-239	SW	25-30
18	12.458714	75.617725							30	68	120	59-89	ENE	25-30
19	12.454975	75.622581							60	50	150	29-59	NE	10,15
20	12.448597	75.644794							5	55	95	209-239	SW	20-25
21	12.462283	75.618033	360	83	270	0-29	NNE	20-25						
22	12.471739	75.652731							35	44	125	209-239	SW	30-35
23	12.470064	75.654097							75	50	165	209-239	SW	30-35
24	12.468036	75.657083							20	43	110	179-209	SSW	40-45
25	12.483214	75.634342	280	21	10	239-269	SWS	10-15						
26	12.443467	75.654726							45	90	0	239-269	WSW	20-25

Details of Joint Data Sets J3 and J4

Sl. No.	Latitude	Longitude	Strike_J3	Dip_J3	Azimuth_J3	Slope direction		Slope angle	Strike_J4	Dip_J4	Azimuth_J4	Slope direction		Slope angle
1	12.450122	75.630578												
2	12.443600	75.639758							42	54	312	0-29	NNE	15-20
3	12.438556	75.652117	290	54	200	29-59	NE	20-25						
4	12.453017	75.638581	290	59	200	299-329	NW	0-5						
5	12.444417	75.653517							45	72	315	269-299	WNW	35-40
6	12.460156	75.650908							57	70	327	149-179	SSE	15-20
7	12.473403	75.650506												
8	12.472997	75.650947												
9	12.458172	75.617572	360	90	0	59-89	ENE	10-15						
10	12.461928	75.614111							50	88	320	29-59	NE	20-25
11	12.455169	75.622228												
12	12.440464	75.651175	306	51	215	329-360	NNW	35-40	35	83	305	329-360	NNW	35-40
13	12.440181	75.650714												
14	12.442825	75.648322	315	85	225	0-29	NNE	35-40						
15	12.442592	75.649358	305	33	215	29-59	NE	30-35						
16	12.444936	75.652633	300	16	210	329-360	NNW	20-25						
17	12.445431	75.652503							50	73	320	209-239	SW	25-30
18	12.458714	75.617725	335	34	245	59-89	ENE	25-30						
19	12.454975	75.622581												
20	12.448597	75.644794	323	32	233	209-239	SW	20-25	75	59	345	209-239	SW	20-25
21	12.462283	75.618033	290	23	200	0-29	NNE	20-25						
22	12.471739	75.652731												
23	12.470064	75.654097							60	80	330	209-239	SW	30-35
24	12.468036	75.657083												
25	12.483214	75.634342							64	58	334	239-269	WSW	10-15
26	12.443467	75.654726												

Details of Foliation Data										
Sl. No.	Latitude	Longitude	Strike	Dip	Azimuth	Slope direction		Slope angle	No. of Sets Intersecting	Seteronet Plot No.
1	12.450122	75.630578	180	66	270	0-29	NNE	30-35	3	9
2	12.443600	75.639758	294	79	24	0-29	NNE	15-20	3	4
3	12.438556	75.652117	320	69	50	29-59	NE	20-25	2	18
4	12.453017	75.638581	330	51	240	299-329	NW	0-5	3	10
5	12.444417	75.653517	133	73	43	269-299	WNW	35-40	3	5
6	12.460156	75.650908	140	85	230	149-179	SSE	15-20	3	13
7	12.473403	75.650506	355	80	85	179-209	SSW	40-45	2	19
8	12.472997	75.650947	330	40	60	239-269	WSW	25-30	2	20
9	12.458172	75.617572	130	62	220	59-89	ENE	10-15	3	11
10	12.461928	75.614111	130	80	220	29-59	NE	20-25	3	14
11	12.455169	75.622228	315	55	45	29-59	NE	20-25	2	21
12	12.440464	75.651175							2	22
13	12.440181	75.650714	320	69	50	0-29	NNE	25-30	3	1
14	12.442825	75.648322	195	46	285	0-29	NNE	35-40	3	3
15	12.442592	75.649358	275	33	5	29-59	NE	30-35	3	2
16	12.444936	75.652633	150	88	60	329-360	NNW	20-25	3	6
17	12.445431	75.652503	325	85	235	209-239	SW	25-30	3	7
18	12.458714	75.617725	135	67	45	59-89	ENE	25-30	3	12
19	12.454975	75.622581	200	30	290	29-59	NE	10-15	2	23
20	12.448597	75.644794							3	8
21	12.462283	75.618033	190	43	100	0-29	NNE	20-25	3	15
22	12.471739	75.652731	315	56	45	209-239	SW	30-35	2	24
23	12.470064	75.654097	330	48	60	209-239	SW	30-35	3	16
24	12.468036	75.657083	315	70	225	179-209	SSW	40-45	2	25
25	12.483214	75.634342	320	74	230	239-269	WSW	10-15	3	17
26	12.443467	75.654726	145	74	235	239-269	WSW	20-25	2	26
The slope direction and slope angle showed are CartoDEM derived										

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 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-4.3) 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-4.3: 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

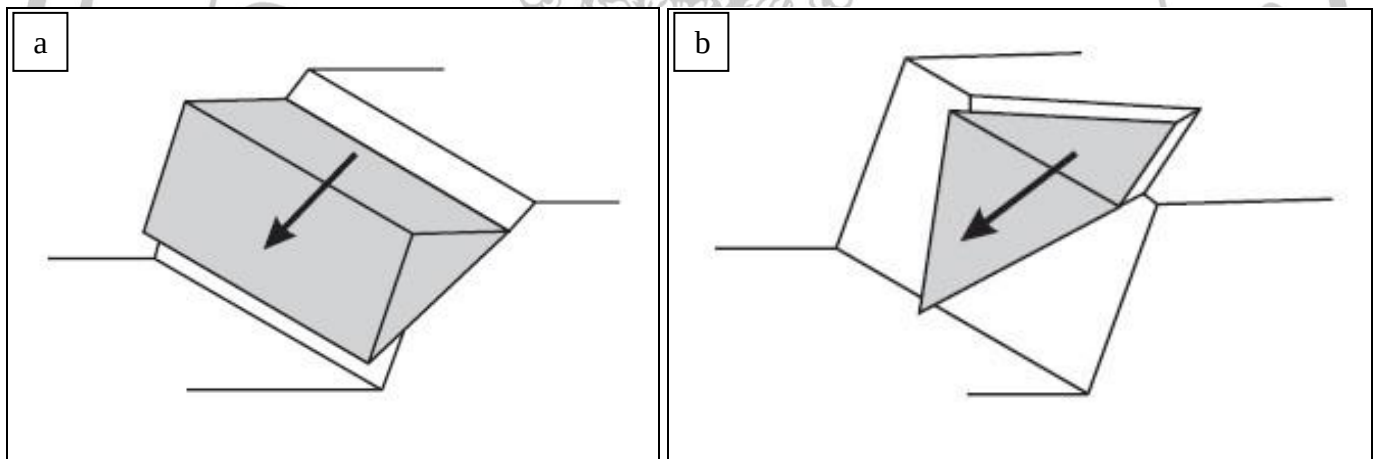


Figure-4.3: Block diagrams for (a) for planar failure; (b) for wedge failure

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”**.

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”**.

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)”**.

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 preparation of 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 worthy to note 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 as shown in table-4.5. Because of this constraint in the present study area, this type of correlation matrix procedure has been utilized in the present study to improve the RMR value and rock quality.

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 the 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-4.4: 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, geotechnical map is prepared using SFM prepared through field work by incorporating RMR values for rocky areas and C and ϕ values for overburden covered slopes. As per the availability, CartoDEM 10m derived topographic contour map is utilized for mapping purposes. The physical properties and the behavior of geological discontinuities of intact rock outcrops were investigated in detail 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 is assessed by the use of Schmidt Hammer and the RQD is assessed in one cubic meters 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 limited resources available at present. The details of RMR value, rock quality at each rock outcrop in the study area, and the corresponding stability assessment condition based on stereonet analysis are shown below;

Table-4.5: Stability assessment of rock outcrops in the study area using kinematic failure and RMR parameters

Stereonet No.	RMR & Rock Quality	Angle of internal friction	Stability Assessment	Remarks
1	60-41;Fair	34-25	Fairly Stable	The J1 joint plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (51°) than the estimated slope (28°) in the direction of the slope within the 20° slope window. There are no signs of planar failure or topple failure.

				Joint planes J1 and J2 are forming a wedge with a plunge of 50°. It is trending within the 40° slope window and has a plunge greater than the angle of internal friction that favors wedge failure but the slope angle is less than plunge which does not favor wedge failure. If the slope angle increased to 57°, the same wedge would fail and the slope would also become daylight to planar failure.
2	60-41;Fair	34-25	Unstable	The foliation plane is striking sub-parallel to the strike of the slope and dipping at a lower angle (33°) than the estimated slope (35°) in the direction of the slope within 20° slope window. This plane is daylighted on the slope face and at the minimum estimated angle of internal friction (25°) the planar failure may occur. Joint plane J2 and foliation plane are forming a wedge with a plunge of 30°. It is trending within the 15° slope window and has a plunge greater than the angle of internal friction and less than the slope angle that makes a critical condition of wedge failure. Joint planes J1 and J2 are forming another wedge with a plunge of 64°. It is trending within 50° slope window and has a plunge greater than the angle of internal friction that favors wedge failure but the slope angle is less than plunge which does not favor wedge failure. If the slope angle increased to 73°, the same wedge would fail.
3	60-41;Fair	34-25	Unstable	The J1 joint plane is striking almost parallel to the strike of the slope and dipping at a higher angle (84°) than the estimated slope (38°) in the direction of the slope within the 10° slope window. There are no signs of planar failure but there is a critical condition of toppling failure or flexural slip which may occur.
4	60-41;Fair	34-25	Fairly Stable	None of the plane daylights on the slope face. However, Joint planes J2 and J4 are forming a wedge with a plunge of 9°. It is trending within 25° slope window and its plunge is less than the dip amount of slope that favors wedge failure. The angle of internal friction is higher than the plunge at present but if the angle of internal friction decreases to 9° due to external forces particularly water, the chances of wedge failure may increase.
5	60-41;Fair	34-25	Unstable	The J2 joint plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (81°) than the estimated

				slope (38°) in the direction of the slope within the 20° slope window. There are no signs of planar failure but there is a critical condition of toppling failure or flexural slip which may occur.
6	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
7	60-41;Fair	34-25	Unstable	The foliation plane is striking parallel to the strike of the slope and dipping at a higher angle (85°) than the estimated slope (30°) in the direction of the slope within the 10° slope window. There are no signs of planar failure but there is a critical condition of toppling failure or flexural slip which may occur.
8	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
9	40-21;Poor	24-15	Unstable	The J2 joint plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (88°) than the estimated slope (33°) in the direction of the slope within the 20° slope window. There are no signs of planar failure but there is a critical condition of toppling failure or flexural slip which may occur. Joint plane J1 and foliation plane are forming a wedge with a plunge of 18°. It is trending within 25° slope window and there is a critical condition of wedge failure which may occur.
10	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
11	60-41;Fair	34-25	Fairly Stable	There are no signs of planar failure or topple failure. Joint planes J1 and J3 are forming a wedge with a plunge of 34°. It is trending within the 10° slope window and has a plunge greater than the angle of internal friction that favors wedge failure but the slope angle is less than plunge which does not favor wedge failure. If the slope angle increased to 35°, the same wedge would fail.
12	60-41;Fair	34-25	Fairly Stable	There are no signs of planar failure or topple failure. Joint plane J2 and foliation plane are forming a wedge with a plunge of 62°. It is trending within the 10° slope window and has a plunge greater than the angle of internal friction that favors wedge failure but the slope angle is less than plunge which does not favor wedge failure. If the slope angle increased to 63°, the same wedge would fail.

13	60-41;Fair	34-25	Fairly Stable	The J4 joint plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (70°) than slope (18°) in the opposite direction of slope within 20° slope window. There are least chances of toppling but if the slope angle increases, the chances of toppling may increase. Joint plane J1 and foliation plane is forming a wedge with a plunge of 12°. It is trending within the 25° slope window and its plunge and the dip amount of slope are having the least difference that favors wedge failure. The angle of internal friction is higher than the plunge at present but if the angle of internal friction decreases to 11° due to external forces particularly water, the chances of wedge failure may increase.
14	60-41;Fair	34-25	Fairly Stable	The J1 joint plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (83°) than slope (23°) in the direction of slope within 15° slope window. The foliation plane is striking parallel to the strike of the slope and dipping at a higher angle (80°) than slope (23°) in the opposite direction of slope within 5° slope window. There are no signs of planar failure but topple failure may occur if the angle of internal friction decreases to 13°. Joint planes J1 and J4 are forming a wedge with a plunge of 83°. It is trending within the 15° slope window and has a plunge greater than the estimated angle of internal friction that favors wedge failure but the slope angle is less than plunge which does not favor wedge failure.
15	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
16	60-41;Fair	34-25	Fairly Stable	The foliation plane is striking parallel to the strike of the slope and dipping at a higher angle (48°) than the estimated slope (33°) in the opposite direction of the slope within the 12° slope window. There are no signs of planar failure and topple failure or flexural slip to occur. However, Joint planes J2 and J4 are forming a wedge with a plunge of 14°. It is trending within 20° slope window and its plunge is less than the dip amount of slope that favors wedge failure. The angle of internal friction is higher than the plunge at present but if the angle of internal friction decreases to 13° due to external forces particularly water, the chances of wedge failure may increase.
17	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any

				failure mode.
18	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
19	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
20	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
21	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
22	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
23	60-41;Fair	34-25	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
24	60-41;Fair	34-25	Fairly Stable	The foliation plane is striking parallel to the strike of the slope and dipping at a higher angle (56°) than the estimated slope (33°) in the same direction of the slope. There are no signs of planar failure but topple failure may occur if the slope increases to 60° or the angle of internal friction decrease to the lowest minimum.
25	40-21;Poor	24-15	Unstable	The foliation plane is striking sub-parallel to the strike of the slope and dipping at a higher angle (70°) than the estimated slope (45°) in the direction of slope within 30° slope window. There are no signs of planar failure but there is a critical condition of toppling failure or flexural slip which may occur. Joint plane J2 and foliation plane are forming a wedge with a plunge of 35°. It is trending within 35° slope window and there is a critical condition of wedge failure which may occur.
26	80-61;Good	45-35	Stable	None of the plane daylights on the slope face. No signs of any failure mode.
Note: The slope angle which is mentioned in the table is estimated from CartoDEM 10m and the angle of internal friction is taken as proxy from RMR.				

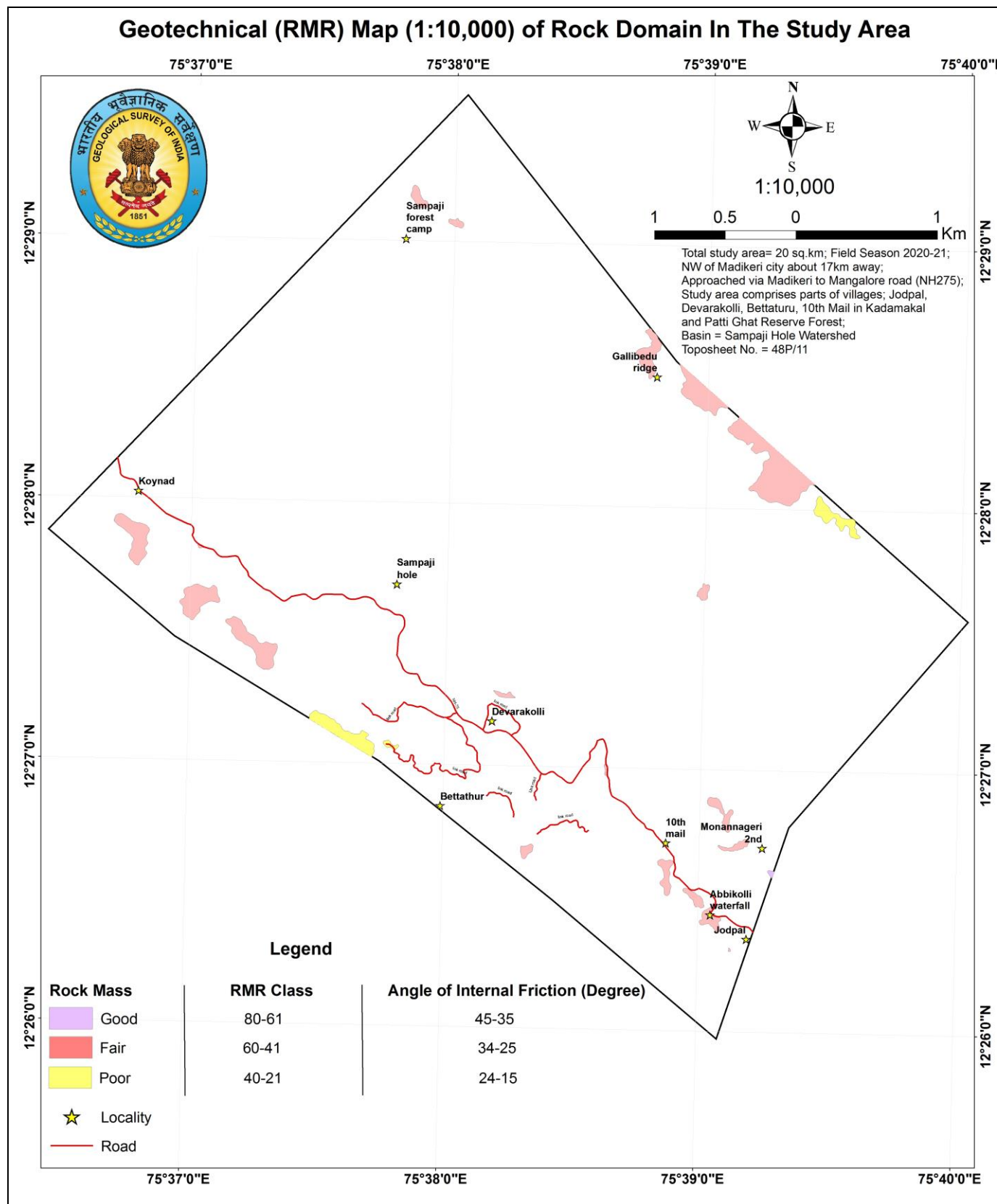
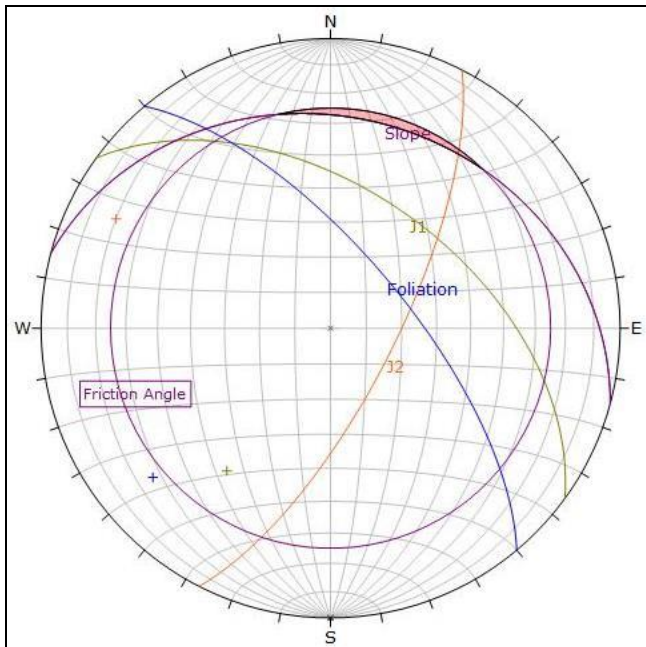
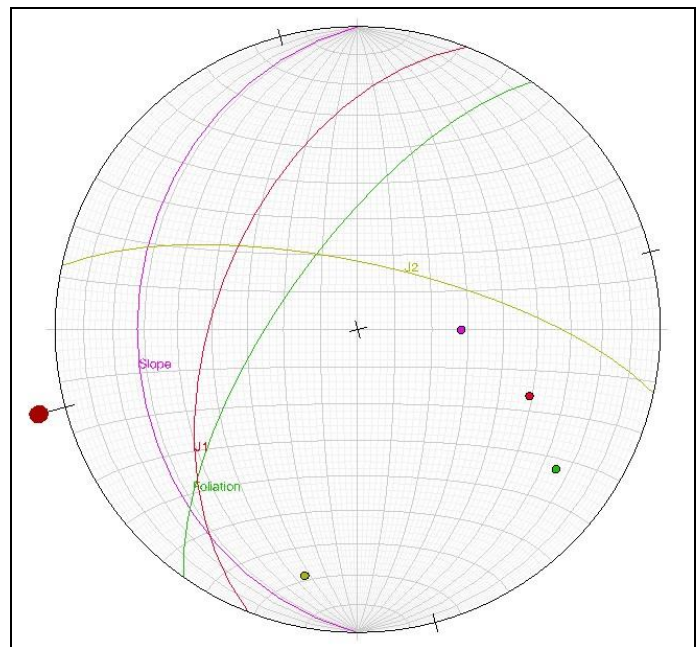


Figure-4.4: Geotechnical map of rock outcrops in the study area prepared on the basis of RMR

Stereonet No. 1: $75^{\circ}39' 2.297''$ E / $12^{\circ}26' 26.731''$ N

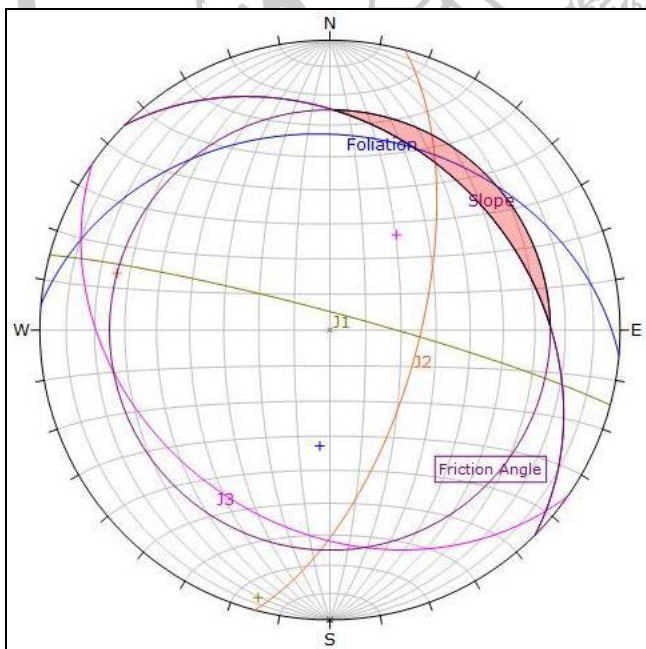


Normal view

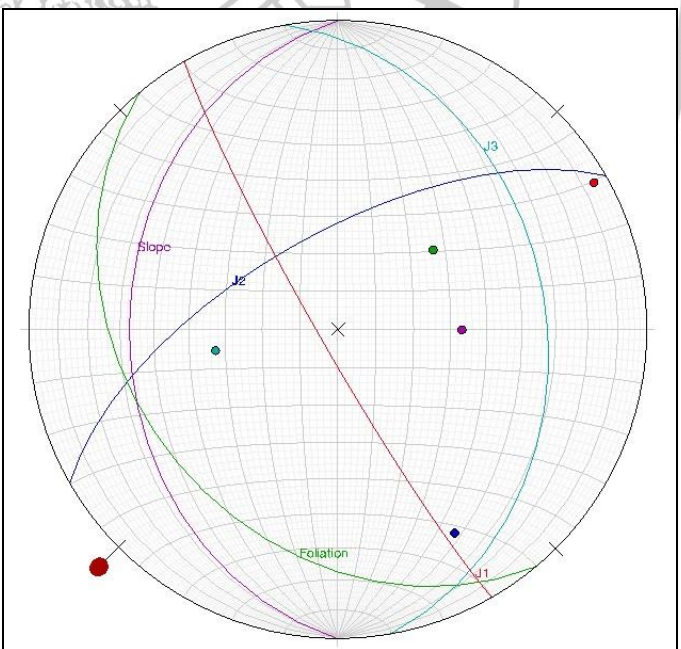


Slope window or slope oriented view

Stereonet No. 2: $75^{\circ}38' 59.089''$ E / $12^{\circ}26' 30.511''$ N

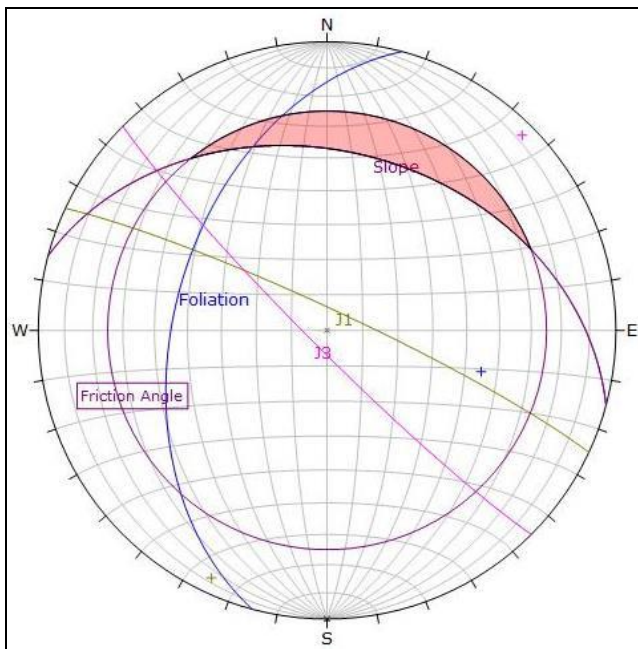


Normal view

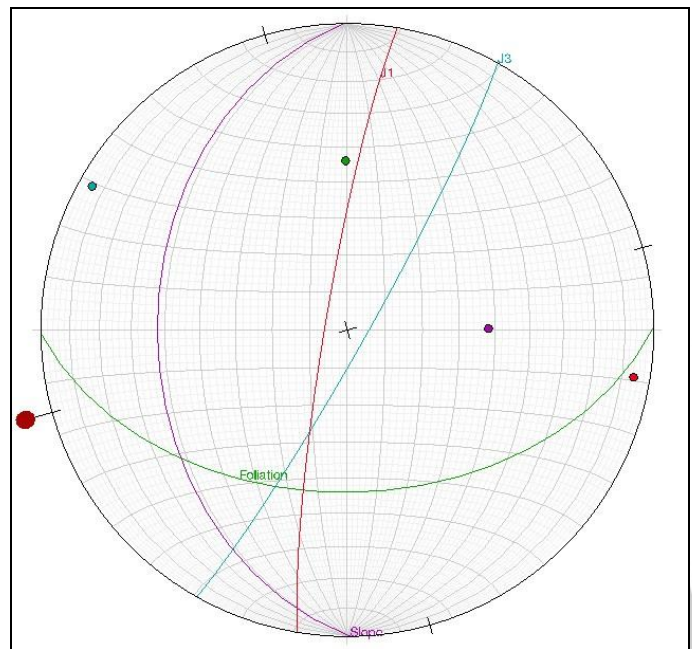


Slope window or slope oriented view

Stereonet No. 3: $75^{\circ}38' 52.305''$ E / $12^{\circ}26' 35.405''$ N

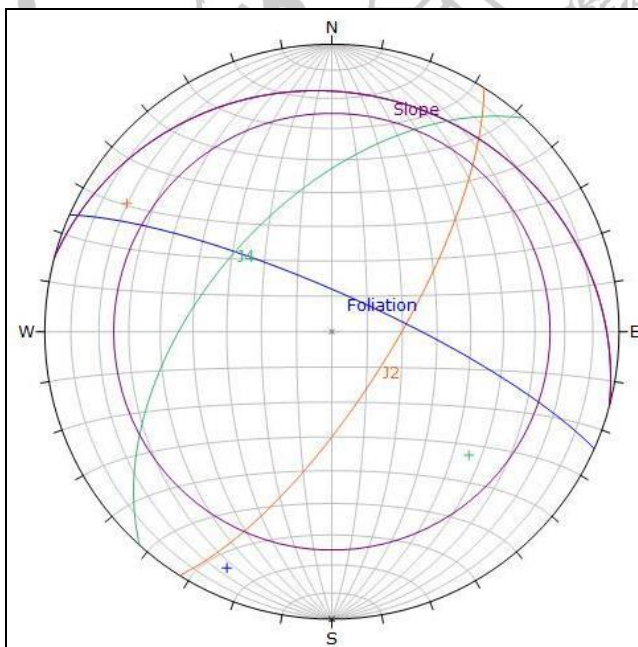


Normal view

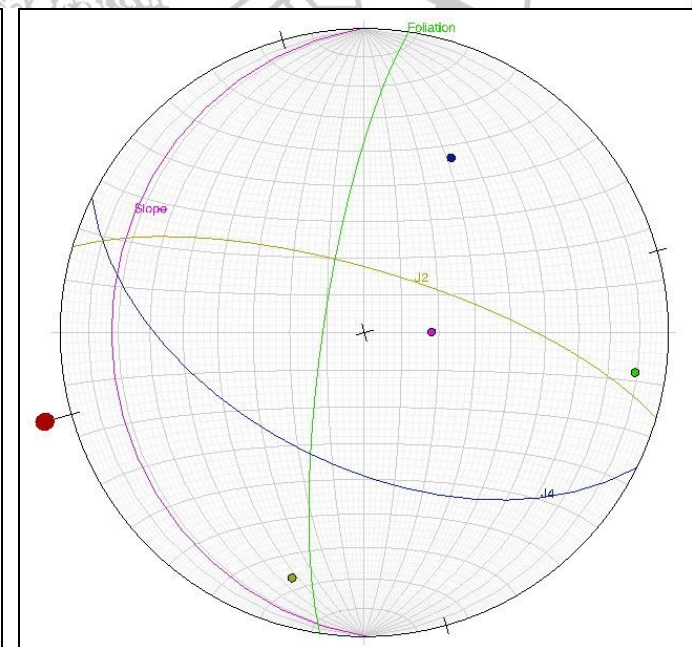


Slope window or slope oriented view

Stereonet No. 4: $75^{\circ}38' 19.749''$ E / $12^{\circ}26' 40.558''$ N

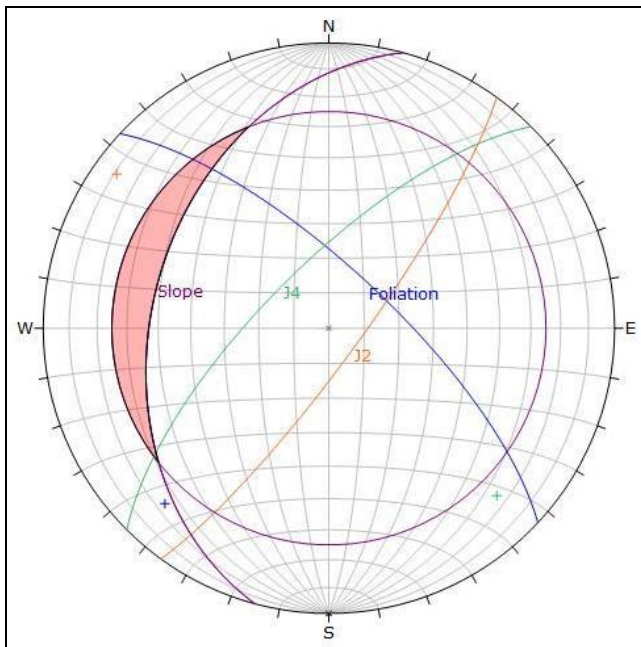


Normal view

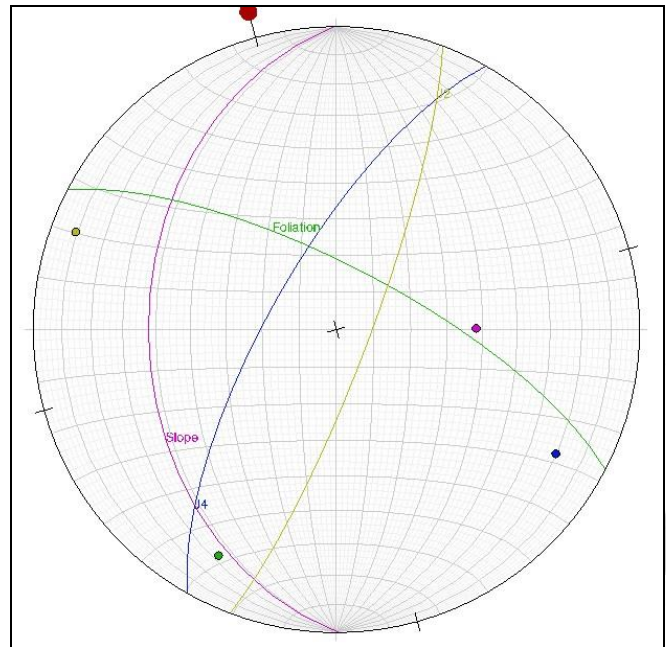


Slope window or slope oriented view

Stereonet No. 5: $75^{\circ}39' 7.148''$ E / $12^{\circ}26' 42.158''$ N

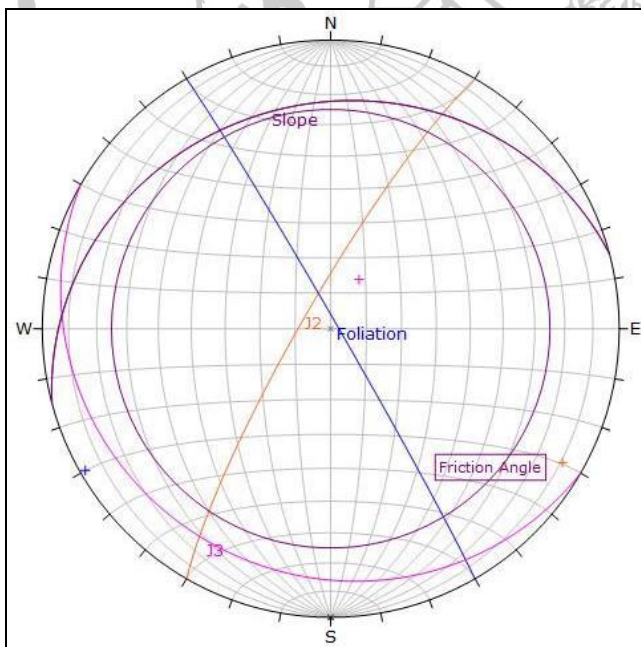


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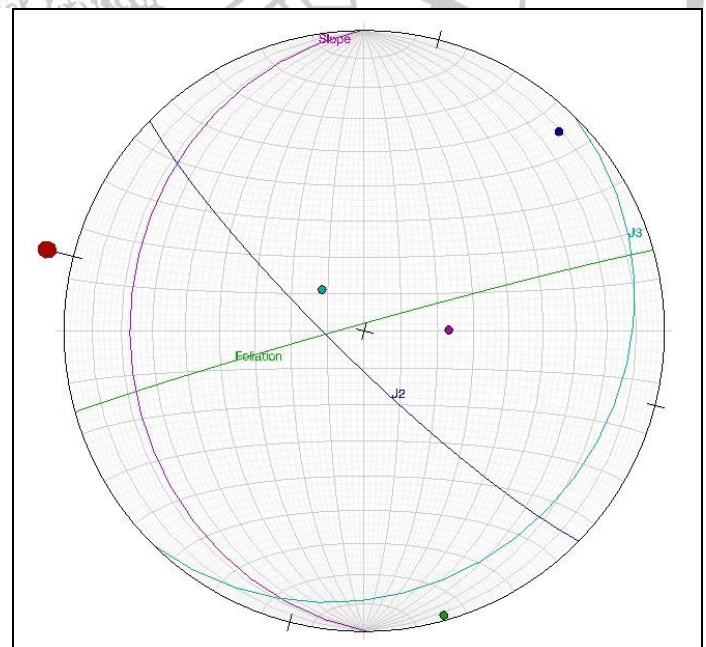


Slope window or slope oriented view

Stereonet No. 6: $75^{\circ}39' 10.122''$ E / $12^{\circ}26' 43.133''$ N

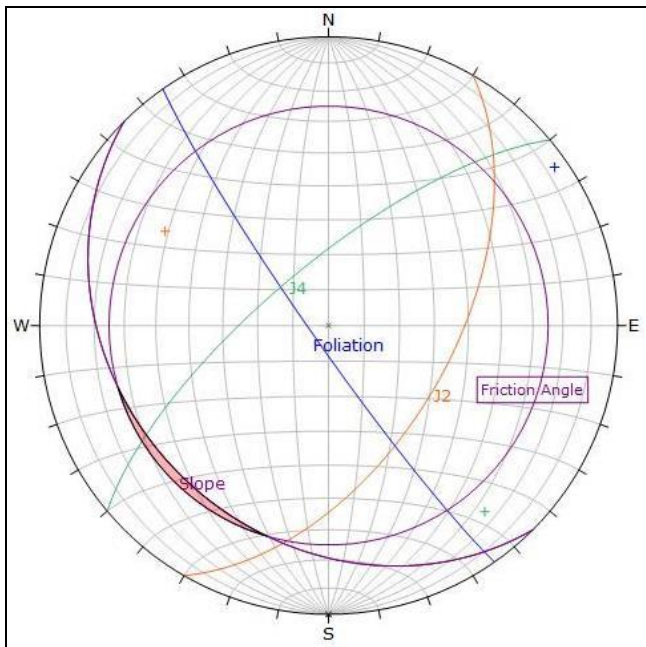


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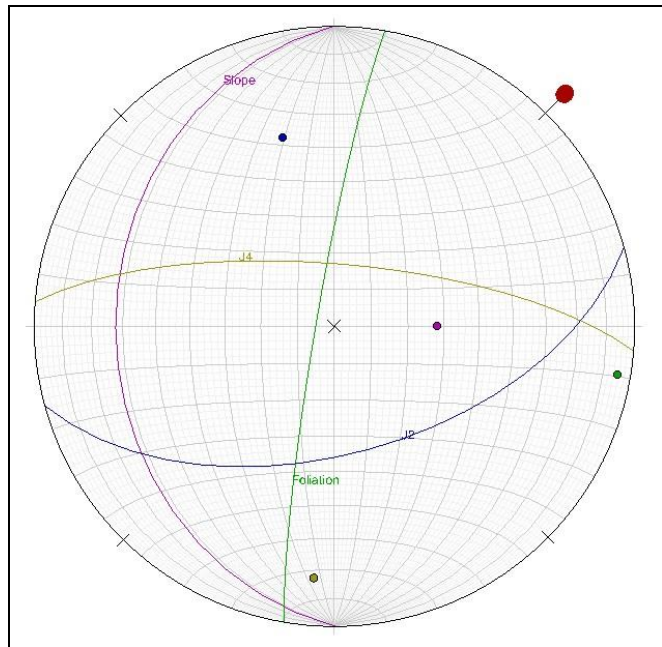


Slope window or slope oriented view

Stereonet No. 7: $75^{\circ}39' 4.935''$ E / $12^{\circ}26' 49.986''$ N

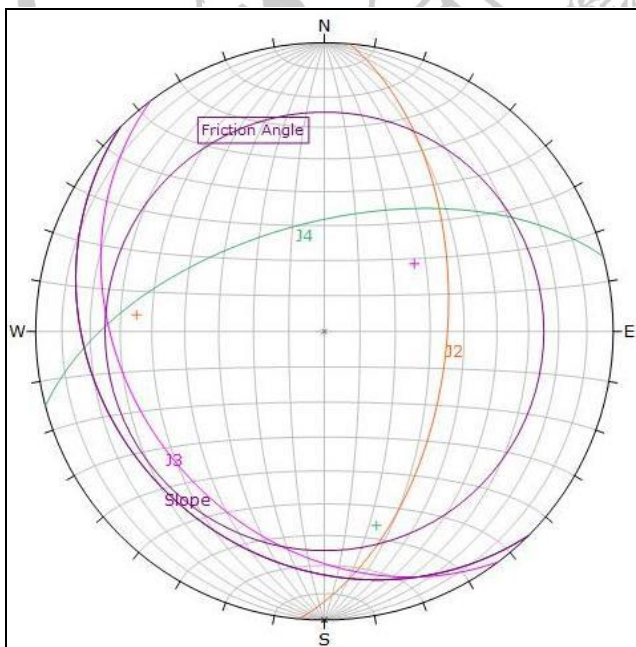


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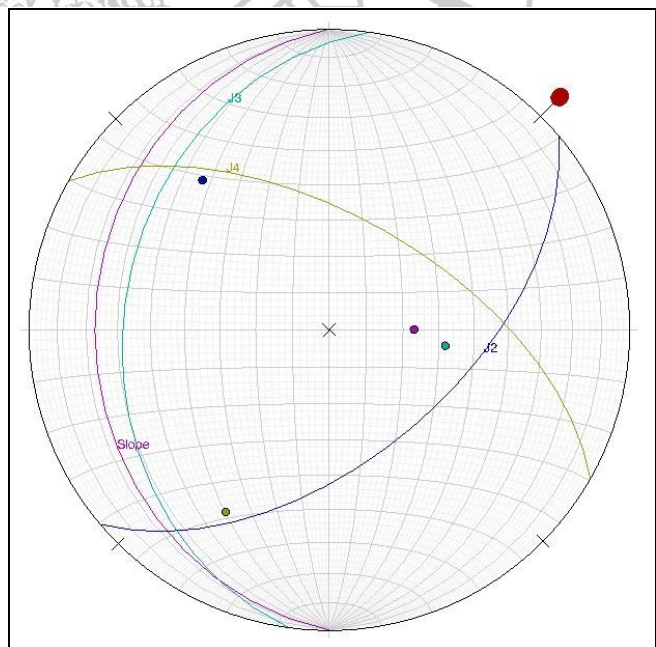


Slope window or slope oriented view

Stereonet No. 8: $75^{\circ}38' 37.897''$ E / $12^{\circ}26' 59.508''$ N

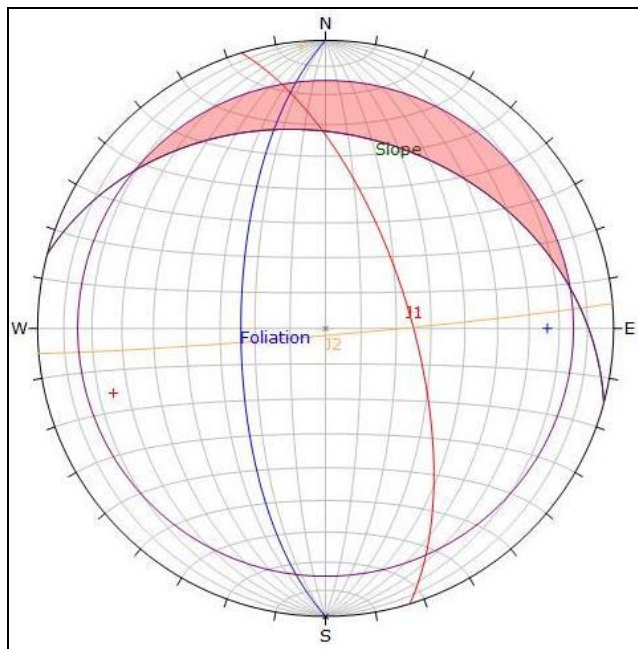


Normal view

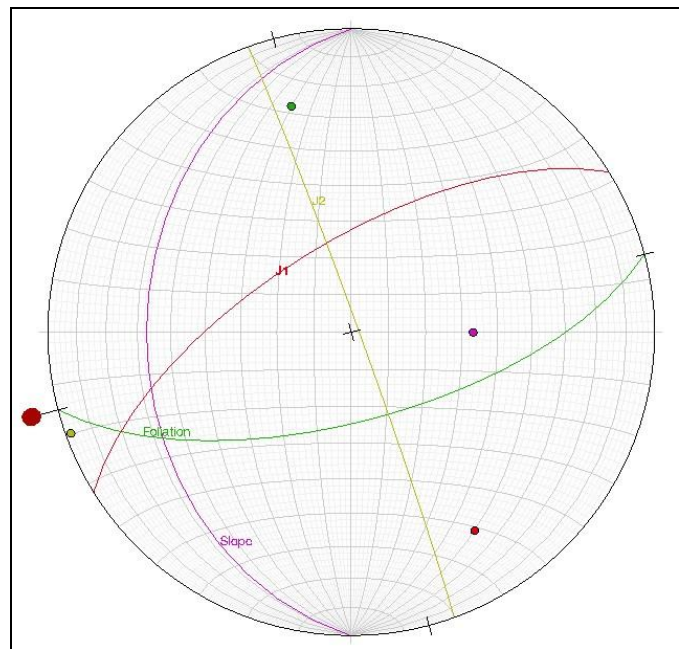


Slope window or slope oriented view

Stereonet No. 9: $75^{\circ}37' 38.203''$ E / $12^{\circ}27' 6.547''$ N

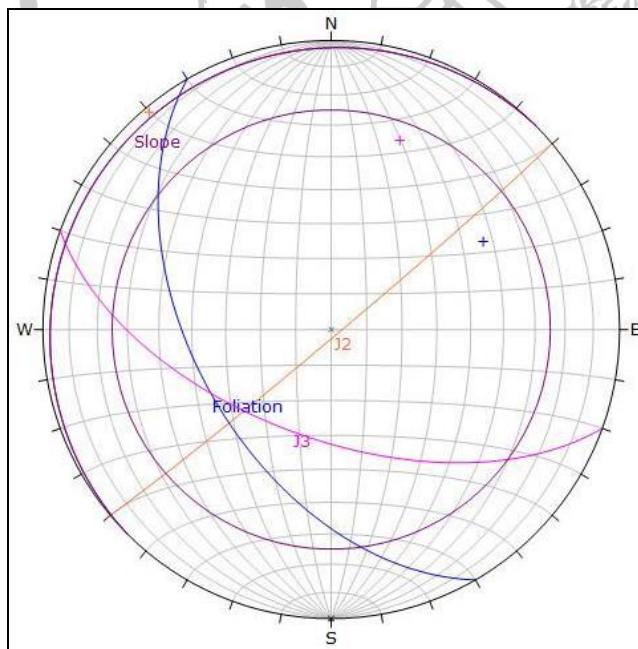


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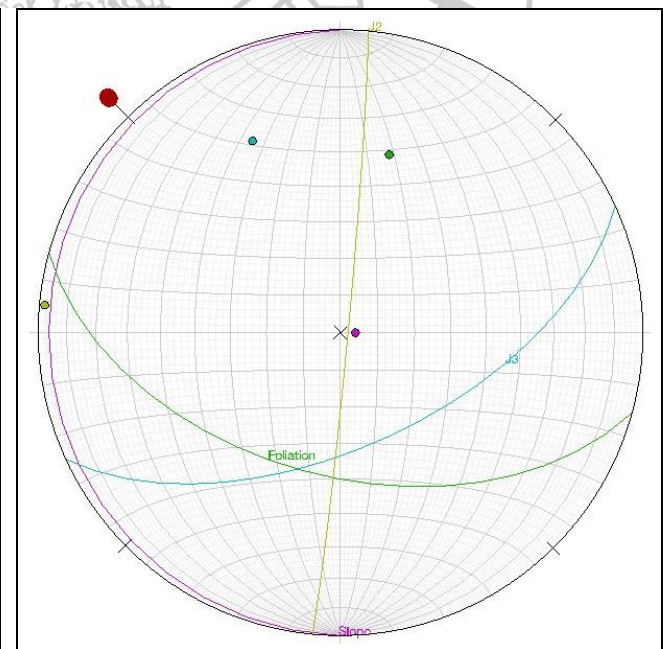


Slope window or slope oriented view

Stereonet No. 10: $75^{\circ}38' 13.899''$ E / $12^{\circ}27' 16.338''$ N

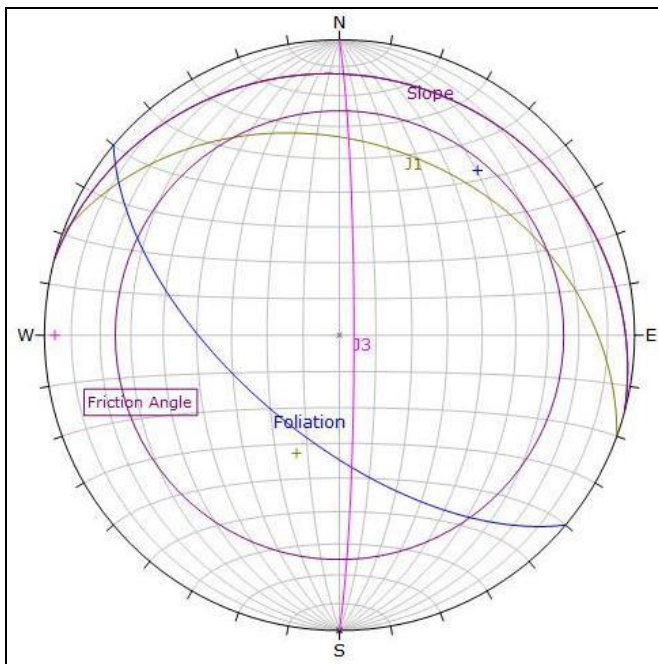


Normal view

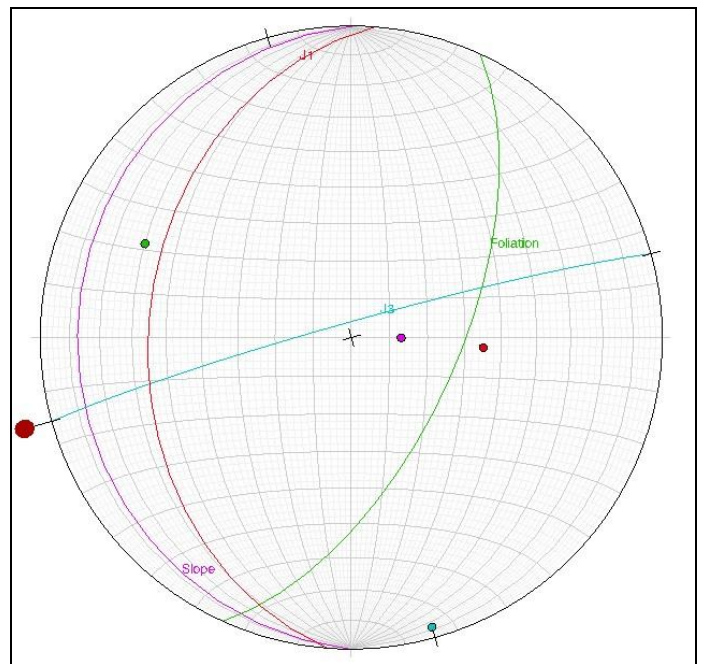


Slope window or slope oriented view

Stereonet No. 11: $75^{\circ}37' 0.017''$ E / $12^{\circ}27' 35.752''$ N

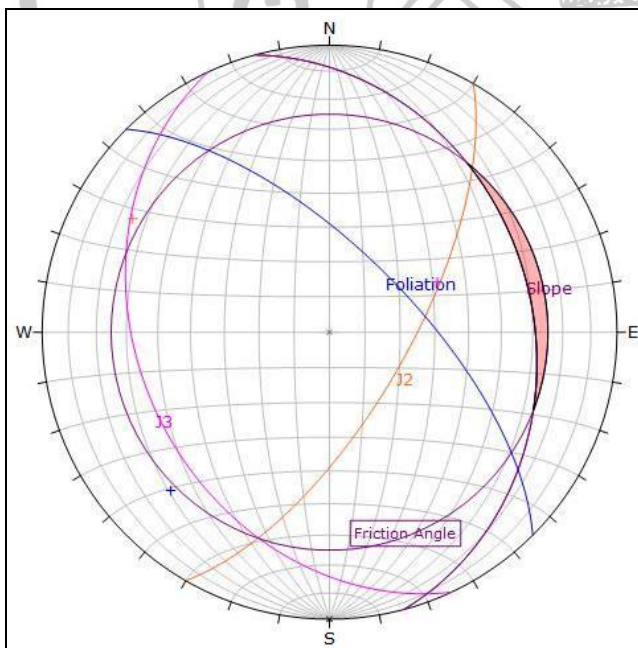


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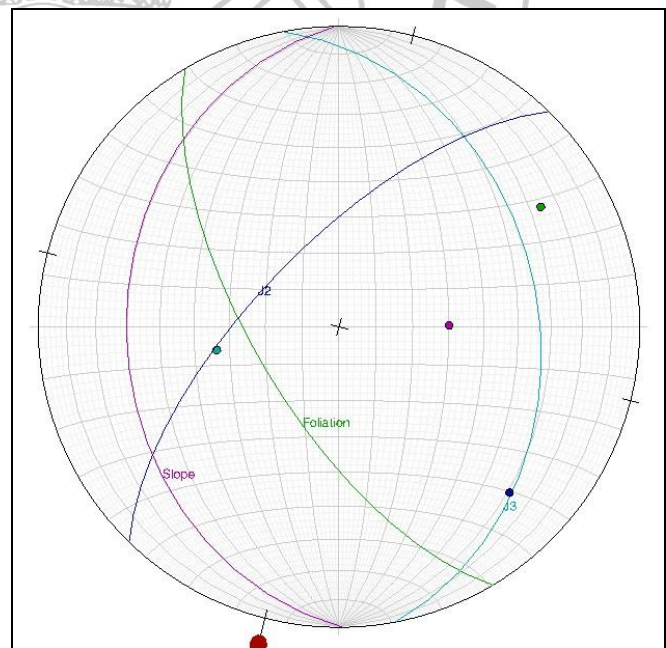


Slope window or slope oriented view

Stereonet No. 12: $75^{\circ}37' 3.588''$ E / $12^{\circ}27' 37.542''$ N

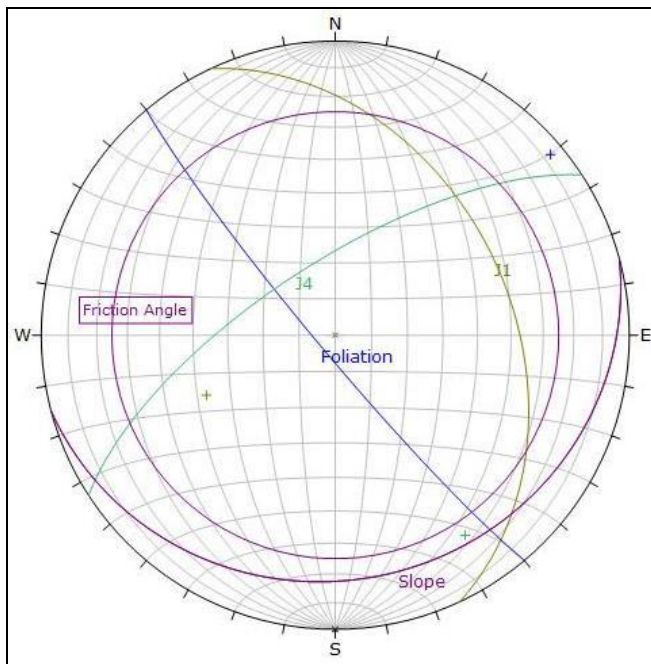


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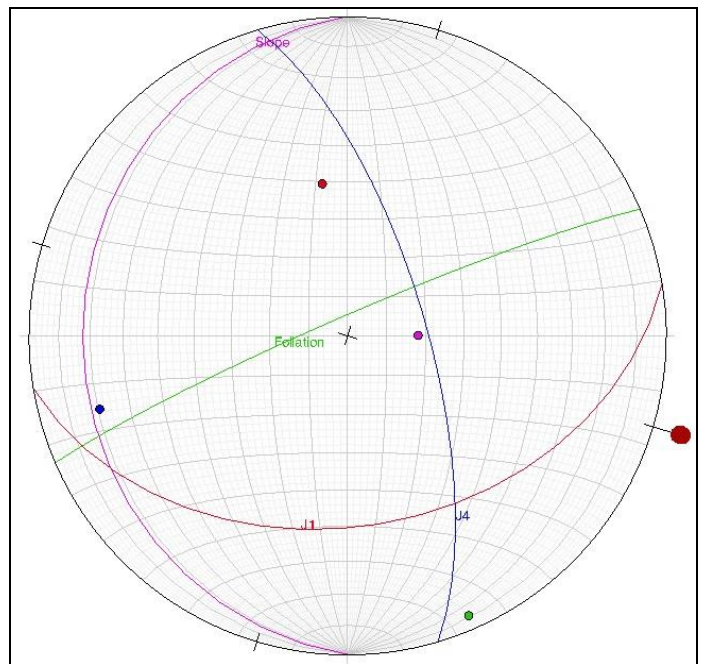


Slope window or slope oriented view

Stereonet No. 13: $75^{\circ}38' 59.845''$ E / $12^{\circ}27' 40.718''$ N

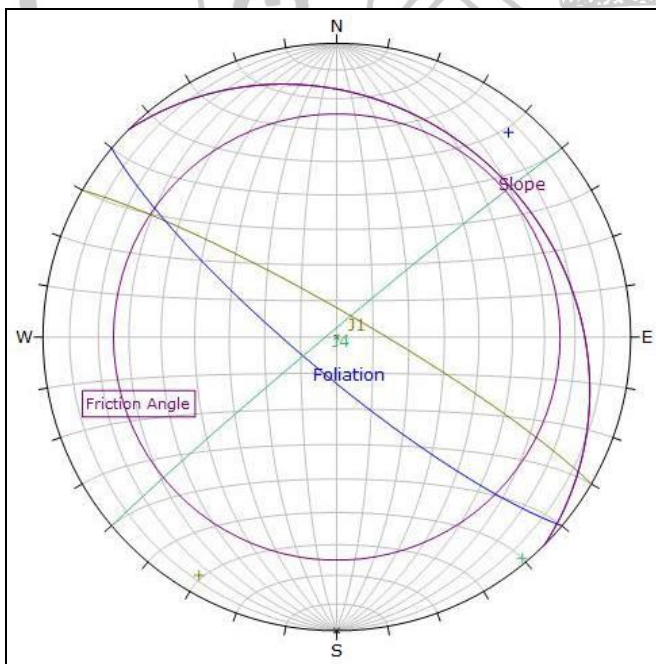


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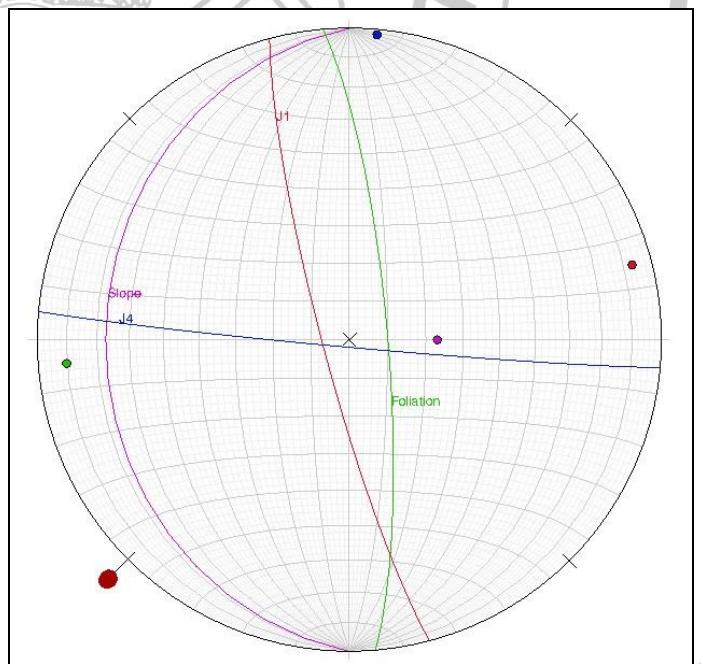


Slope window or slope oriented view

Stereonet No. 14: $75^{\circ}36' 47.610''$ E / $12^{\circ}27' 46.633''$ N

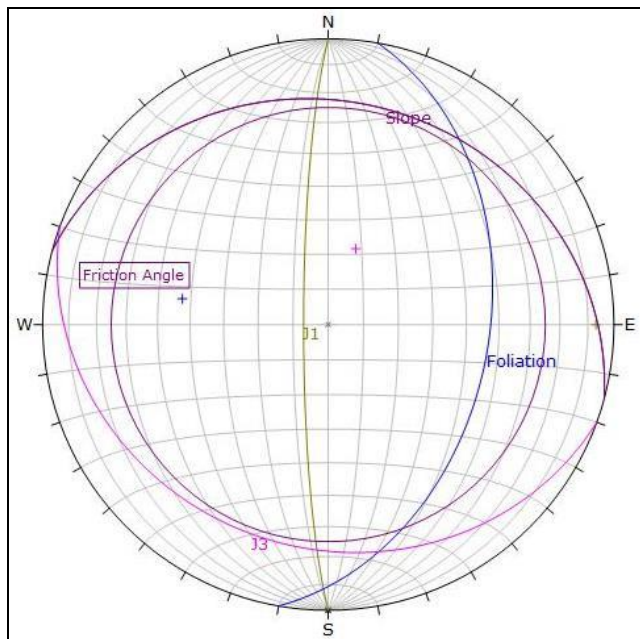


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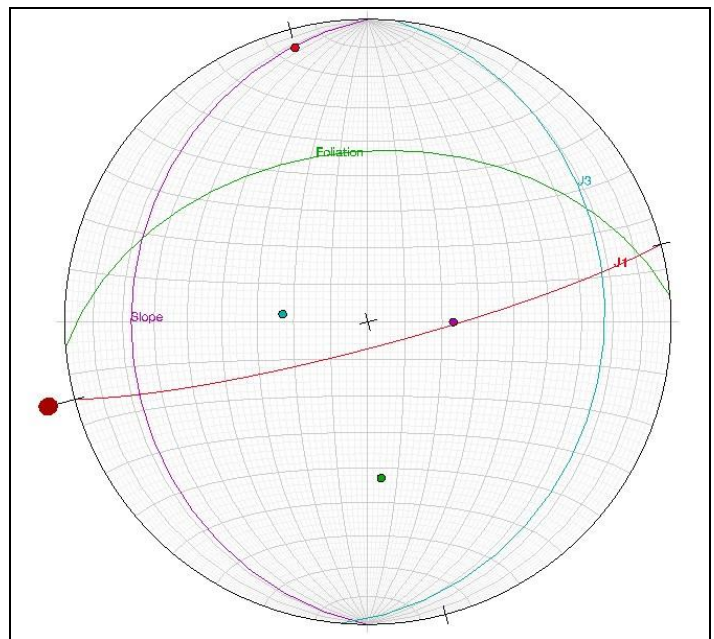


Slope window or slope oriented view

Stereonet No. 15: $75^{\circ}37' 2.339''$ E / $12^{\circ}27' 48.884''$ N

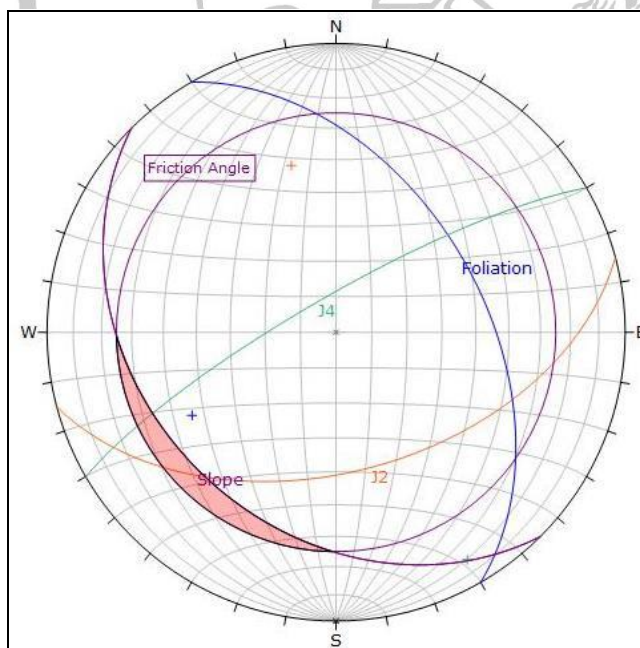


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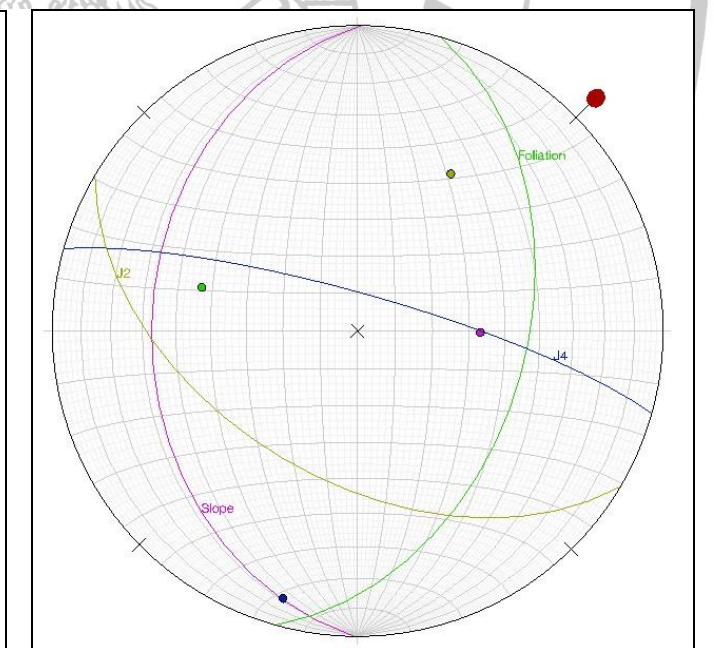


Slope window or slope oriented view

Stereonet No. 16: $75^{\circ}39' 17.575''$ E / $12^{\circ}28' 6.855''$ N

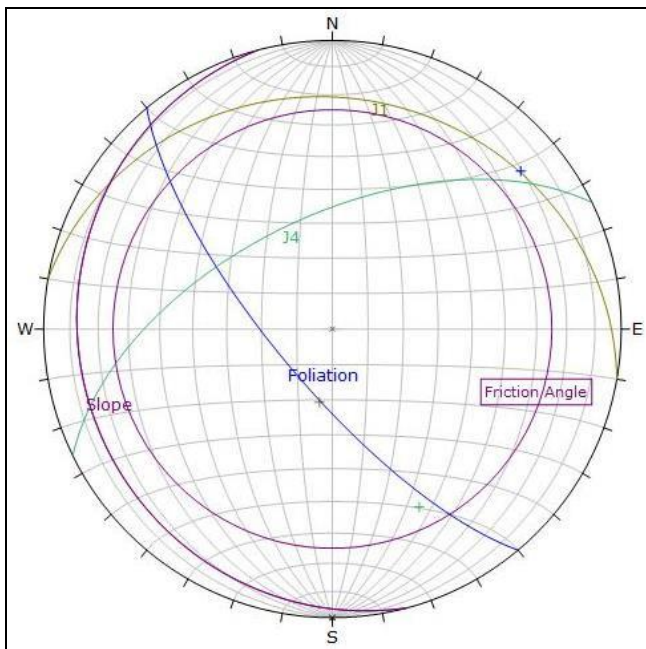


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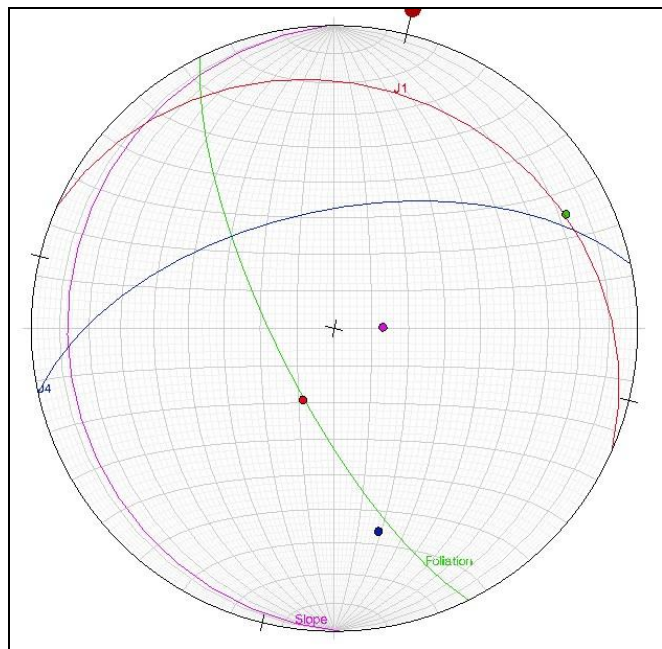


Slope window or slope oriented view

Stereonet No. 17: $75^{\circ}37' 55.135''$ E / $12^{\circ}29' 7.981''$ N

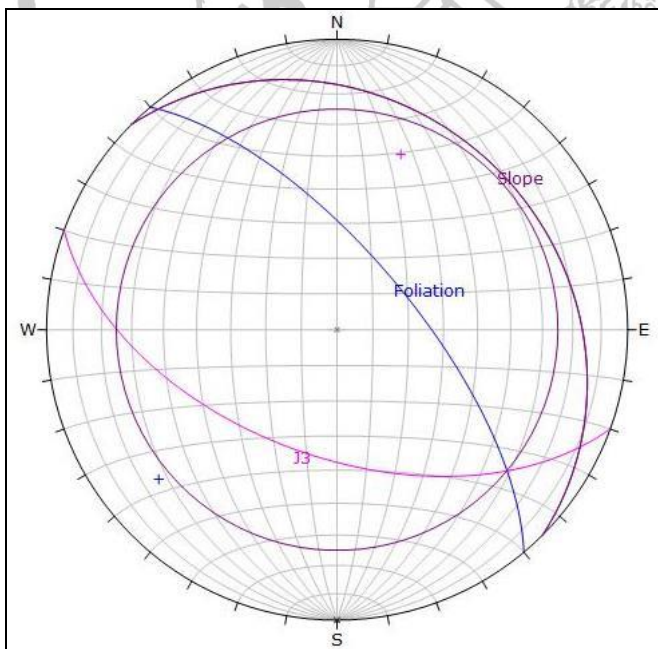


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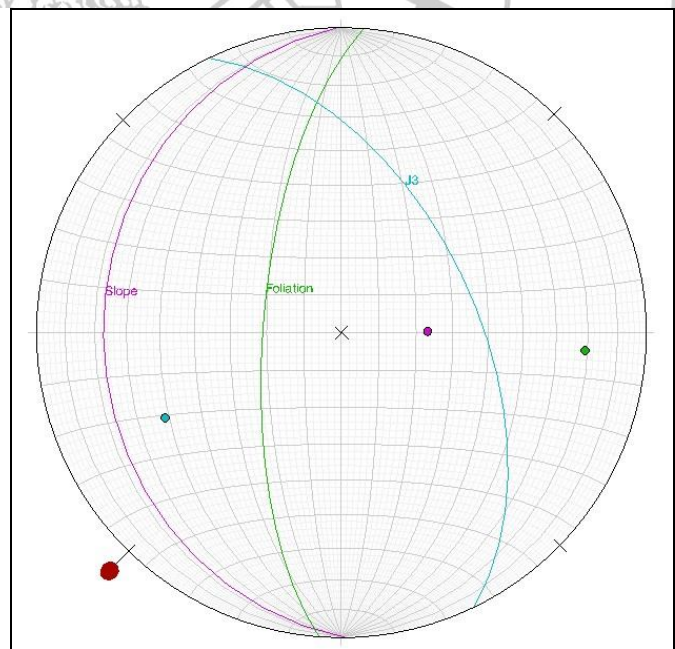


Slope window or slope oriented view

Stereonet No. 18: $75^{\circ}39' 7.569''$ E / $12^{\circ}26' 18.802''$ N

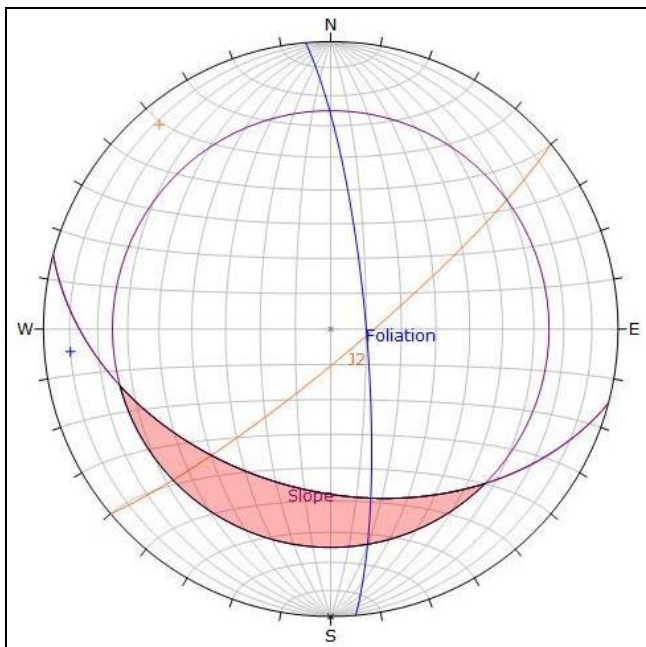


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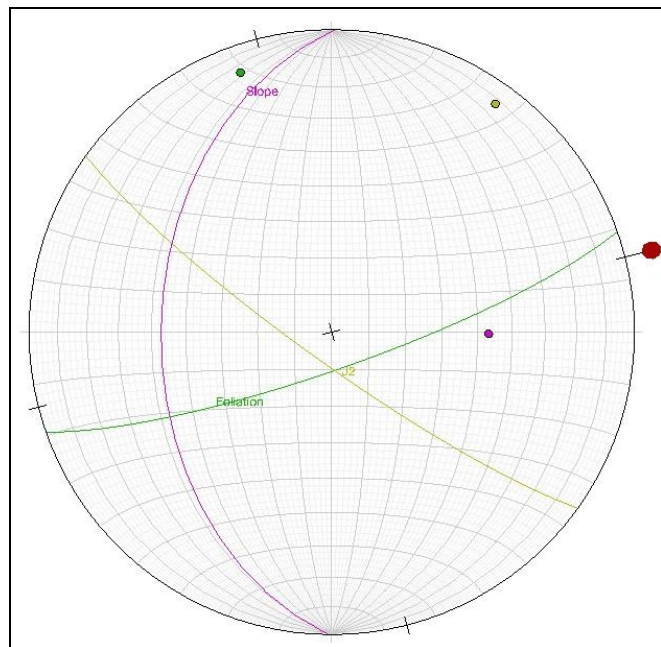


Slope window or slope oriented view

Stereonet No. 19: $75^{\circ}38' 46.067''$ E / $12^{\circ}28' 35.145''$ N

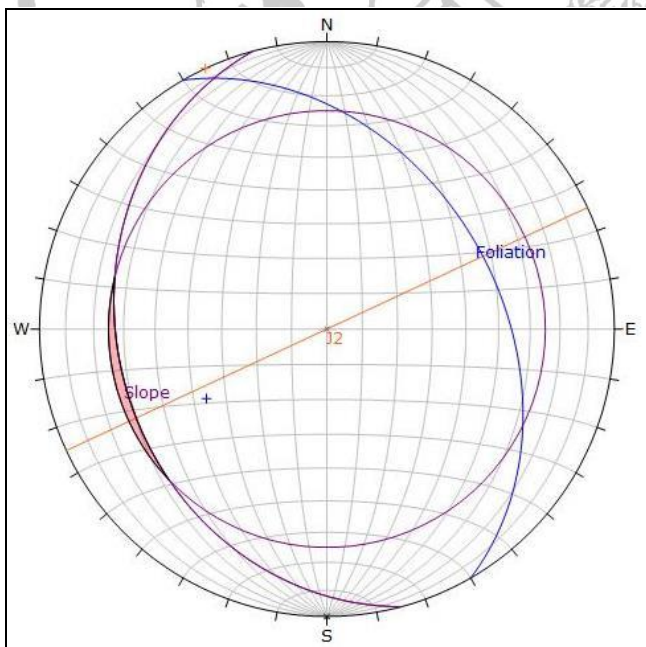


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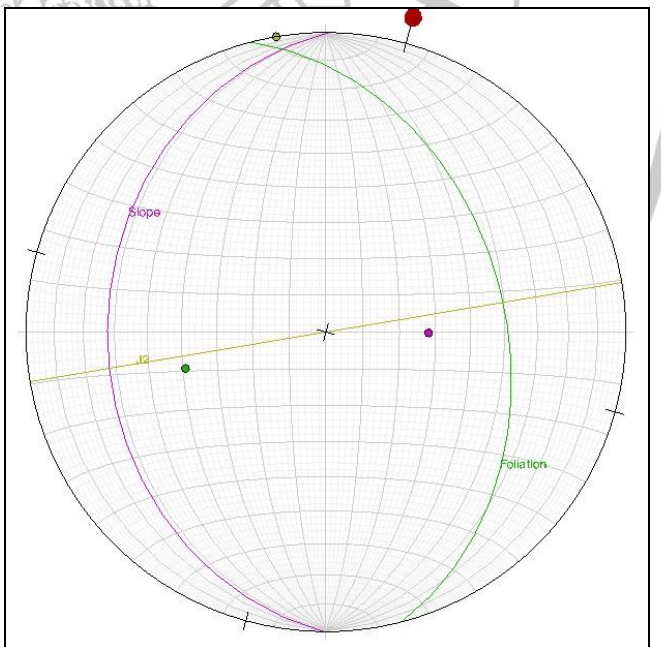


Slope window or slope oriented view

Stereonet No. 20: $75^{\circ}38' 58.604''$ E / $12^{\circ}28' 26.722''$ N

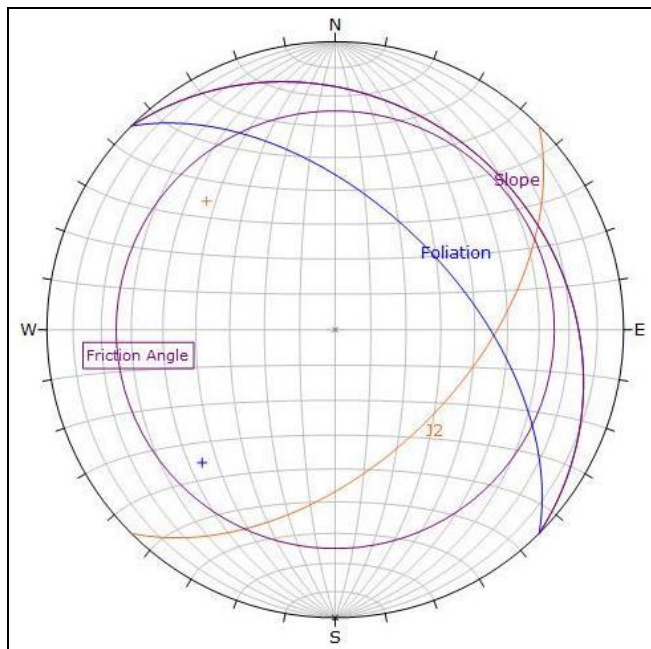


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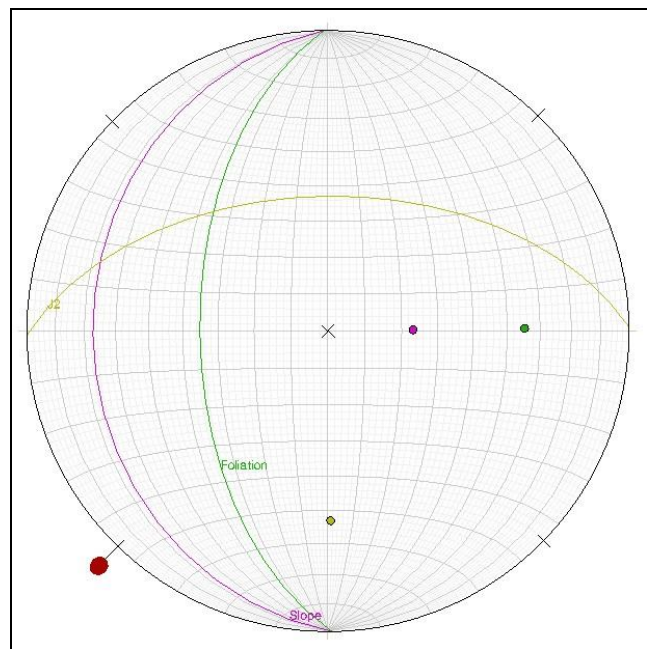


Slope window or slope oriented view

Stereonet No. 21: $75^{\circ}37' 12.343''$ E / $12^{\circ}27' 29.430''$ N

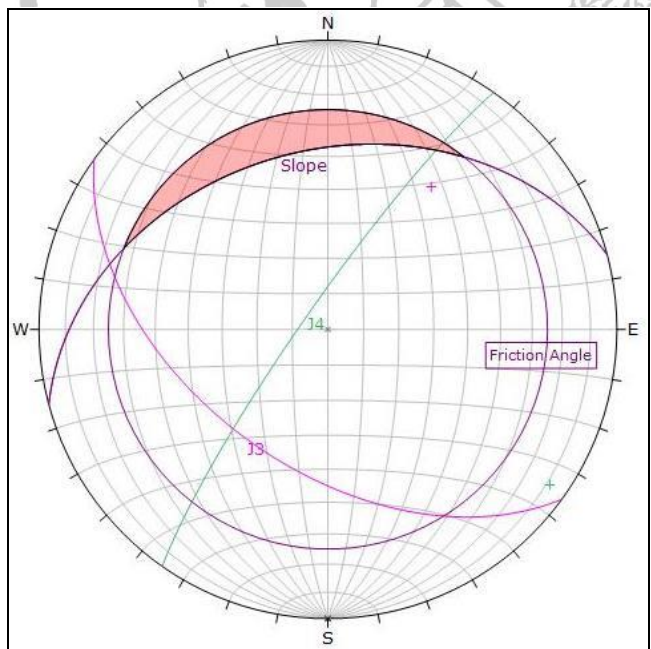


Normal view

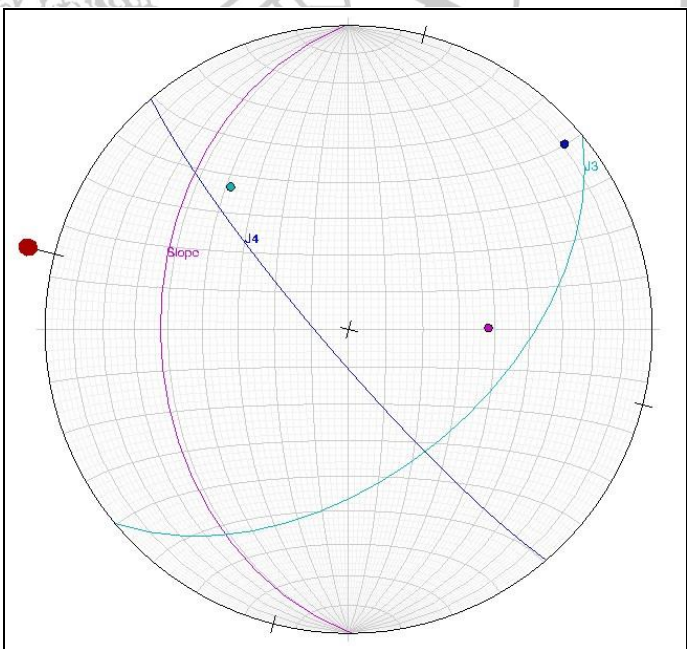


Slope window or slope oriented view

Stereonet No. 22: $75^{\circ}39' 4.115''$ E / $12^{\circ}26' 24.587''$ N

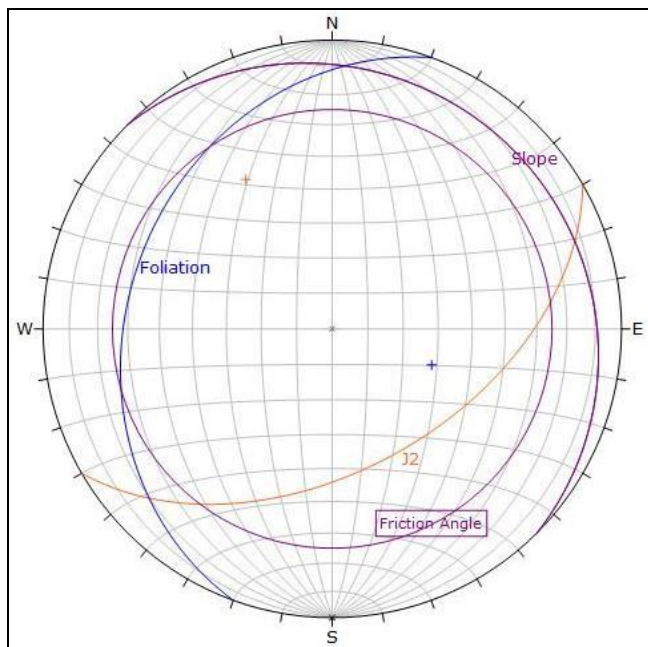


Normal view

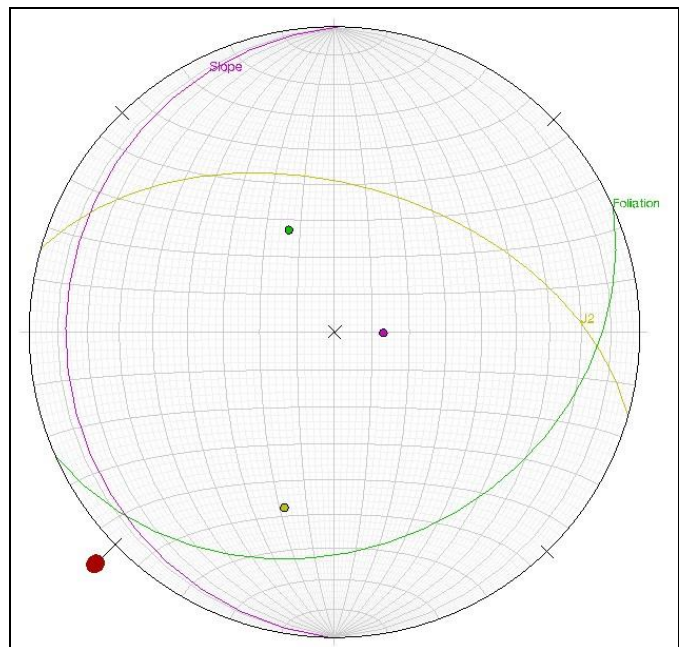


Slope window or slope oriented view

Stereonet No. 23: $75^{\circ}37' 17.783''$ E / $12^{\circ}27' 24.230''$ N

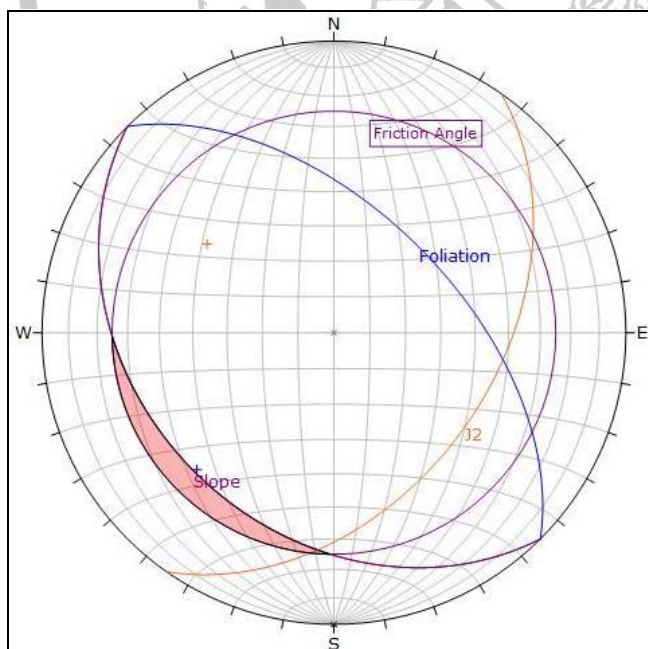


Normal view

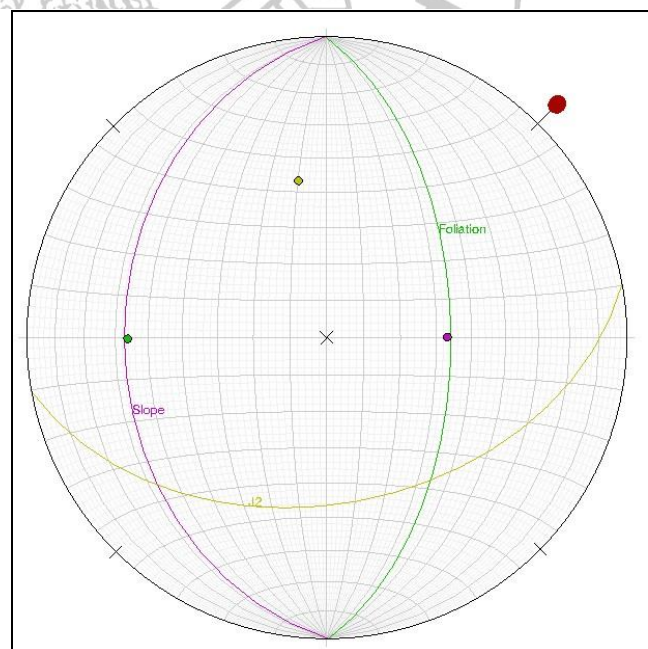


Slope window or slope oriented view

Stereonet No. 24: $75^{\circ}39' 10.336''$ E / $12^{\circ}28' 16.717''$ N

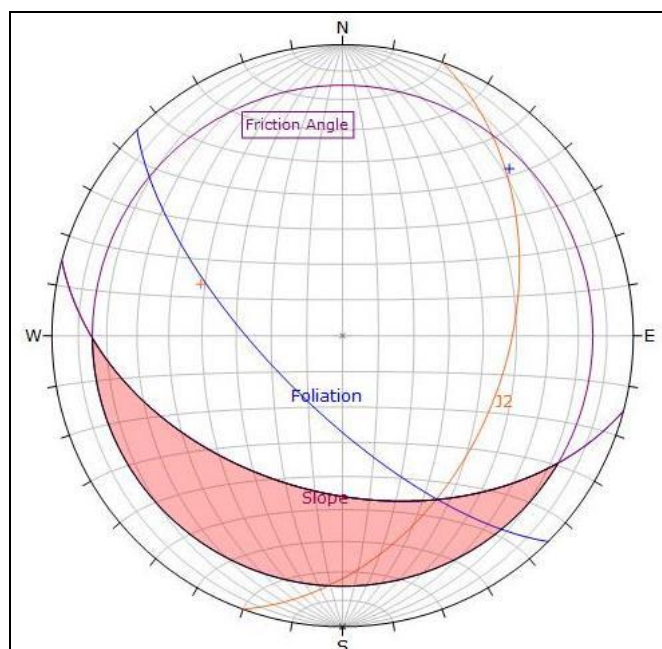


Normal view

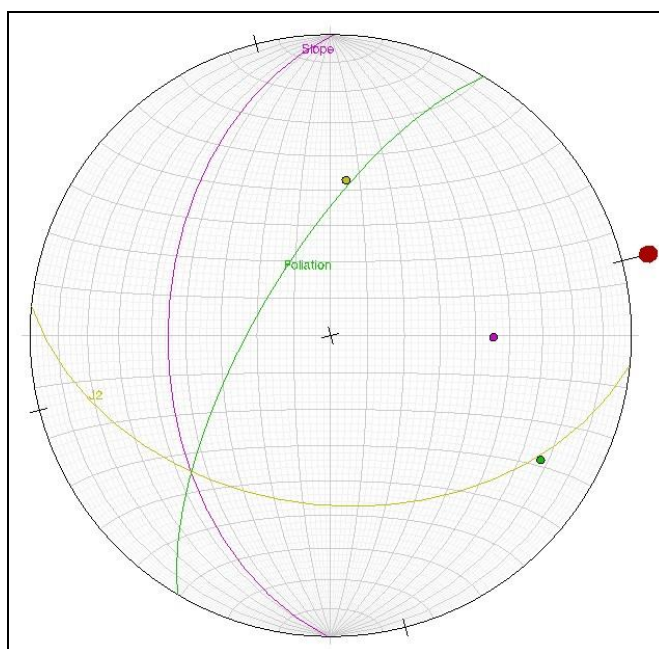


Slope window or slope oriented view

Stereonet No. 25: $75^{\circ}39' 30.401''$ E / $12^{\circ}27' 58.392''$ N

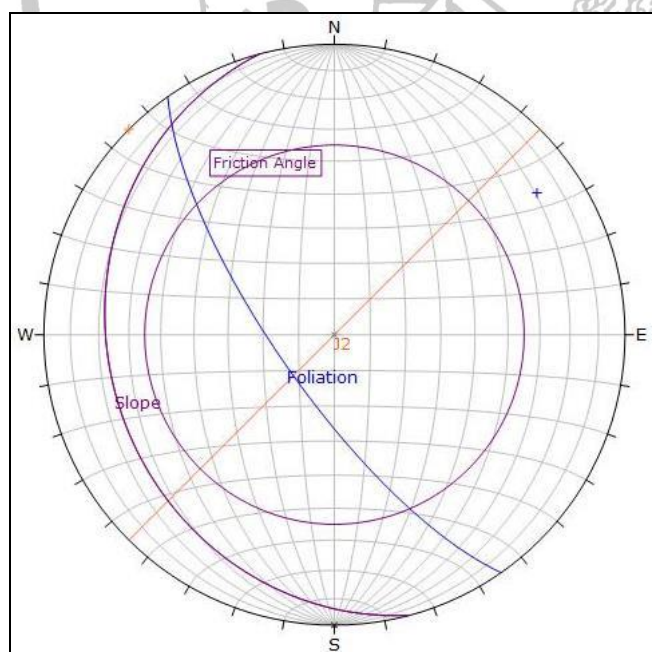


Normal view

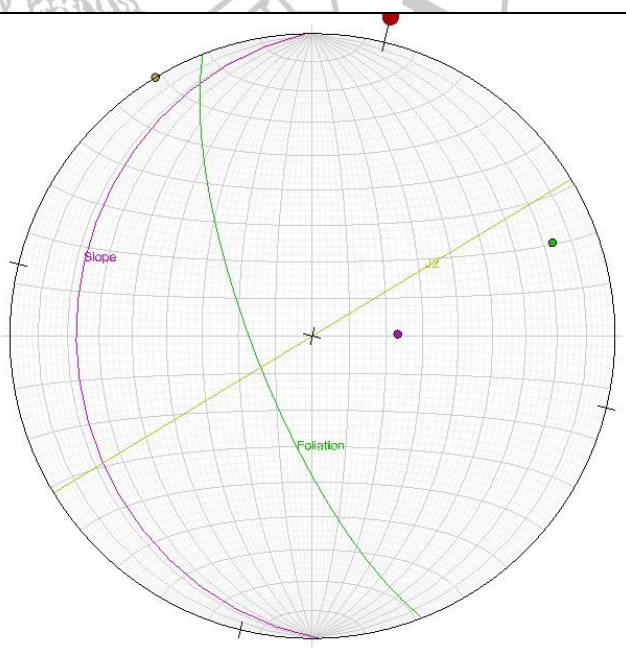


Slope window or slope oriented view

Stereonet No. 26: $75^{\circ}39' 16.925''$ E / $12^{\circ}26' 36.366''$ N



Normal view



Slope window or slope oriented view

Figure-4.5: List of stereonet prepared for each individual outcrop in the study area

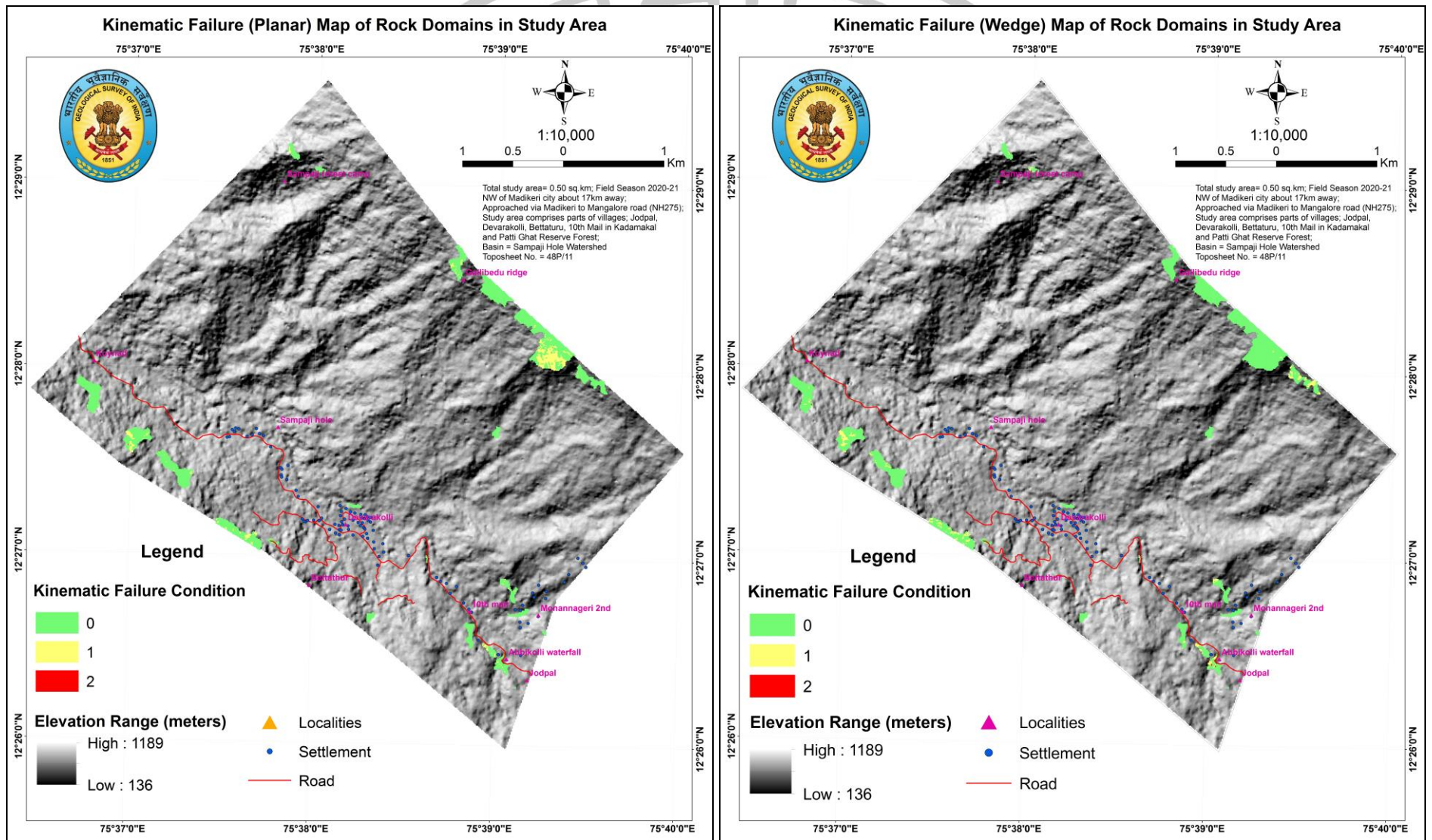


Figure-4.6: Planar failure and wedge failure maps are overlapped on CartoDEM 10m derived hillshade map.

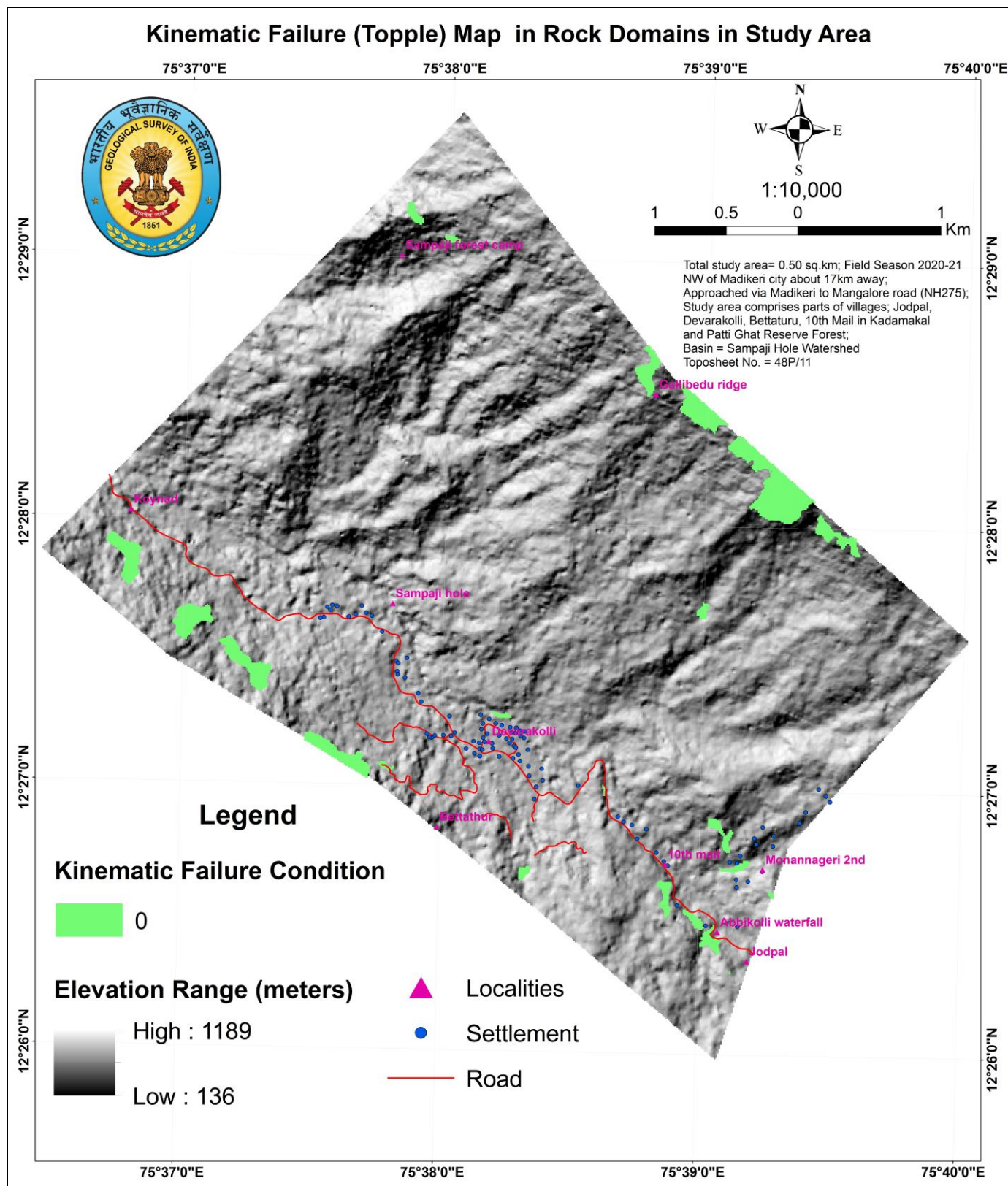


Figure-4.7: Topple failure map is overlapped on CartoDEM 10m derived hillshade map

Table-4.6: Dip amount (DA), dip direction (DD) of discontinuity planes and trend direction (TD), plunge amount (PA) of their intersections used in stereonet plotting and kinematic failure analysis.

Details of 3_set joint data														
Stereonet Plot No.	Latitude	Longitude	DA1	DD1	DA2	DD2	DA3	DD3	TD_W1	PA_W1	TD_W2	PA_W2	TD_W3	PA_W3
1	75°39' 2.297" E	12°26' 26.731" N	51	36	72	117	69	50	50	50	333	67	78	29
2	75°38' 59.089" E	12°26' 30.511" N	85	15	65	105	33	215	95	64	286	12	181	28
3	75°38' 52.305" E	12°26' 35.405" N	84	25	85	225	46	285	306	61	301	45	311	43
4	75°38' 19.749" E	12°26' 40.558" N	73	122	54	312	79	24	35	9	84	69	310	54
5	75°39' 7.148" E	12°26' 42.158" N	81	153	72	315	73	43	39	18	64	72	355	66
6	75°39' 10.122" E	12°26' 43.133" N	82	300	16	210	88	60	212	16	342	79	149	8
7	75°39' 4.935" E	12°26' 49.986" N	55	120	73	320	85	235	44	19	151	51	308	72
8	75°38' 37.897" E	12°26' 59.508" N	55	95	32	233	59	345	174	17	43	41	272	36
9	75°37' 38.203" E	12°27' 6.547" N	66	73	88	175	66	270	89	65	352	18	260	66
10	75°38' 13.899" E	12°27' 16.338" N	88	140	59	200	51	240	227	56	228	50	242	51
11	75°37' 0.017" E	12°27' 35.752" N	35	20	86	90	62	220	3	34	305	10	176	53
12	75°37' 3.588" E	12°27' 37.542" N	68	120	34	245	67	45	198	25	81	62	319	10
13	75°38' 59.845" E	12°27' 40.718" N	40	65	70	327	85	230	41	38	141	12	307	69
14	75°36' 47.610" E	12°27' 46.633" N	83	30	88	320	80	220	33	83	304	30	242	79
15	75°37' 2.339" E	12°27' 48.884" N	83	270	23	200	43	100	184	22	182	8	166	20
16	75°39' 17.575" E	12°28' 6.855" N	50	165	80	330	48	60	243	14	111	35	49	48
17	75°37' 55.135" E	12°29' 7.981" N	21	10	58	334	74	230	54	15	316	13	298	52

Details of 2_set joint data								
Stereonet Plot No.	Latitude	Longitude	DA1	DD1	DA2	DD2	TD_W1	PA_W1
18	75°39' 7.569" E	12°26' 18.802" N	54	200	69	50	129	25
22	75°39' 4.115" E	12°26' 24.587" N	51	215	83	305	224	51
26	75°39' 16.925" E	12°26' 36.366" N	90	0	74	235	225	70
23	75°37' 17.783" E	12°27' 24.230" N	50	150	30	290	227	15
21	75°37' 12.343" E	12°27' 29.430" N	53	135	55	45	92	44
25	75°39' 30.401" E	12°27' 58.392" N	43	110	70	225	150	35
24	75°39' 10.336" E	12°28' 16.717" N	44	125	56	45	99	41
20	75°38' 58.604" E	12°28' 26.722" N	90	0	40	60	65	40
19	75°38' 46.067" E	12°28' 35.145" N	82	140	80	85	102	80

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 were assessed based on kinematic analysis and rock mass rating system. Besides, the slope angle has been 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 slope angle gets steep particularly during rainfall periods. The external forces that are applied on rock outcrops during the 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 the external forces is a matter of concern. That is why 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 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. 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 found compatible with slope angle class $>45^{\circ}$, therefore their LSER has been kept towards higher side so that the ground reality would prevail on susceptibility map. The landslide susceptibility evaluation ratings were taken for each geo-factor class in the study area from the given rating system as follows;

Table-4.7: 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-4.8: 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-4.9: 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-4.10: 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-4.7, 4.8, 4.9 & 4.10 were given to each thematic class of geo-factor maps selected for the generation of landslide susceptibility map in the rock slide and rockfall domains. The landslide susceptibility evaluation ratings (LSER) for each geo-factor class were 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 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;

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-4.11: 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-4.12: 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
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 by 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 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 0.4931 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 the table- 4.13. Later the five classes were reclassified into three classes of landslide susceptibility as mentioned in table- 4.14.

Table-4.13: Landslide susceptibility map attributes for rock slide domain

Value	Pixel Count	TESV
1	15	0.6
2	3509	0.7
3	1143	0.9
4	256	1.1
5	8	1.3

Table-4.14: Modified landslide susceptibility map attributes for rock slide domain

Value	Pixel Count	TESV	Susceptibility Class	Map Area Percentage
1-2	3524	0.6-0.7	Low	71.47
3	1143	0.9	Moderate	23.18
4-5	264	1.1-1.3	High	5.35

The rock slide in the high susceptibility map area has been validated on the ground and most of the area is found satisfactory. The high susceptibility class has retained those areas which are more prone to rock slides. As such, no rock slide was demarcated till the end of the present investigation in the study area but one rock slide (wedge failure; slide no. 20) has later occurred on a rock slope in Abbikolli waterfalls which is predicted into the high susceptible zone. Whereas the moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 23.18 percent. This signifies that qualitatively the adopted model has predicted 77 percent 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 the rainfall may change the resulted susceptibility scenario in the study area at any time. The basic parameters like 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 resulted total estimated susceptibility value (TESV) ranges from 0.6 to 1.7 and it divides the map area into five classes as mentioned in the table- 4.15.

Keeping 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- 4.16.

Table-4.15: Landslide susceptibility map attributes for rock fall domain

Value	Pixel Count	TESV
3	13	0.6
4	2407	0.7
5	1386	0.9-1.0
6	806	1.2-1.5
7	244	1.7

Table-4.16: Modified landslide susceptibility map attributes for rock fall domain

Value	Pixel Count	TESV	Susceptibility Class	Map Area Percentage
3-4	2420	0.6-07	Low	49.84
5	1386	0.9-1.0	Moderate	28.54
6-7	1050	1.2-1.7	High	21.62

The rockfall in the high susceptibility map area has been validated on the ground and most of the area is found satisfactory. The high susceptibility class has retained those areas which are more prone to rockfall due to the 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 zone 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 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 the moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 28.54 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 susceptible class over 28 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 resulted susceptibility scenario in the study area at any time.

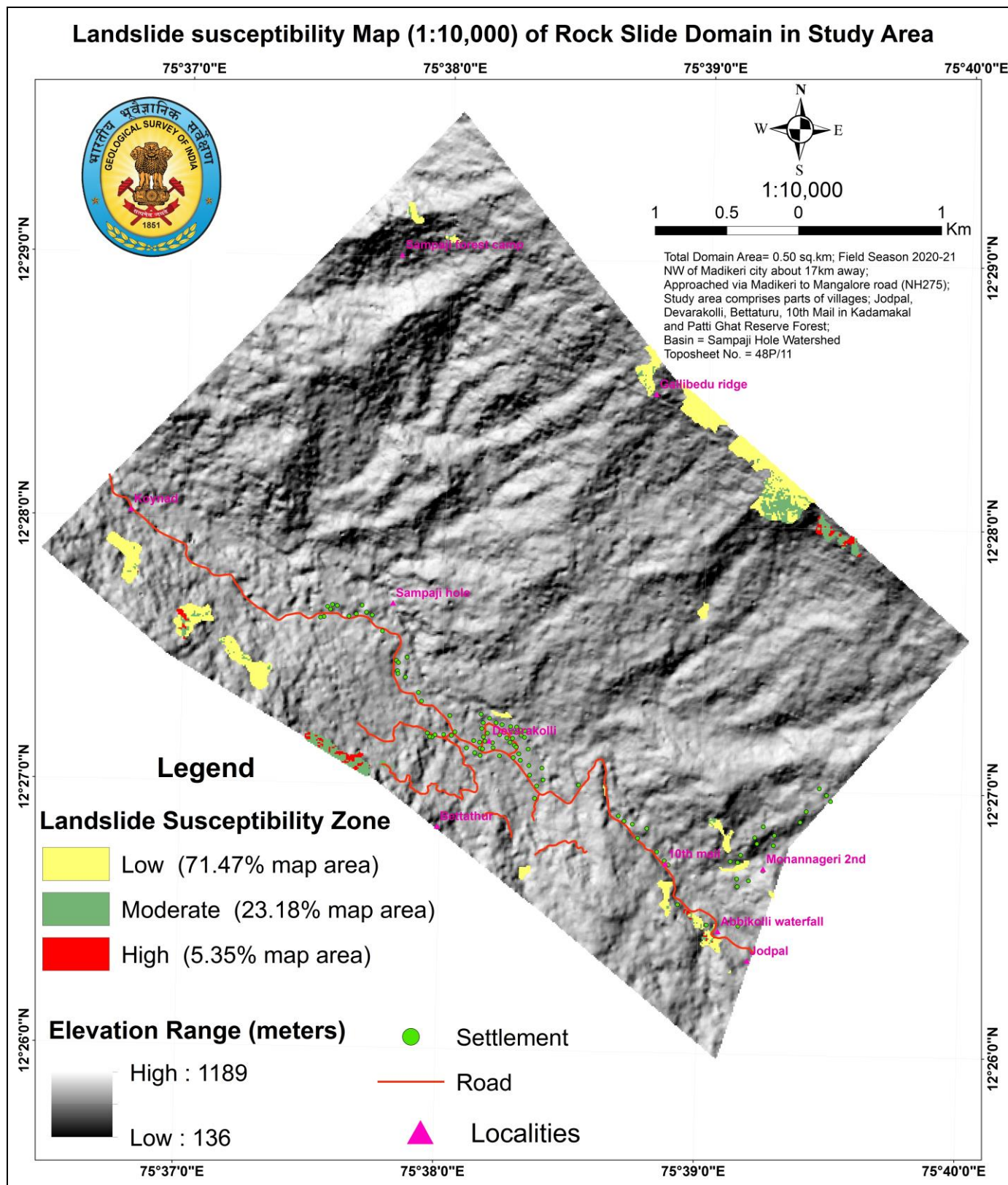


Figure-4.8: Landslide susceptibility map of rock slide domain in the study area

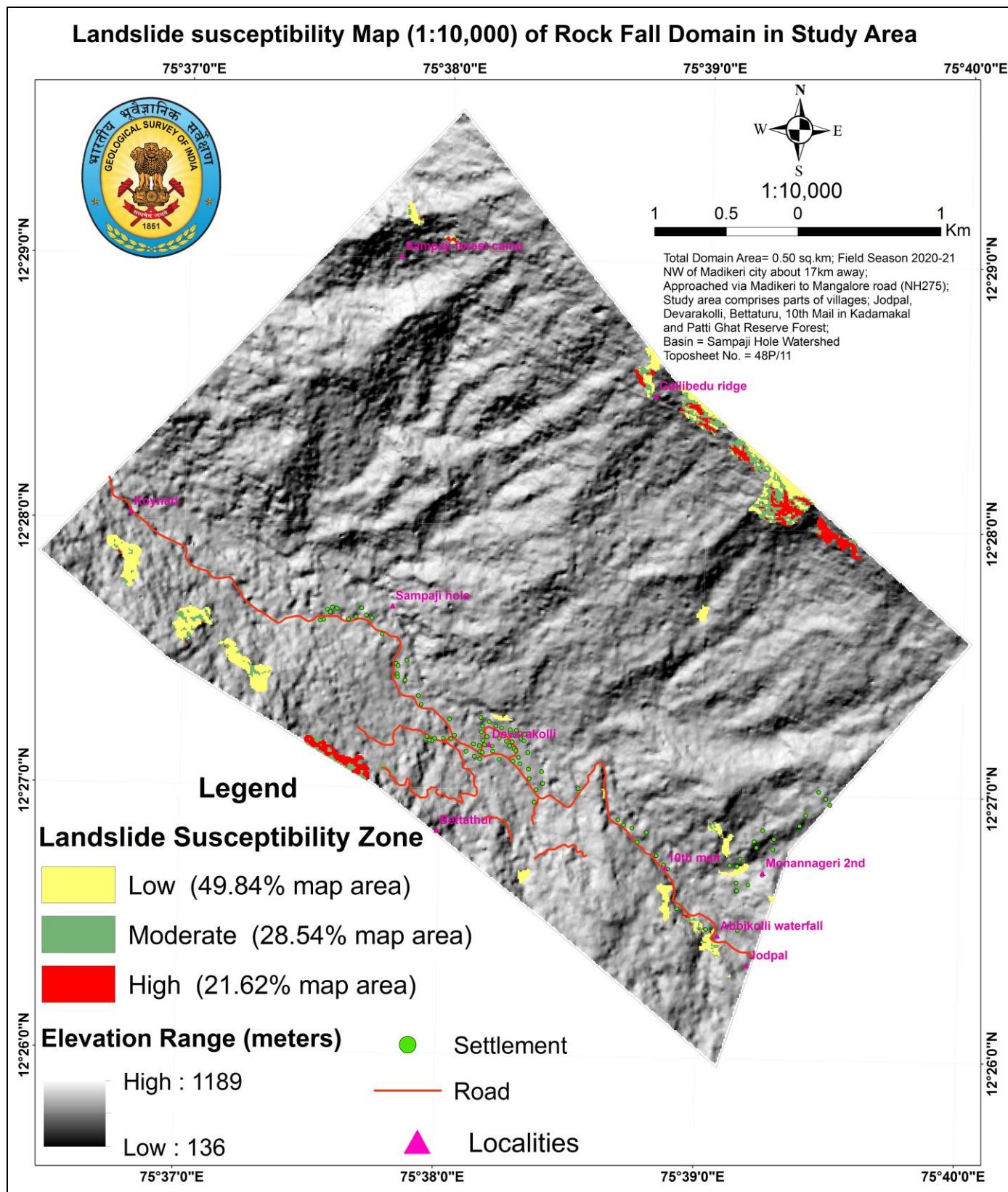


Figure-4.9: Landslide susceptibility map of rockfall domain in the study area

4.4 Debris/Earth slide domain (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.

To prepare the debris/earth domain map, the slope forming material map is used as a proxy. For debris domain map immature soil, colluvium, boulder material, loose debris have been extracted, assuming that above mentioned materials in the study area have probability for debris slope failure and named as debris slide domain. The areas covered with mature soil converted into earth slide domain based on field evidence like silt and clay proportion. Around 95% of the study area comes under the overburden domain (Debris 65% and Soil 30%). A total 12 nos of landslides are falling in debris domain and 3 nos of landslides are falling in the earth failure domain. During monsoon season due to saturation, the soil and the weathered rock failed together 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 produce 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 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, 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 mechanical factors consist of reinforcement of soil by roots, surcharge, wind-loading, and surface protection (Greenway, 1987). The effects of vegetation cover on the hydrological processes of shallow land sliding can be subdivided into the loss of precipitation by interception, removal of soil moisture by evapotranspiration, and the effects on hydraulic conductivity (Van Beek, 2002; Wilkinson et al., 2002a,b). The slopes can be de-stabilized by unscientific modification of slope by daylighting of the vulnerable planes, reducing the toe support, loading, and unloading. LULC has been prepared and finalized in two stages, i.e. pre-field mapping (as part of pre-field the LULC map prepared from downscaling of the NLSM 1:50K and remote sensing data (Google earth recent imageries for better visualization and Cartosat Pan image also used) and post field update using field data.

Most of the study area comes under the Kadamakal reserve forest. In 2018 the study area was devastated by many landslides as per the records of post disaster study of year 2018. This large-scale

natural disaster changed the land cover pattern of the study area in a few places. During the pre-field study, thick mixed vegetation and a few small patches of plantation, settlements, barren, and cultivated land were identified. During the field observation the plantation area was classified into different types of plantation like rubber plantation, Arecanut plantation with coffee and cocoa plantation, coffee plantation with mixed vegetation, settlement, barren and thick vegetation. Coffee and cocoa and cashew could not be delineated during the prefield study as dense canopy present in the study area. The rubber plantation (HHP) observed near Devarakolli village are planted in gently undulating hillslopes having slope angles ranging from 5°-25°. Mixed plantations are marked at a few places around Devarakolli, Abbikolli waterfalls, and adjacent to the Sampaji hole where coffee, Cashew, and Arecanut are planted together. Barren class is noticed all along the ridge and 2-3 no's of landslides are documented in the barren class. Most of the study area (15.26 Sqkm) is covered by thick vegetation which accounts for 80.97% of the total area. High height plantation covers an area of 1.3 Sqkm while Barren area covers 0.9 Sqkm.

Table-4.17: Landslide susceptibility evaluation rating (LSER) for the Landuse/Landcover map.

Sr.No	Class	LSER
1.	Barren	1
2.	Flat ground	0
3.	Grass land	0.6
4.	High height plantation	0.4
5.	Low height plantation	0.6
6.	Mixed plantation	0.5
7.	Moderate vegetation	0.5
8.	River	0
9.	Settlement	0.2
10.	Sparse vegetation	0.8
11.	Thick vegetation	0.3

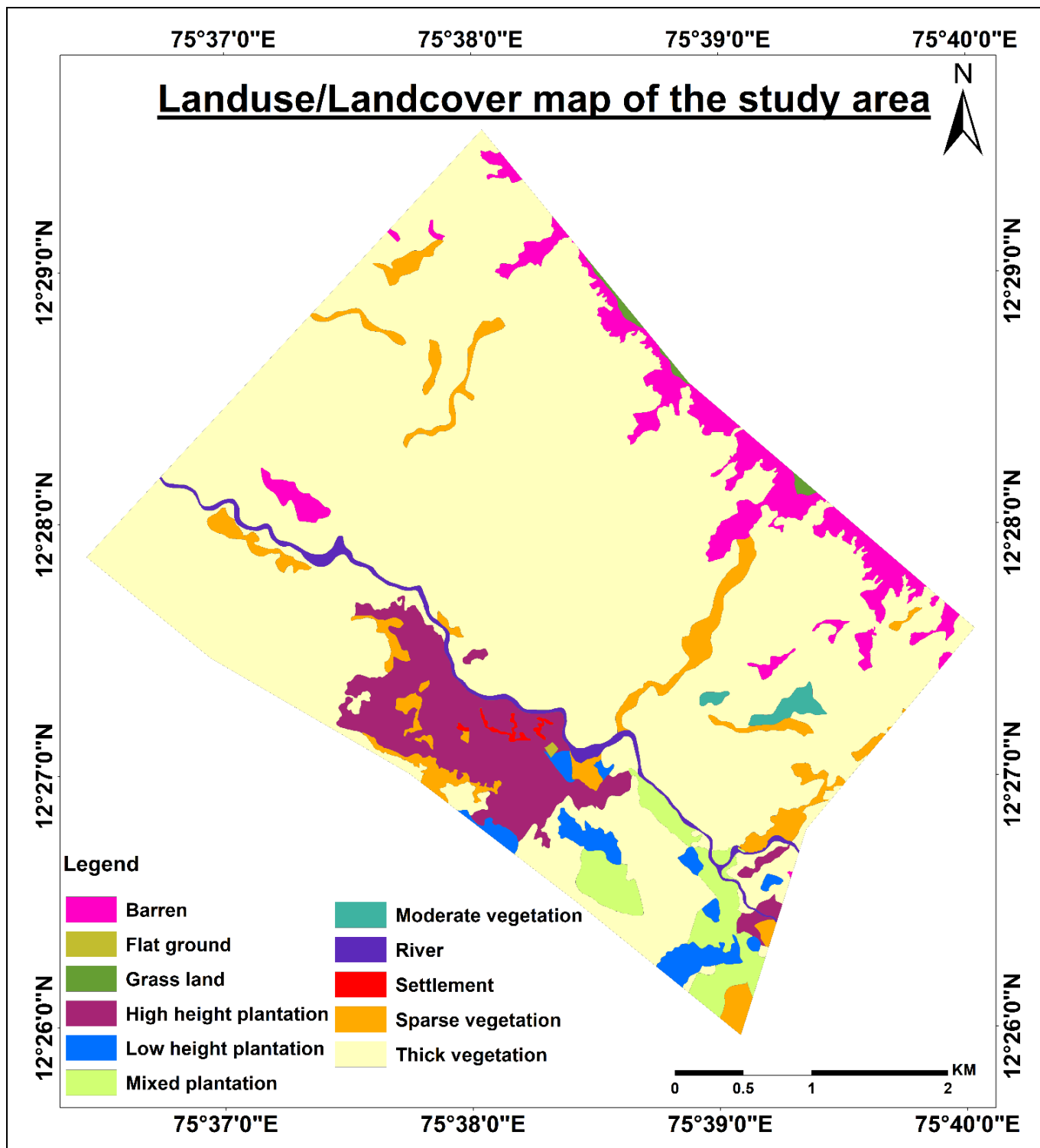


Figure-4.10: Field-based Land use/Land cover map of the study area

4.4.2 Geomorphon/Landform Map

At a larger scale (1:10,000) the identification of individual geomorphological class becomes difficult due to 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 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 landform using the 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 (8³=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. 4.11). Figure 4.12 shows the different geomorphic classes observed in the study area.

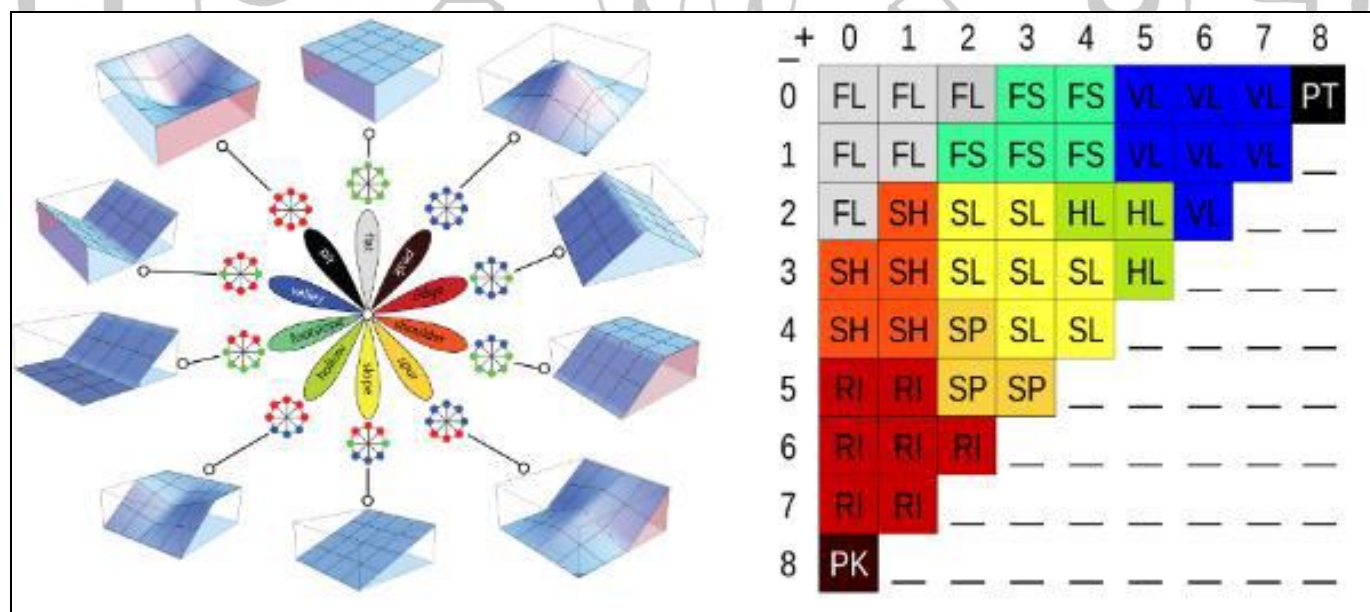


Figure-4.11: Representative 3-D pattern of 10 most common landforms and lookup table for reclassification of landforms into the 10 common landform types. Rows/columns in a table indicate the number of (-1)/(1) ternary elements in the landform pattern. Abbreviations for common landform elements are: FL — flat; PK — peak; RI — ridge; SH — shoulder; HL — hollow; SL — slope; SP — spur; FS — footslope; VL — valley; PT — pit

The above-simplified reclassification of geomorphons are 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 assigned to flat, summit, valley, etc. even the anthropogenic induced landslide also comes under the geomorphon unit of the slope.

Table-4.18: Landslide susceptibility evaluation rating (LSER) for Geomorphon

Sr.No	Class	LSER
1.	Summit	0.2
2.	Ridge	0.4
3.	Spur	0.6
4.	Slope	0.5
5.	Hollow	1
6.	Valley	0.2
7.	Depression	0.4

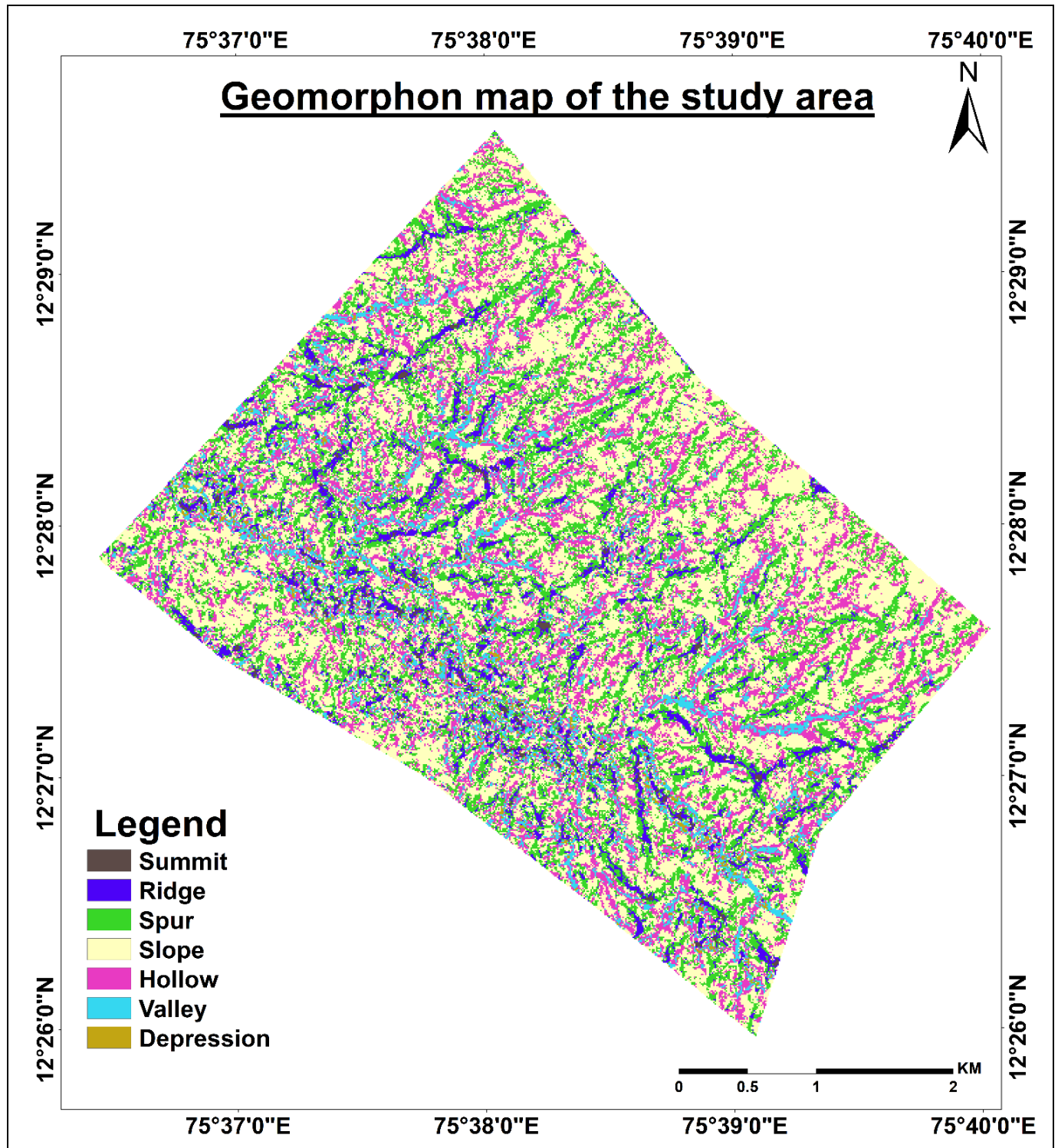


Figure-4.12: Geomorphon map of the study area derived from 10 m $\times$ 10 m Cartosat-DEM

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.

Table-4.19: Landslide susceptibility evaluation rating (LSER) for Stream power Index (SPI)

Sr.No	Class	LSER
1	0 (Very low erosion)	0
2	0-2 (Moderate erosion)	0.6
3	2-5 (High erosion)	0.8
4	>5 (Very high erosion)	1

For the stream power index map, maximum LSER is assigned to >5 classes assuming that the erosive power of the stream is maximum in that area, likewise, the minimum LSER is assigned to minus

to zero values, there the erosive power is minimum. In-ground reality, most of the natural landslides are initiated in the 0-1 classes, hence 0.6 values are assigned to 0-1 classes.

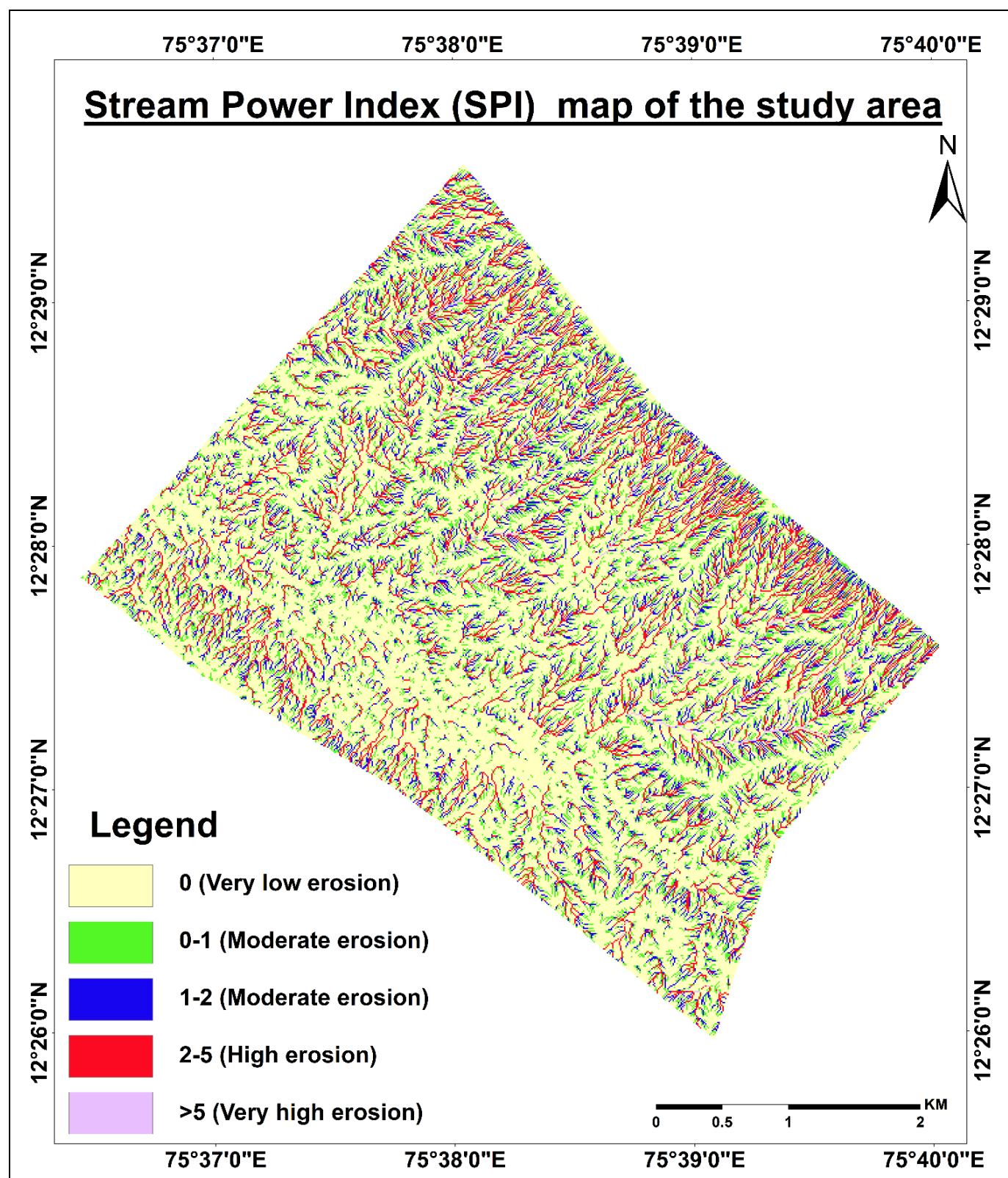


Figure-4.13: Stream Power Index map of the study area

4.4.4 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, and infiltration, etc. of the slope forming material. The 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 parameter of the overburden in terms of cohesion (C) and internal angle friction (ϕ) is an important geo-factor that determines the shear strength of the material and the ability to resist sliding. The sampling had been done in the gridded pattern (1*1 Sqkm) and different elevations, however in the inaccessible areas, the samples are collected without considering the elevation factor. A total of 27 no's of UDS and 20 no's of DS samples were collected but received C and ϕ only for 27 no's of UDS and the cohesion ranges from 18 to 32 kN/m² while the angle of internal friction 21° to 29°. 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 are 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.

Table-4.20: Classification of overburden material based on shear parameters and LSER rating.

Cohesion (C) as per Ghoshal <i>et al.</i> , 2013	Cohesion (C) Re-adjusted	Angle of Internal Friction (ϕ)) as per Ghoshal <i>et al.</i> , 2013	>30°	21°-30°	11°-20°	<=10°
		Angle of Internal Friction (ϕ) Re-adjusted	<22	22-25	26-29	>29
<5 kN/m ²	<19		(1) Very bad	(1) Very bad	(1) Very bad	(0.6) Fair
5-15 kN/m ²	19-24		(0.6)Fair	(0.8)Bad	(0.8)Bad	(0.4)Good
16 to 30 kN/m ²	25-29		(0.4)Good	(0.6)Fair	(0.6)Fair	(0.4)Good
>30 kN/m ²	>29		(0.4)Good	(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 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 the 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 and compacted colluvium whereas as per the disposition at higher slope the same material also falls fair to bad category. The loose debris material falls in Very bad to fair class likewise immature soils also fall in Very bad to fair classes.

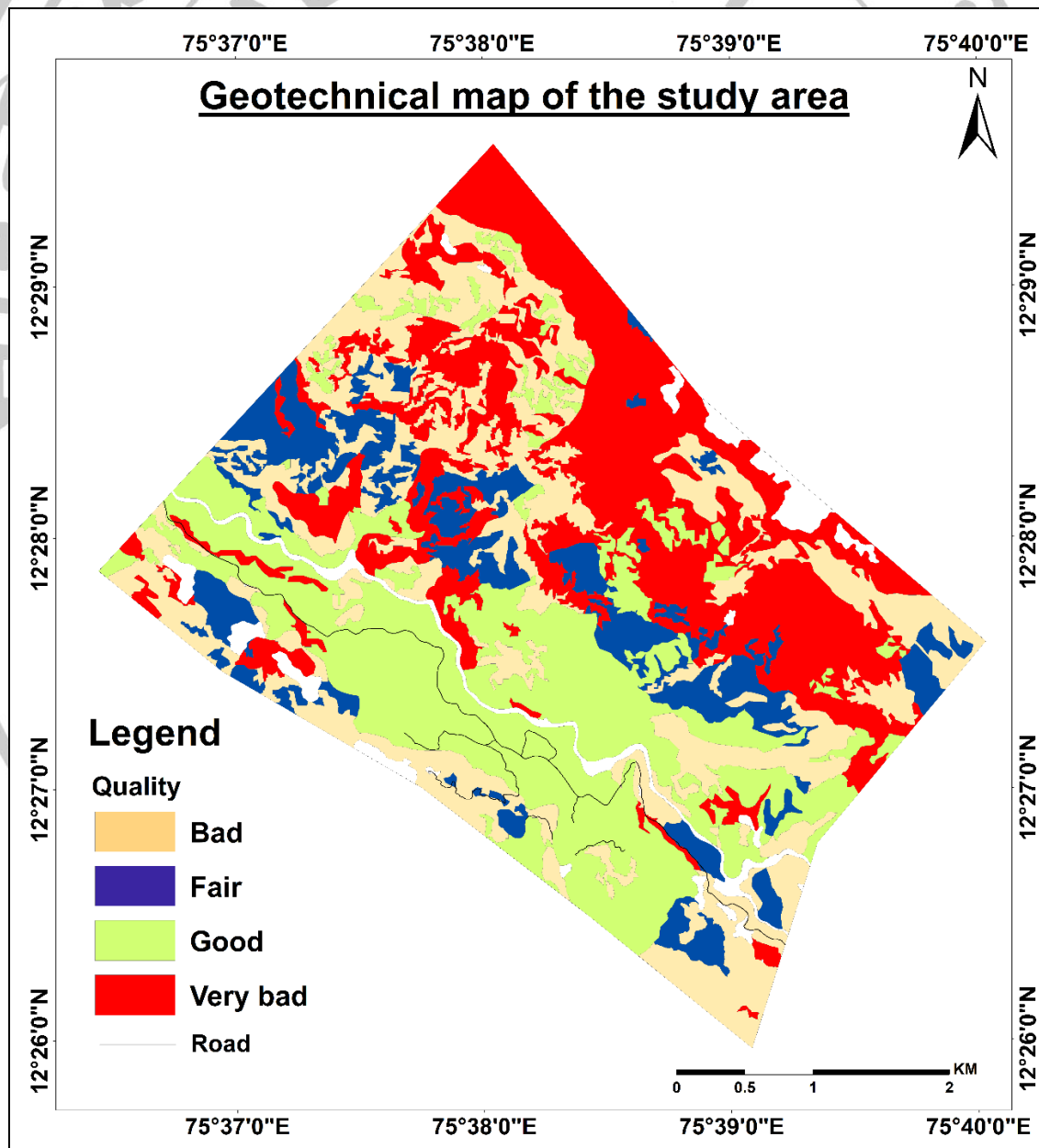


Figure-4.14: Geotechnical map of the debris slide and earth slide domains (overburden)

4.4.5 Overlay Analysis for TESV Calculation for 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). Landslide susceptibility evaluation rating was assigned to each pixel for all causative factors and LSER was modified as per the present study area condition and how much that particular class contribute to the landslide. The TESV was then calculated by combining LSER of individual causative factors for each pixel which includes LULC, landform, SFM, SPI, and geotechnical maps for overburden-dominated pixels.

TESV for overburden covered slopes = Σ LSER [Geotechnical map + LULC + Landform + Stream power (Index SPI)].

Table-4.21: TESV and pixel count for the overburden domain

Pixel Count	TESV
2	0.6
87	0.8
1888	0.9
1180	1
4602	1.1
11973	1.2
13677	1.3
8293	1.4
8863	1.5
14239	1.6
17926	1.7
19295	1.8
14096	1.9
5710	2
9139	2.1
8594	2.2
10032	2.3
5981	2.4
6259	2.5
4691	2.6

4636	2.7
961	2.8
4052	2.9
1117	3
2838	3.1
479	3.2
681	3.3
541	3.4
5	3.5
355	3.6
223	3.8
3	4

Table-4.22: Modified TESV and pixel count for the overburden domain

Pixel Count	TESV	Susceptibility Class	Map Area Percentage
82729	0.6-1.79	Low	45.35
46688	1.80-2.1	Moderate	25.59
53001	2.11-4	High	29.05

4.4.6 Mesoscale Landslide Susceptibility Map of the Overburden Domain

The landslide susceptibility map (Fig.4.15) of the study area as obtained by using the heuristic method of ratings is a map that can be used to understand the relative stability of the study area. The map provides a fair idea of the slope susceptibility to failure of any type in response to the interaction of the considered geo-environmental factors. The Total Estimated Susceptibility Value ranges from 0.6 to 4. For this TESV range, the breakup has been done as per the field knowledge.

After the TESV calculations by overlay analysis derived the Landslide Susceptibility map which has categorized the entire study area into zones of varying degrees of susceptibility classes from low, moderate, and high susceptibility. TESV classes calculated from the prepared maps show 45.35%, 25.59%, 29.05% of the area falling under low, moderate & high susceptibility classes in overburden-covered areas. The map shows the southern portion of the Abbikolli waterfalls, opposite to Abbikolli waterfalls (right bank of Sampaji hole) comes under the moderate to a high susceptible zone. Moreover, during the field check, surface cracks and subsurface water flow were noted. Along the NH-275 most of the portion comes under the low susceptible zone however certain patches of road section come under the

moderate to high susceptible zone. The village Devarakolli comes under the low susceptible zone. The map shows the uppermost slope portions are coming under the high susceptible zone, this is also verified during the field traverses as the numbers of natural debris flow initiated on this slope. The high susceptible zone in the NE and NW are fairly well represented as per the field conditions and even the southern part of the upper slope. 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. The low susceptible slope facets are considered stable under the given set of geo-environmental conditions considered in the study. However, any adverse triggering mechanism in terms of unmethodical anthropogenic interference, incessant rainfall can still initiate landslides. The susceptibility map 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 can affect the susceptibility of the area over a period of time.

The Overburden slides in the high susceptibility map area have been validated on the ground and most of the area is found satisfactory. The high susceptibility class has occupied those areas which are more prone to debris and earth slides. The moderate susceptibility comes under 25.59% of the total area and it is not exceeding 30%. It indicates that the uncertainty is very less and the adopted model reveals that 75 % map area with efficacy.

Out of 18.95 Sqkm of the overburden domain, 13.04 Sqkm accounts for the debris domain, and the landslide susceptibility map of the debris domain (Fig 4.16) is given below. In 13.04 Sqkm around 42% of the area that accounts for 5.52 Sqkm comes under low susceptible, 27.25% of the area account for 3.55 Sqkm moderate susceptible , and 30.42% of the area account for 3.96 Sqkm comes under high susceptible zone.

Out of 18.85 Sqkm of the overburden domain, 5.90 Sqkm accounts for the earth domain, and the landslide susceptibility map of the debris domain (Fig 4.17) is given below. Out of 5.90 Sqkm, around 52.14% of the area account for 3.07 Sqkm comes under low susceptible, 21.91% of the area account for 1.29 Sqkm comes under moderate susceptible and 25.94% of the area account for 1.53 Sqkm comes under high susceptible zone.

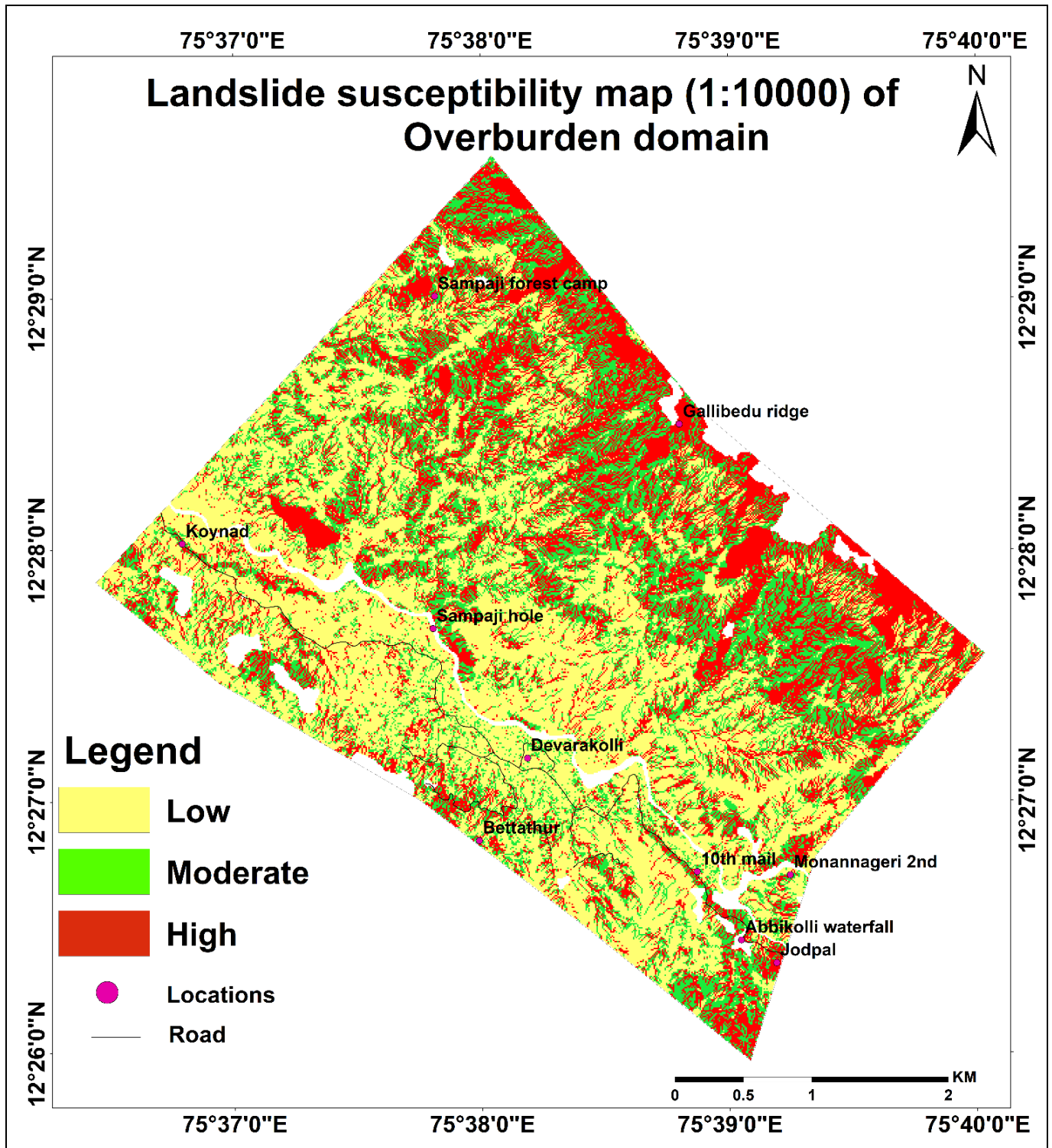


Figure-4.15: Landslide susceptibility map of both debris slide and earth slide domains in the study area

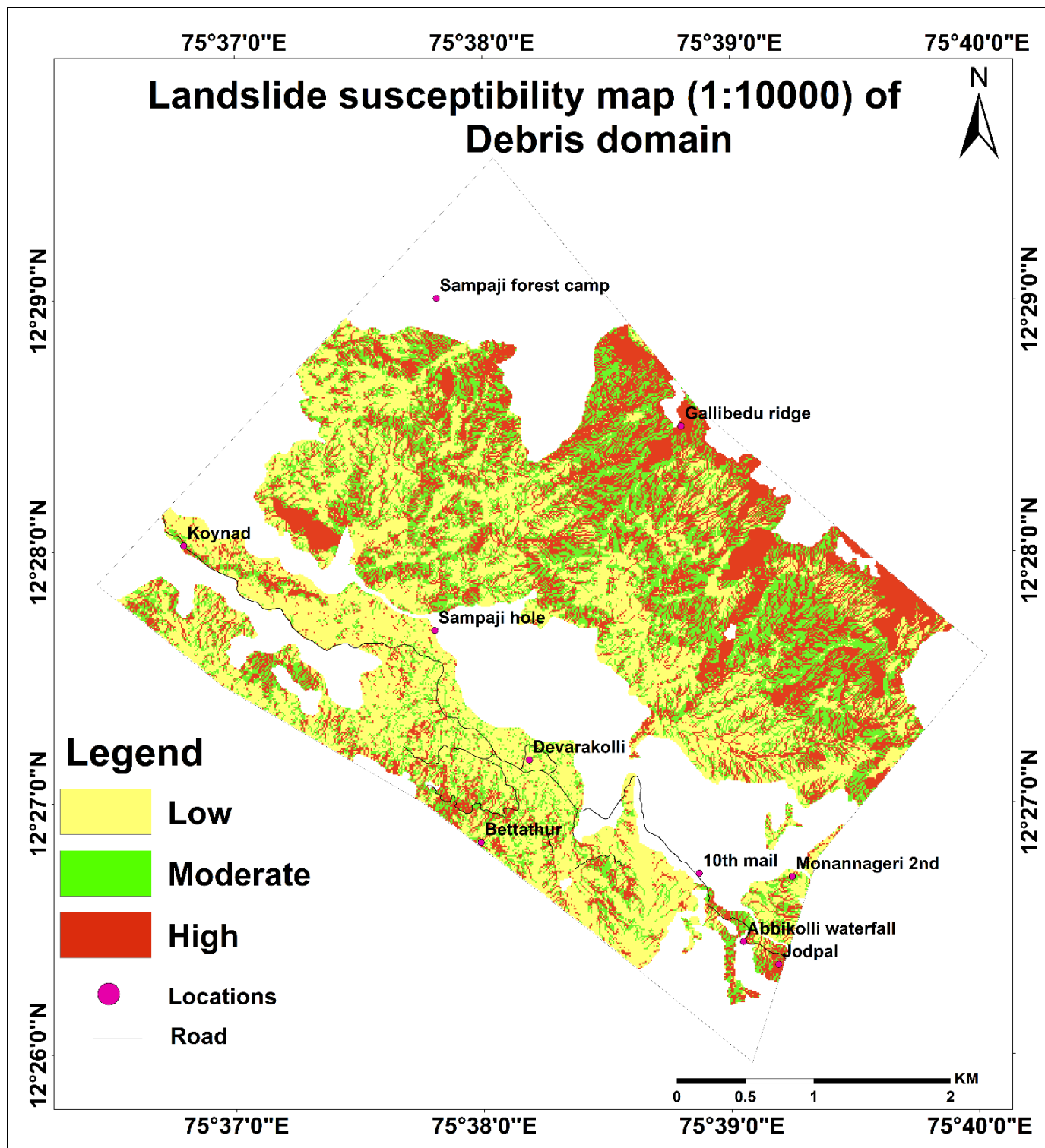


Figure-4.16: Landslide susceptibility map of debris slide domain in the study area

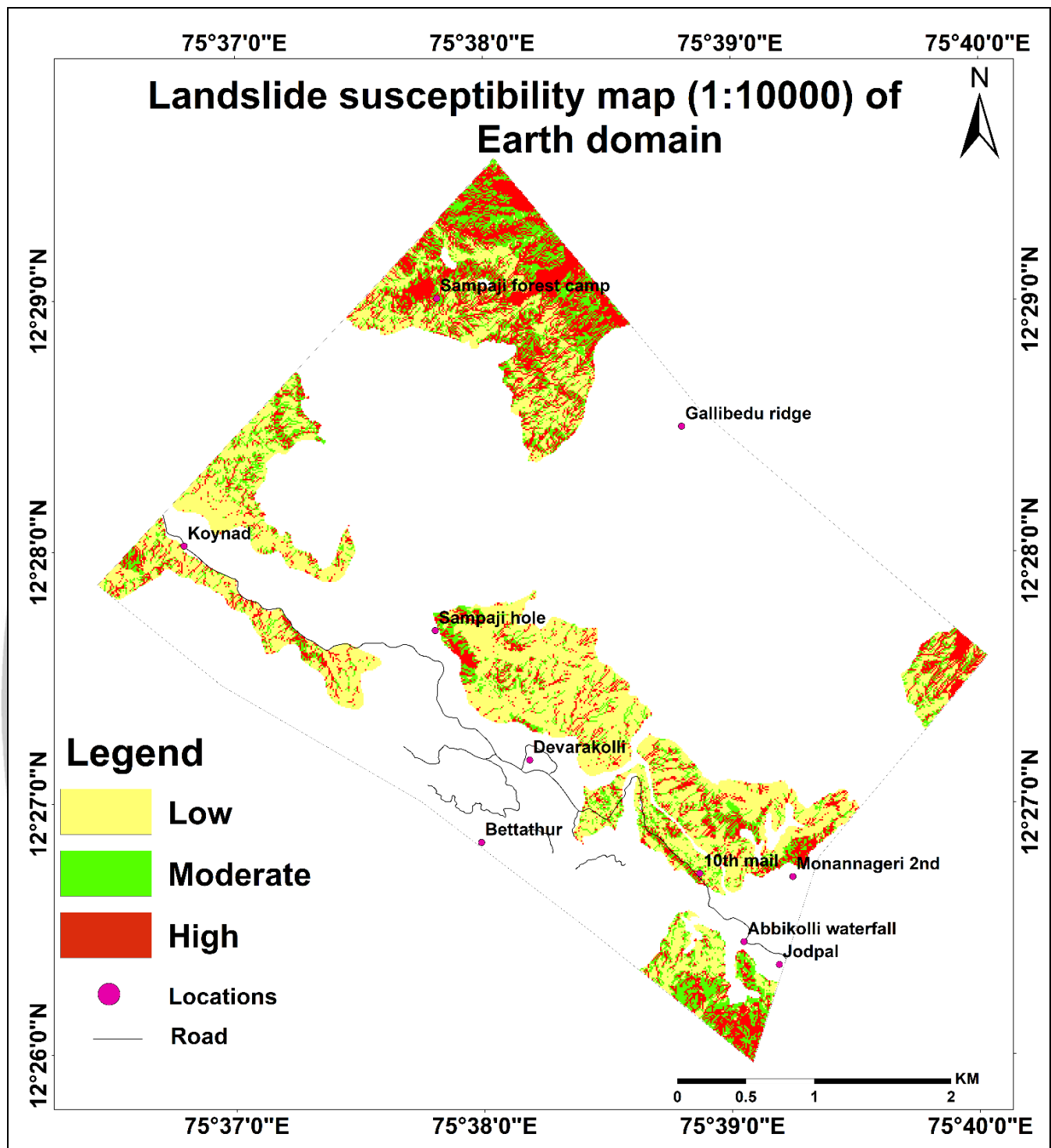


Figure-4.17: Landslide susceptibility map of earth slide domain in the study area

4.4.7 Validation of Susceptibility Map with the Landslide Incidences

Although the heuristic method is employed for modelling the susceptibility, the available landslide data is necessary to study the variable causal relation of different geo-factors and therefore help in the knowledge-based ratings of different geo-factor classes.

In the present study, landslide inventory was prepared using primarily field documentation and reports of earlier workers. During the investigation 20 no's of landslide inventory were collected and they were classified into 5 no's of classes, i.e. 14 no's of debris slide, 03nos of earth slide, 1 rockslide, 1 no. of creep movement, and 1 no. of subsidence. Out of 20 landslides, 07 no's of movement initiated by anthropogenic activity and were smaller dimensions and 04 no's of movement initiated by river erosion (Toe cut by stream). The spatial distribution of the smaller dimensional landslides are initiated low angle slope however, spatial distribution larger dimension (debris flow) initiated on the higher angle slope and they were all triggered by incessant rainfall.

Overlay of analysis of landslide inventory map with landslide susceptibility map indicates that, out of 16 landslides (overburden domain), 06 debris flow larger landslide falls in the high susceptible area of 5.5sqkm. All these natural debris flows are falling in the high susceptible area, however, anthropogenic induced landslides are falling in the moderate to high susceptible zone. For example, Koyanad subsidence, creep movement before the Devarakolli village, Devarakolli Chamudeshwari temple slide comes under the moderate to high. Similarly 06 no's of mass movements fall in moderate to high and 04 no's of landslide falls in low susceptible an area of 8.56 sq. km. The validation of the landslide susceptibility map reveals that a total of 75% of the landslides are falling in the moderate to high susceptible classes, and only 25% of the landslides coming under the low susceptibility.

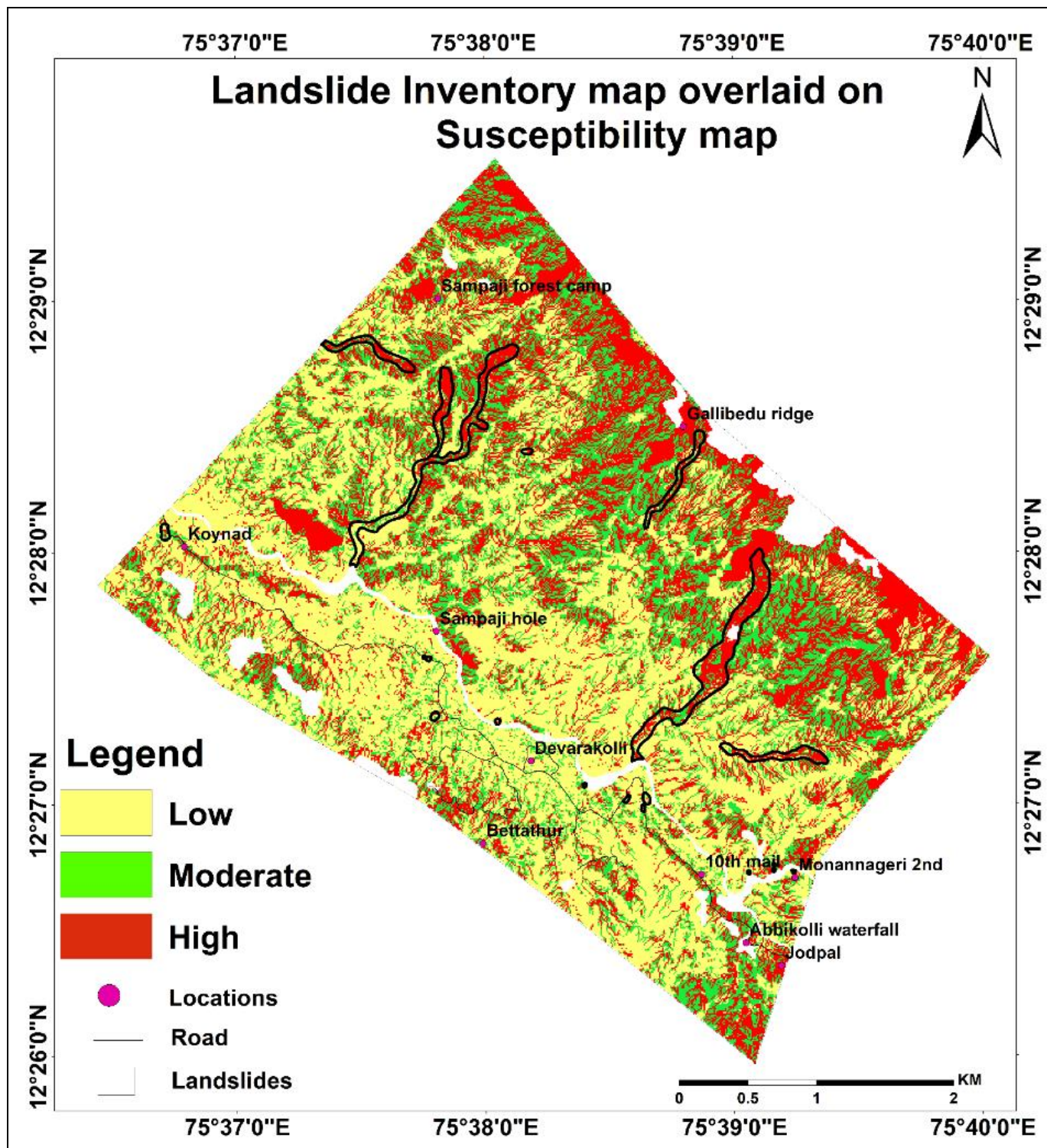


Figure-4.18: Landslide incidences overlay on landslide susceptibility map for validation

4.5 Cut-slope Domain

Cut-slopes are mostly results of anthropogenic activities performed on the earth's surface for road & railway line construction, settlement buildings 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 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 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.

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 0-50 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 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

FID	SFM	Landslide Domain	Cut-Slope Height	Upslope Angle	Failure Tendency
0	In-situ soil	Earthslide domain	3-6m	16-35	0.6
1	In-situ soil	Earthslide domain	3-6m	0-15	0.2
2	Colluvium (Uncompacted)	Debris slide domain	7-10m	16-35	0.9
3	Colluvium (Uncompacted)	Debris slide domain	3-6m	36-45	0.9
4	In-situ soil	Earthslide domain	3-6m	16-35	0.6
5	In-situ soil	Earthslide domain	3-6m	0-15	0.2
6	Rock	Rockslide domain	3-6m	36-45	0.8
7	In-situ soil	Earthslide domain	<3m	0-15	0.1
8	In-situ soil	Earthslide domain	<3m	36-45	0.7
9	Rock	Rockslide domain	3-6m	16-35	0.6
10	In-situ soil	Earthslide domain	7-10m	36-45	0.9
11	In-situ soil	Earthslide domain	7-10m	16-35	0.8
12	In-situ soil	Earthslide domain	3-6m	16-35	0.6
13	Colluvium (Uncompacted)	Debris slide domain	7-10m	0-15	0.4
14	Colluvium (Uncompacted)	Debris slide domain	3-6m	0-15	0.3
15	In-situ soil	Earthslide domain	3-6m	0-15	0.2
16	In-situ soil	Earthslide domain	3-6m	16-35	0.6
17	In-situ soil	Earthslide domain	<3m	16-35	0.4
18	In-situ soil	Earthslide domain	<3m	16-35	0.4
19	In-situ soil	Earthslide domain	<3m	>45	1
20	In-situ soil	Earthslide domain	<3m	36-45	0.7
21	In-situ soil	Earthslide domain	<3m	16-35	0.4
22	In-situ soil	Earthslide domain	<3m	0-15	0.1
23	In-situ soil	Earthslide domain	<3m	16-35	0.4
24	In-situ soil	Earthslide domain	<3m	0-15	0.1
25	In-situ soil	Earthslide domain	<3m	15-35	0.4
26	In-situ soil	Earthslide domain	3-6m	0-15	0.2
27	In-situ soil	Earthslide domain	<3m	16-35	0.4
28	In-situ soil	Earthslide domain	3-6m	16-35	0.6
29	In-situ soil	Earthslide domain	3-6m	16-35	0.6
30	In-situ soil	Earthslide domain	3-6m	16-35	0.6

31	In-situ soil	Earthslide domain	<3m	36-45	0.7
32	In-situ soil	Earthslide domain	<3m	16-35	0.4

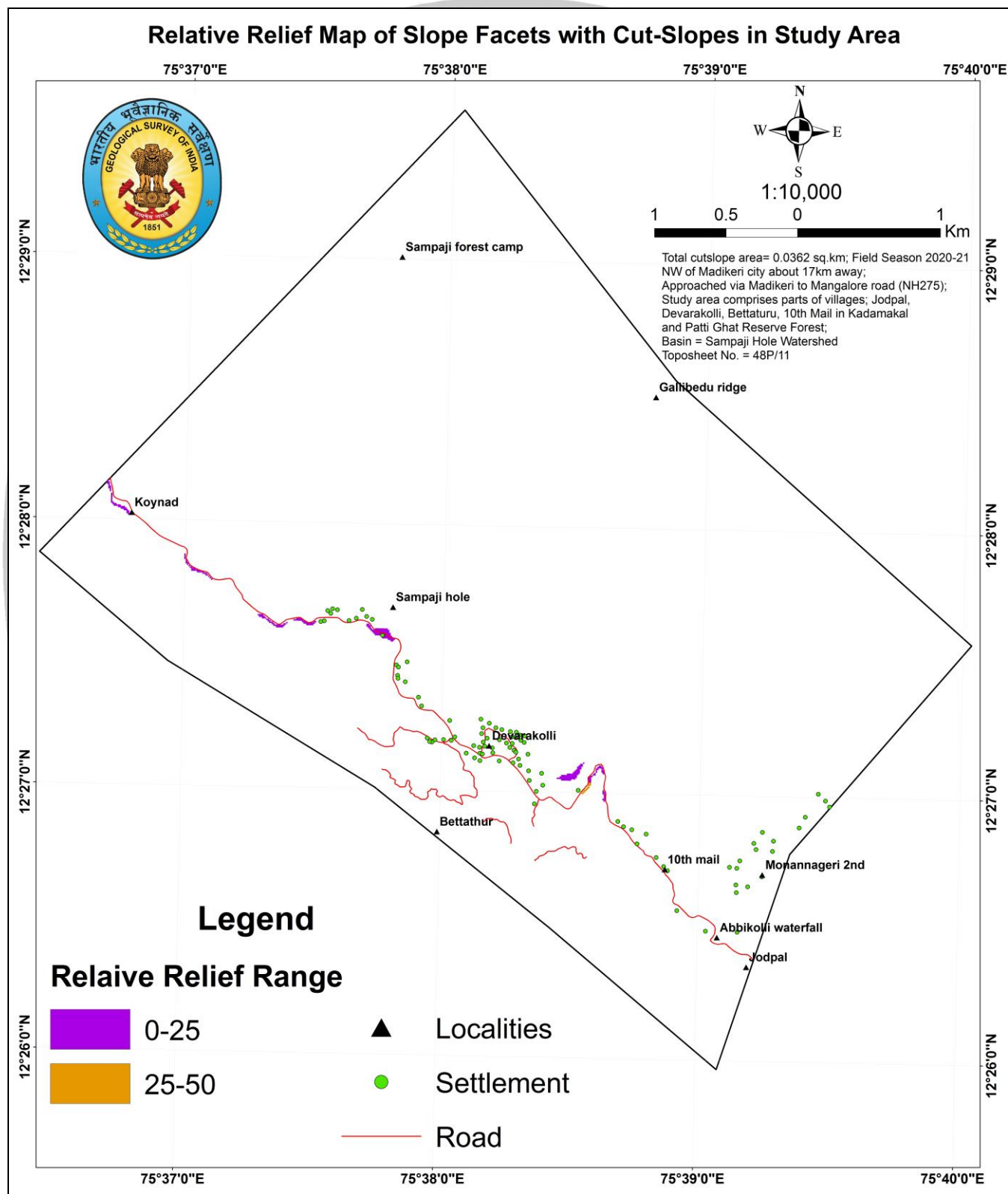


Figure-4.19: Relative relief map of slope facets with cut-slopes in the study area

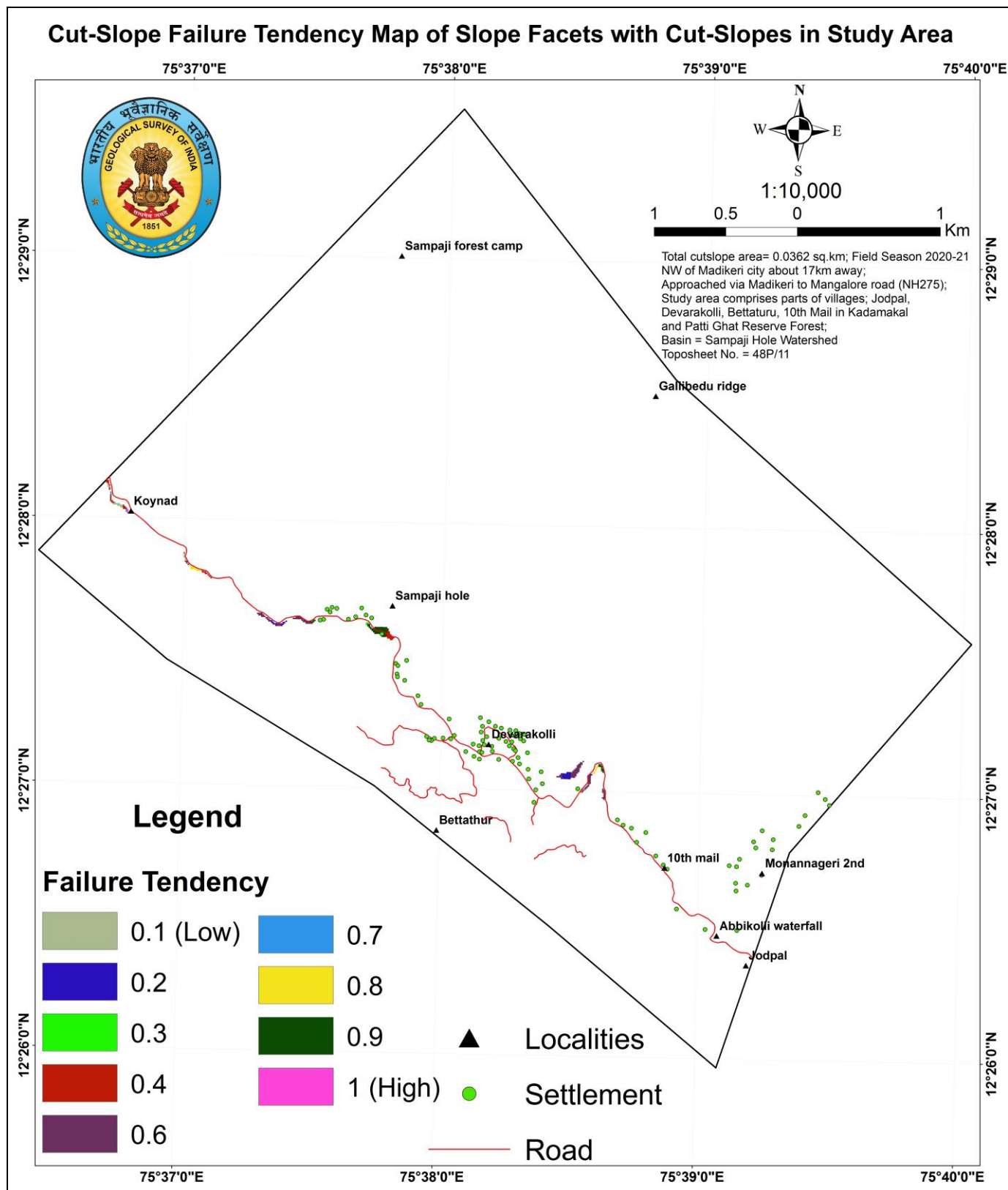


Figure-4.20: Cut-slope failure tendency map of slope facets with cut-slopes in the study area

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 relative relief of each slope facet, the impact of 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-4.24 & 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 in giving LSER in cut-slope failure tendency map and has increased LSER by 0.1 for a correlation matrix class which represents loose debris material. 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 total estimated susceptibility value (TESV) was performed in the GIS platform by using the below-mentioned calculation;

Total estimated susceptibility value (TESV) = $\sum$ (LSER_Relative Relief map + LSER_Cut-slope Failure Tendency map)

Table-4.26: Maximum LSER of factor maps selected for preparation of landslide susceptibility map in the cut-slope domain.

Factor Map	Factor Class		Maximum LSER
Relative relief map	0-25		0.2
	26-50		0.4
Cut-slope failure tendency map	Cut-slope Height (m)	Upslope Angle (Degree)	
	<3	0-15	0.1
	3-6	0-15	0.2
	7-10	0-15	0.3
	<3	16-35	0.4
	3-6	16-35	0.6
	<3	36-45	0.7
	3-6	36-45	0.8
	7-10	16-35	0.8
	7-10	36-45	0.9
	<3	>45	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 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 0.0362 sq. km area. The result of the total estimated susceptibility value (TESV) ranges from 0.3 to 1.2 and it divides the map area into nine classes as mentioned in table- 4.27. Later the nine classes were reclassified into three classes of landslide susceptibility as mentioned in table- 4.28.

Table-4.27: Landslide susceptibility map attributes for cut-slope domain

Value	Pixel Count	TESV
2	20	0.3
3	44	0.4
4	3	0.5
5	53	0.6
6	119	0.8
7	14	0.9-1.0
8	25	1.0-1.1
9	81	1.1
10	3	1.2

Table-4.28: Modified landslide susceptibility map attributes for cut-slope domain

Value	Pixel Count	TESV	Susceptibility Class	Map Area Percentage
2-4	67	0.3-0.5	Low	18.51
5	53	0.6	Moderate	14.64
6-10	242	0.8-1.2	High	66.85

The high susceptibility map area in the cut-slope domain has been validated on the ground and for most of the area, it is found satisfactory. The high susceptibility class has retained those areas which are more prone to upslope failures. All the 3 landslides (ls5, ls16 & ls18) which occurred in the cut-slope domain fall in the high susceptibility zone. It signifies that the validation of applied model prediction by existing landslides is 100%. Whereas the moderate susceptibility does not exceed more than 30 percent of the total map area and remains at 14.64 percent. This signifies that qualitatively the adopted model has predicted 85 percent map area with efficacy and there is the least uncertainty in terms of moderate susceptibility over the 15 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 also stated that the impact of external forces particularly rainfall water action may change the resulted susceptibility scenario in the study area at any period.

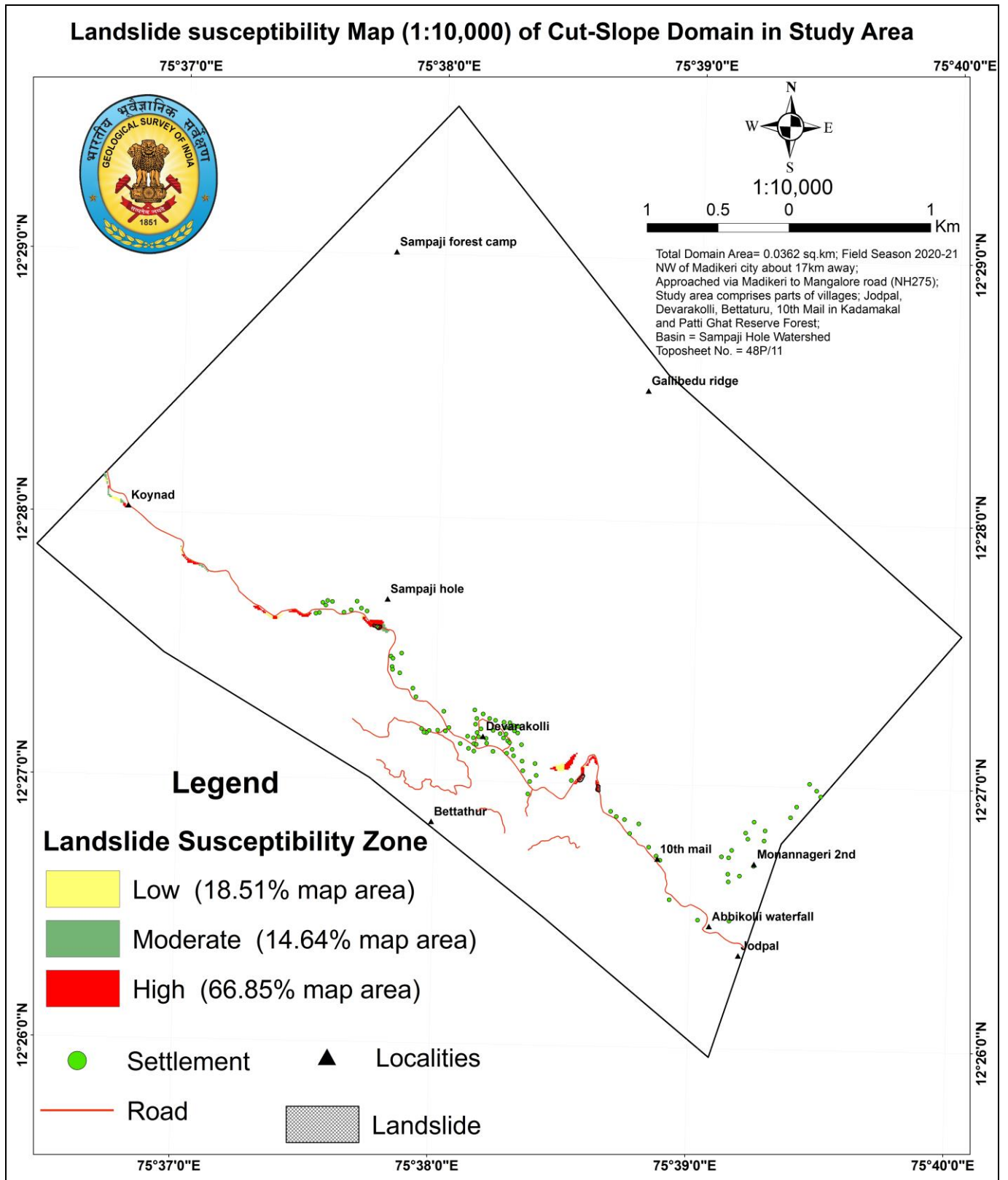


Figure-4.21: Landslide susceptibility map of the cut-slope domain in the study area

CHAPTER – 5

CONCLUSIONS AND RECOMMENDATIONS

Thorough discussions on field observations, analysis and interpretation of field data collected during the field survey in each failure domain, interpretation of geotechnical parameters of overburden samples collected in debris slide and earth slide domains, and the final landslide susceptibility score map for each failure domain and their prediction ability have provided a deep understanding to summarize the conclusions of the whole investigation.

5.1 Conclusions

- ❖ The study area of 20 sq. km is a part of hilly terrain in Western Ghat and contains overburden material covering over 18.95 sq. km area whereas the rock covered area is only 0.50 sq. km area and the rest 0.55 sq. km area is occupied by water bodies. Out of the 18.95 sq. km area of overburden cover, 5.90 sq. km area is earth material and 13.05 sq. km area is debris material.
- ❖ The study area is a part of the 6th stream order-level watershed with a 62.58 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 streams.
- ❖ Two minor fold types were observed in the study area. One fold is observed as tight, plunging vertically and its axial plane is parallel to the regional foliation strike. However second fold is observed as open, plunging vertically and its axial plane is perpendicular to the regional foliation strike. It is concluded that a joint system which may be the cleavage plane of second fold is intersecting with foliation plane due to which small sized rock fragments have detached from in-situ rock outcrops which are most susceptible to move downslope. This interference between joint and foliation planes has played an important role in evolutionary process of hilly terrains in the study area.
- ❖ The NE-SW trending joint sets (J2 and J4) are observed frequently in the study area. These joint sets are closely spaced and have a dependent relationship with the regional foliation in the area. Joint set J2 would be the cleavage plane of the regional fold in the area. These joint sets play a prominent role in the erosional process & evolution of hilly terrains and the development of different geomorphological features in the area. The southwestern side of Galibido ridge is one of the examples where surface outcrop material is torn out under the influence of these joint sets.
- ❖ The process of dislocation of wedge blocks by the interference of J1, J2 joint sets, and foliation plane (see stereonet-9) is also playing a prominent role in the erosional process & evolution of

hilly terrains and the development of different geomorphological features in the area. The dislocated blocks are susceptible to move on slopes that are open to the atmosphere in NE direction preferably within 20° slope window. This possibility of the vulnerability of wedge failure is witnessed in the Devarakolli village area where a wide colluvium zone has evolved by this phenomenon. The joint data analysis and their stereo-net plots are favoring these two possibilities of dislocation of rock blocks from an intact rock outcrop in the study area.

- ❖ Some fault-related geomorphological and lithological evidence have been observed along a zone in the NE and SW direction of Abbikolli waterfalls. These shreds of evidence suggest that a fault is traversing through the area wherein there would be more chances of mass movement in the future.
- ❖ Total 20 nos. of landslides have been demarcated using inputs of remote sensing data sources and field study. Landslides demarcated from remote sensing sources have been checked and validated during field study and were found existing on the ground. All 20 nos. of landslide sites were studied thoroughly during the field study. It is observed that all landslides are rainfall-induced and most of the landslides have occurred in the overburden domain. Both natural, as well as anthropogenic-related causes, were found responsible for landslide occurrences in the area. 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. Whereas in anthropogenic causes, cutting of natural slopes for road construction and 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 2018 rainfall period as per the local inhabitants. After analyzing the rainfall data from 2015-2018, the conclusion made by *Aijaz Ahmad Bhat and Dr. Zameer Ahmad Shah., 2019* has been found quite relevant that the Madikeri taluk in which present study area lies, received more than 4000mm actual rainfall during June-September period 2018 which accounts 2000mm rise over 2500mm actual rainfall intensity in previous three years record. The 2000mm rise in actual rainfall intensity not annually but in a particular event (June-September) has resulted mostly debris and earth flows and subsequently stream channel erosion by landslide debris material through runout distance.
- ❖ It is concluded indirectly from analysis of daily rainfall data recorded at Madikeri, Galibidu and Sampaje rainfall stations that for the study area and its adjoining area, the 150mm rainfall is the threshold limit and whenever the said threshold limit would achieve, the hill slopes which have some inherent weaknesses in overburden material or the hill slopes on which cut-slopes are given, would be considered most susceptible for landslides.

- ❖ In the present study, the upscaled mapping methodology is adopted for the preparation of various geo-factor feature classes which are generic in nature. The landslide domain-based approach (called earth surface failure domain modeling) 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 domain were prepared by incorporating both remote sensing as well as field inputs to enhance the qualitative property of each feature class.
- ❖ There are five failure/landslide domains identified in the study area viz; rock slide domain, rockfall 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.
- ❖ The landslide susceptibility to a rock slide and rockfall has been assessed in the 0.50 sq. km area of the rockslide and rockfall domain. In the rockslide domain, qualitatively the adopted model has predicted 5.35 percent map area in high susceptibility and 71.47 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 23 percent map area. Whereas in the rockfall domain, qualitatively the adopted model has predicted 21.62 percent map area in high susceptibility and 49.84 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 28.54 percent map area. The high susceptibility class has retained those areas which are more prone to rock slides and rockfall.
- ❖ The landslide susceptibility to debris slides and earth slides has been assessed in the 18.95 sq. km area of the debris slide and earth slide domain. Qualitatively the adopted model has predicted 29.05 percent map area in high susceptibility and 45.35 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 25.59 percent map area.
- ❖ The cut-slopes in the study area have been given mostly by anthropogenic activities for road construction and settlement buildings construction purposes over 0.0362 sq. km area. It is observed during the field study that places, where untreated cut-slopes have been given, are more prone to landslides and efficiently the high susceptibility class has retained those areas in the applied model. Qualitatively the adopted model has predicted 66.85 percent map area in high susceptibility and 18.51 percent map area in low susceptibility with efficacy and there is the least uncertainty in terms of moderate susceptible class over 14.64 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. Each watershed can perform as per the natural conditions apply without any human interference. 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 in flooding areas of higher-order streams or main draining streams which receives waters from all lower hierarchy stream orders during heavy rainfall period.
3. Proper lined drainage network arrangements on natural slopes with societal importance and along roads should be given so that runoff waters during rainfall periods would be easily drained out.
4. The areas showing high susceptibility in the rockslide and rockfall domain and their zone of influence should be avoided for any type of settlement construction until and unless the high susceptible rock outcrop portions would be treated or reinforced by appropriate stabilization measures.
5. The slope modifications and cut-slopes should be avoided but if given for any purpose should not be left untreated. However, the untreated cut-slopes showing high susceptibility should be immediately reinforced by appropriate stabilization measures.
6. Seven probability high risk (PHR) zones have been identified in the study area and were shared with 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 present study) will achieve, the district administration authorities should be remain on high alert to evacuate the public from hill slopes which are falling in high to moderate landslide susceptibility in surrounding areas of Madikeri, Galibidu and Sampaje rainfall stations as per the investigations carried out by GSI under NLSM and Meso-scale landslide susceptibility programmes.

5.3 Landslide Management Mapping and Area Specific Recommendations

Overburden Slopes

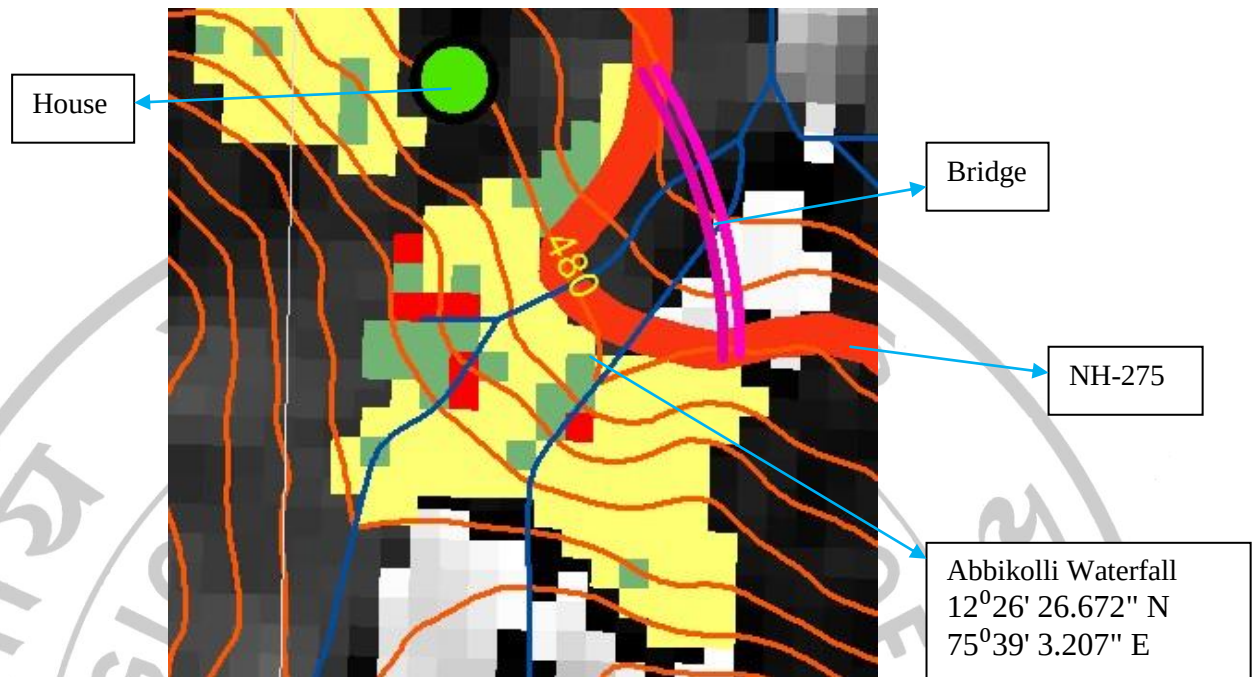
1. Tensional cracks are observed opposite to the Abbikolli waterfall slope, right bank of Sampaji Hole. The area falls under the moderate to highly susceptible and 2-3 settlements are also situated on that

slope. It is recommended that along the nala concrete structure be given to minimize the aggravation or extension of the tensional cracks. Infiltration of surface water may reactivate the presence of tensional cracks, therefore, a contour drain is recommended to channel the water to the nearby streamlet in the south of the settlements. In addition, large-scale slope modification on these slopes must be avoided as these slopes represent potential slope instability during an adverse hydrological condition.

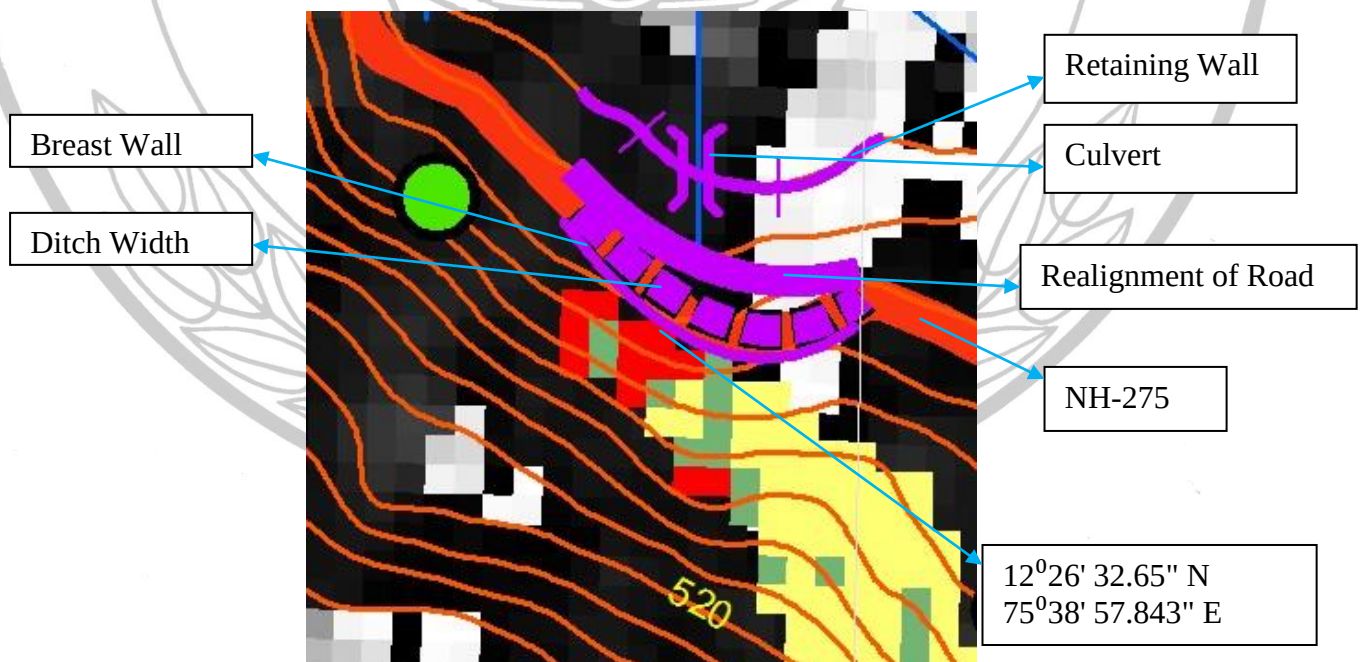
2. From the Abbikolli waterfalls 0.6 km towards NNE, the slopes are highly susceptible and three settlements are located at different levels after modifying the natural slope, where extensive slope cut has been made ($12^{\circ} 26'43.83''$ N/ $75^{\circ}39'9.75''$ E and $12^{\circ} 26'45.59''$ N/ $75^{\circ}39'9.55''$ E). The slope is characterized by the steeply dipping and pockets of weathered rock and thick insitu soil. To prevent the slope behind the lower level settlement, a concrete wall is to be constructed and for the upper-level settlement, benching has to be done.
3. From the NNE, down of the Galibeedu ridge tow settlements ($12^{\circ} 27'39.69''$ N/ $75^{\circ}39'52.06''$ E and $12^{\circ} 27'37.89''$ N/ $75^{\circ}39'53.29''$ E) are evacuated during the rainfall time as the area comes under the high susceptible zone.
4. From the Devarakolli village, 0.5km towards Madikeri, right bank of Sampaji Hole down the road bench one settlement ($12^{\circ} 27'1.24''$ N/ $75^{\circ}38'38.60''$ E) were located. During field traverses, noted the presence of creep movement. The susceptibility map shows area comes under the moderate to high susceptible class. To protect this slope down the road bench retaining wall has to be provided and along the right bank river training is recommended to avoid the toe cut.
5. In the Devarakolli Chamudeshwari temple, upslope comes under the moderate to highly susceptible zone. To avoid further slope movement, it is recommended that benching of both the flanks and construction of boulder gabion wall in the toe of the slide.
6. For the Koyanad subsidence area, it is recommended that construction of river training towards the left bank to protect the banks from erosion. Although it is noticed that the construction of retraining wall initiated down the road bench to stabilize the slope from toe erosion.

Rocky Slopes

7. It has been found that the rocky slope at Abbikolli waterfall has high susceptibility to a rock slide and rockfall. Therefore it is suggested that a bridge may be constructed over the flowing stream at a distance of 100-150 meters away from rock slope influence as illustrated below. A site-seeing viewpoint shall be constructed for visitors and the waterfall-influenced area would be declared as a no-entry zone.



8. About 500-700 meters away from Abbikolli waterfall towards 10th mail village, there is a rocky slope with <0.5m overburden cover which has high susceptibility for a rockslide, and the element at risk is NH-275. Therefore it is suggested that there is a need to realign the road, around 7-10m away from slope face which would become a ditch width to occupy the rock blocks susceptible to move. Besides a breast wall structure for slope face and retaining wall structure at the stream bank would be constructed for strengthening and a suitable culvert would be given for safe passage of runoff water.



LOCALITY INDEX

Locality Name	Longitude (DMS)	Latitude (DMS)	Elevation (m)
JODPAL	75°39' 11.443" E	12°26' 21.301" N	595
ABBIKOLLI WATERFALL	75°39' 2.895" E	12°26' 26.752" N	564
MONANNAGERI 2ND	75°39' 14.735" E	12°26' 42.254" N	606
10TH MAIL	75°38' 52.210" E	12°26' 43.048" N	518
DEVARAKOLLI	75°38' 11.107" E	12°27' 10.239" N	417
BETTATHUR	75°37' 59.426" E	12°26' 50.589" N	554
KOYNAD	75°36' 47.539" E	12°28' 1.457" N	249
GALLIBEDU RIDGE	75°38' 48.059" E	12°28' 29.830" N	1150
SAMPAJI HOLE	75°37' 48.298" E	12°27' 41.178" N	318
SAMPAJI FOREST CAMP	75°37' 48.851" E	12°29' 0.449" N	758

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ANNEXURE-I: Geo-parameters of 20 nos. of landslides demarcated in the study area

1	SLIDE_NO	KA/KOD/48P11/2020/01
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Deverakolli, Madenadu village
6	NH_SH_LOCATION	Nil
7	Latitude	12.45363
8	Long	75.63501
9	LENGTH	20
10	WIDTH	20
11	HEIGHT	15
12	LS_AREA	400
13	DEPTH	4
14	LS_VOLUME	1600
15	RUNOUT_DISTANCE	Nil
16	MATERIAL_TYPE	Earth
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Active
20	DISTRIBUTION	Widening
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	Sep-20
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Damp
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Toe erosion by 5th order river action. Increase in weight of the overburden slope material by saturation.
37	PREL_REMEDIAL_MEASURES	Provide toe support by appropriate measures.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The landslide initiated adjacent to the river bank and it happened due to toe erosion by river action. It is

		observed the failed materials are soil. The overburden thickness is 10-15m. It is recommended that the removal debris and tree trunk from the course of the stream and also suggested to provide toe support by appropriate measures.
41	ENTRY_DATE	01-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/02
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Deverakolli-1
6	NH_SH_LOCATION	NIL
7	Latitude	12.44885
8	Long	75.64133
9	LENGTH	12
10	WIDTH	15
11	HEIGHT	10
12	LS_AREA	180
13	DEPTH	3
14	LS_VOLUME	540
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Moderate
19	ACTIVITY	Dormant
20	DISTRIBUTION	Widening
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Hollow
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	HHP
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Agriculture
36	GEOSCIENTIFIC_CAUSE	Saturation of the overburden slope material and toe erosion stream and anthropogenic activities
37	PREL_REMEDIAL_MEASURES	Provide toe support by appropriate measures, stabilized by wooden piles at contour breaks.
38	REMARKS	If landslide retrograde 2-3 m, the house will get affected
39	PHOTOS	Attached
40	ABSTRACT	Small dimensional landslide happed due to the toe erosion by the stream and the river course also changed during heavy rainfall time. It is recommended

		that construction of appropriate concrete structure along the bank of the stream at necessary places (settlements) to reduce further toe erosion.
41	ENTRY_DATE	06-12-2020
42	ALERT	II



1	SLIDE_NO	KA/KOD/48P11/2020/03
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Deverakolli-2
6	NH_SH_LOCATION	NIL
7	Latitude	12.45585
8	Long	75.62995
9	LENGTH	35
10	WIDTH	30
11	HEIGHT	30
12	LS_AREA	1050
13	DEPTH	NIL
14	LS_VOLUME	0
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Moderate
19	ACTIVITY	Active
20	DISTRIBUTION	Advancing
21	STYLE	Single
22	FAILURE_MECHANISM	Deep translational failure
23	History	2016
24	Geomorphology	Hollow
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	HHP
28	HYDROLOGICAL_CONDITION	Flowing
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Plantation
36	GEOSCIENTIFIC_CAUSE	Anthropogenic activity
37	PREL_REMEDIAL_MEASURES	Proper drainage arrangement, Toe support with weep holes.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The landslide was initiated due to the combined effect of anthropogenic activity and rainfall. During the rainfall, the overburden materials (Colluvium) got saturated and failed.

		Successive crown cracks are developed over the crown. From the failed debris material flowing of water noticed, it indicates that the materials are fully saturated and material flowing towards the road. In future, the crown cracks may extend, and the chances of retrogression and widening are more. As a remedial measures construction of retaining or boulder gabion wall suggested.
41	ENTRY_DATE	13-12-2020
42	ALERT	II



1	SLIDE_NO	KA/KOD/48P11/2020/04
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Deverakolli-3
6	NH_SH_LOCATION	NH-275
7	Latitude	12.44404
8	Long	75.65476
9	LENGTH	35
10	WIDTH	10
11	HEIGHT	20
12	LS_AREA	350
13	DEPTH	NIL
14	LS_VOLUME	0
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Confined
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Hollow
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep slope and toe erosion by stream
37	PREL_REMEDIAL_MEASURE	Nil

	S	
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The landslide initiated the 2018 monsoon and presently the landslide is stabilized. The slide occurred adjacent to the small stream. The failed materials are mostly soil.
41	ENTRY_DATE	13-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/05
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Deverakolli-4
6	NH_SH_LOCATION	NH-275
7	Latitude	12.45908
8	Long	75.63054
9	LENGTH	10
10	WIDTH	20
11	HEIGHT	8
12	LS_AREA	200
13	DEPTH	3
14	LS_VOLUME	600
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Confined
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	HHP
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	Road blocked
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Plantation
36	GEOSCIENTIFIC_CAUSE	Anthropogenic activities
37	PREL_REMEDIAL_MEASURES	Easing of the slope by benching and proper toe drain maintenance

38	REMARKS	Down the road bench, the slopes are very steep and the slide material is dumped towards the valley side.
39	PHOTOS	Attached
40	ABSTRACT	The landslide occurred adjacent to the NH-275 and was initiated during the 2018 monsoon. Geo-scientific causes are toe-cutting for road construction followed by leaving the disturbed slope without providing any retention structure. The thick overburden material failed due to heavy rainfall. Remedial measures are; constructing a retaining structure and constructing a lined drain.
41	ENTRY_DATE	14-12-2020
42	ALERT	II



1	SLIDE_NO	KA/KOD/48P11/2020/06
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Monnangeri
6	NH_SH_LOCATION	NIL
7	Latitude	12.446
8	Long	75.65265
9	LENGTH	8
10	WIDTH	6
11	HEIGHT	7
12	LS_AREA	48
13	DEPTH	0.5
14	LS_VOLUME	24
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Soil
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Dormant
20	DISTRIBUTION	Confined
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	16-08-2018
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	LHP
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Plantation
36	GEOSCIENTIFIC_CAUSE	Saturation of the overburden slope material and anthropogenic activities
37	PREL_REMEDIAL_MEASURES	Reinforce the cut slope with an appropriate concrete structure.
38	REMARKS	Since the surface cracks have developed in the vicinity of the settlement, it is suggested that during rainfall the

		area should be monitored round the clock and if necessary, the people may be moved to safer places.
39	PHOTOS	Attached
40	ABSTRACT	The highly weathered rock material has failed due to cut-slope for settlement purposes. The dimension of the landslide is small but the element at risk is high. It is suggested to reinforce the cut slope with an appropriate concrete structure.
41	ENTRY_DATE	17-12-2020
42	ALERT	II



1	SLIDE_NO	KA/KOD/48P11/2020/07
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Monnangeri-I
6	NH_SH_LOCATION	NIL
7	Latitude	12.44547
8	Long	75.6526
9	LENGTH	12
10	WIDTH	8
11	HEIGHT	10
12	LS_AREA	96
13	DEPTH	1
14	LS_VOLUME	96
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Relict
20	DISTRIBUTION	Confined
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	Unknown
24	GEOMORPHOLOGY	Hollow
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	LHP
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Plantation
36	GEOSCIENTIFIC_CAUSE	Steep slope, slope modified by anthropogenic activity, removal of toe support, cut-slopes made for settlement purpose
37	PREL_REMEDIAL_MEASURES	Provide toe support by appropriate concrete measures, adopt plantation of strong and long-living trees at the toe line of the slope, avoid cut-slopes and if given do not leave cut-slopes untreated.
38	REMARKS	Since the surface cracks have developed in the vicinity of the settlement, it is suggested that during rainfall the area should be monitored round the clock and if necessary the people may be vacated to safer places.

39	PHOTOS	Attached
40	ABSTRACT	The slope is modified for plantation and settlement purposes. In the right flank of the slide, loose material is still lying on the steep slope that can move down the slope at any time.
41	ENTRY_DATE	17-12-2020
42	ALERT	I



1	SLIDE_NO	KA/KOD/48P11/2020/08
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	
7	Latitude	12.44523
8	Long	75.65111
9	LENGTH	12
10	WIDTH	6
11	HEIGHT	8
12	LS_AREA	72
13	DEPTH	4
14	LS_VOLUME	288
15	RUNOUT_DISTANCE	
16	MATERIAL_TYPE	Soil
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Active
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Hollow
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Toe erosion by stream water action
37	PREL_REMEDIAL_MEASURES	Provide toe support by appropriate concrete measures.

38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The slide occurred due to a cut slope by the flowing stream. The movement of slope material may lead to further failure in future.
41	ENTRY_DATE	17-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/09
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	2nd Monnangeri
6	NH_SH_LOCATION	NIL
7	Latitude	12.45271
8	Long	75.65615
9	LENGTH	150
10	WIDTH	40
11	HEIGHT	60
12	LS_AREA	6000
13	DEPTH	7
14	LS_VOLUME	42000
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Deep translational failure
23	History	2018
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	Foliation 125/75 SW
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Damp
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	
31	PEOPLE_AFFECTED	
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep slope, toe erosion by stream water action during rainfall period, water saturation of overburden debris material due to which effective stress decreased.

37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which may be for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	It is a large dimensional landslide that occurred during the 2018 monsoon period. The failed material is debris produced from weathered rock. Despite thick vegetation, the slope material has failed by rainfall trigger.
41	ENTRY_DATE	19-12-2020
42	ALERT	III



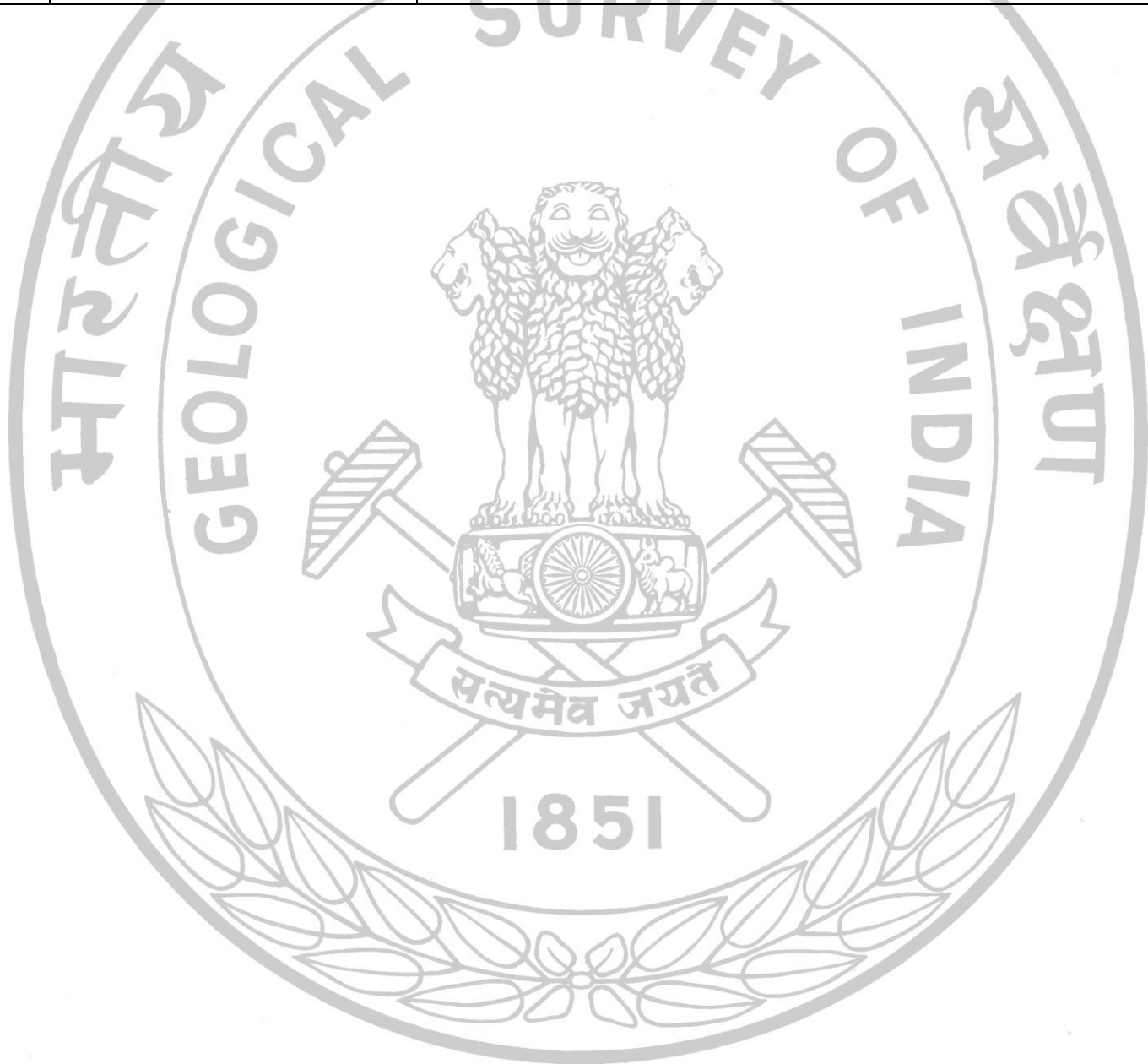
1	SLIDE_NO	KA/KOD/48P11/2020/10
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	2nd Monnangeri-1
6	NH_SH_LOCATION	NIL
7	Latitude	12.46675
8	Long	75.65182
9	LENGTH	360
10	WIDTH	110
11	HEIGHT	150
12	LS_AREA	39600
13	DEPTH	10
14	LS_VOLUME	396000
15	RUNOUT_DISTANCE	1000
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Active
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Deep translational failure
23	History	2018
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	Foot track
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep and convex barren slope, toe erosion by stream water action during rainfall period, water saturation of overburden debris material due to which effective stress decreased, increase in unit

		mass at convex portion and gravity pull
37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which may be for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	This slide occurred on a steep slope of 1st order stream during 2018 rainfall. The rock is highly weathered with thin soil cover. The failed material has moved down the stream which later performed channel erosion. The slide is retrograding as seen from the picture.
41	ENTRY_DATE	24-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/11
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	Kadamakal reserve forest
7	Latitude	12.47321
8	Long	75.63636
9	LENGTH	20
10	WIDTH	10
11	HEIGHT	15
12	LS_AREA	200
13	DEPTH	2
14	LS_VOLUME	400
15	RUNOUT_DISTANCE	
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Moderate
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Thick overburden cover produced by weathering, water saturation of overburden debris material due to which effective stress decreased

37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls or resistant wooden piles at appropriate contour intervals to enhance the toe support strength.
38	REMARKS	The slide has occurred deep inside the Kadamakal reserve forest in the sampaje hole area
39	PHOTOS	No image available as image file corrupted
40	ABSTRACT	Although the slide is small dimensional, the slide has damaged the foot tract for forest guards as well as forest animals.
41	ENTRY_DATE	24-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/12
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NIL
7	Latitude	12.48009
8	Long	75.63541
9	LENGTH	350
10	WIDTH	110
11	HEIGHT	150
12	LS_AREA	38500
13	DEPTH	10
14	LS_VOLUME	385000
15	RUNOUT_DISTANCE	2000
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Retrogressive
21	STYLE	Multiple
22	FAILURE_MECHANISM	Deep translational failure
23	History	2018
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep slope having weathered rock material, toe erosion by stream water action during rainfall period, lubrication by rainwater infiltration along the contact of overlying weathered rock material

		and hard rock surface
37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which might be good for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The landslide occurred is a debris slide and of large dimensional slide. Despite of thick vegetation, the weathered debris material has failed by rainfall trigger and the slides material has moved along stream course that performed channel erosion.
41	ENTRY_DATE	26-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/13
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NIL
7	Latitude	12.4787
8	Long	75.6307
9	LENGTH	340
10	WIDTH	85
11	HEIGHT	200
12	LS_AREA	28900
13	DEPTH	5
14	LS_VOLUME	144500
15	RUNOUT_DISTANCE	500
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Confined
21	STYLE	Single
22	FAILURE_MECHANISM	Deep translational failure
23	History	2018
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	Debris
27	LANDUSE_LANDCOVER	Flow
28	HYDROLOGICAL_CONDITION	Very rapid
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	Nil
31	PEOPLE_AFFECTED	Nil
32	LIVESTOCK_AFFECTED	Nil
33	COMMUNICATION_AFFECTED	Nil
34	INFRASTRUCTURE_AFFECTED	Nil
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep slope with considerable thick weathered rock cover, toe erosion by stream water action during rainfall period, lubrication by rainwater infiltration along the contact of overlying weathered rock

		material and hard rock surface, water saturation of overburden material which decreased effect stress level.
37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which might be good for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The landslide that occurred is a debris slide and it is a large dimensional slide. Despite thick vegetation, the weathered debris material has failed by rainfall trigger and the slide material has moved along stream course that performed channel erosion.
41	ENTRY_DATE	26-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/14
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NIL
7	Latitude	12.47867
8	Long	75.62886
9	LENGTH	450
10	WIDTH	75
11	HEIGHT	300
12	LS_AREA	33750
13	DEPTH	4
14	LS_VOLUME	135000
15	RUNOUT_DISTANCE	1500
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Abandoned
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Shallow translational failure
23	History	2018
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Thick vegetation
28	HYDROLOGICAL_CONDITION	Damp
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	Nil
31	PEOPLE_AFFECTED	Nil
32	LIVESTOCK_AFFECTED	Nil
33	COMMUNICATION_AFFECTED	Nil
34	INFRASTRUCTURE_AFFECTED	Nil
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	The steep and convex slope of the spur, toe erosion by stream water action during rainfall period, water saturation of overburden debris material due to which effective stress decreased, increase in unit

		mass at convex portion and gravity pull.
37	PREL_REMEDIAL_MEASURES	Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which might be good for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	It is a large dimensional landslide that occurred in a thickly vegetated forest during the rainfall period. The slide material has moved along the stream course that performed channel erosion.
41	ENTRY_DATE	26-12-2020
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/15
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	South of Galibeedu
6	NH_SH_LOCATION	NIL
7	Latitude	12.47596
8	Long	75.64733
9	LENGTH	200
10	WIDTH	40
11	HEIGHT	35
12	LS_AREA	8000
13	DEPTH	10
14	LS_VOLUME	80000
15	RUNOUT_DISTANCE	3000
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Flow
18	MOVEMENT_RATE	Very rapid
19	ACTIVITY	Active
20	DISTRIBUTION	Retrogressive
21	FAILURE_MECHANISM	Deep translational failure
22	STYLE	Single
23	History	2020
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Sparse vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	Nil
31	PEOPLE_AFFECTED	Nil
32	LIVESTOCK_AFFECTED	Nil
33	COMMUNICATION_AFFECTED	Nil
34	INFRASTRUCTURE_AFFECTED	Nil
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Steep slope with thick overburden cover, barren slope surface, water saturation of overburden material, toe erosion by stream water action during rainfall period, water saturation of overburden debris material due to which effective stress decreased, accumulation of excess runoff water at concave portions of slope that may have

		increase infiltration rate.
37	PREL_REMEDIAL_MEASURES	Plantation of trees/Grass/Plants which can consume more water so that slope moisture will reduce. Provide wooden bamboo walls at appropriate contour intervals to check the erosion material and slowly the contour breaks would develop which might be good for for natural toe support.
38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	This debris flow type of landslide occurred in the 2020 monsoon period and was initiated just below the Galibeedu ridge top. It is a large dimensional landslide that occurred by rainfall trigger. The slide material has moved along the stream course that performed channel erosion.
41	ENTRY_DATE	21-01-2021
42	ALERT	III



1	SLIDE_NO	KA/KOD/48P11/2020/16
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NH-275
7	Latitude	12.4483
8	Long	75.64478
9	LENGTH	12
10	WIDTH	13
11	HEIGHT	6
12	LS_AREA	156
13	DEPTH	
14	LS_VOLUME	0
15	RUNOUT_DISTANCE	
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Moderate
19	ACTIVITY	Active
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	Planar failure
23	History	2020
24	GEOMORPHOLOGY	Hollow
25	GEOLOGY	Granite gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Sparse vegetation
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	Nil
31	PEOPLE_AFFECTED	Nil
32	LIVESTOCK_AFFECTED	Nil
33	COMMUNICATION_AFFECTED	Nil
34	INFRASTRUCTURE_AFFECTED	Nil
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Cut-slope having considerable height, loose weathered rock material, an increase of unit mass of hanging material, and gravity pull

37	PREL_REMEDIAL_MEASURES	Give a site suitable and proper dimensional reinforcement by appropriate concrete measures.
38	REMARKS	Cut-slopes may be avoided but if given, then do not leave these untreated.
39	PHOTOS	Attached
40	ABSTRACT	It is a small dimensional landslide that occurred due to cut-slope during the widening of the NH-275. This type of failure has experienced to occur at the initial periods of prolonged rainfall along road, river, and settlement cut-slopes. Initially, the infiltration rate remains high and the upper overburden cover gets more and more weight day by day. During this process, the cut slope portions that are left untreated become vulnerable to landslides.
41	ENTRY_DATE	02-03-2021
42	ALERT	II



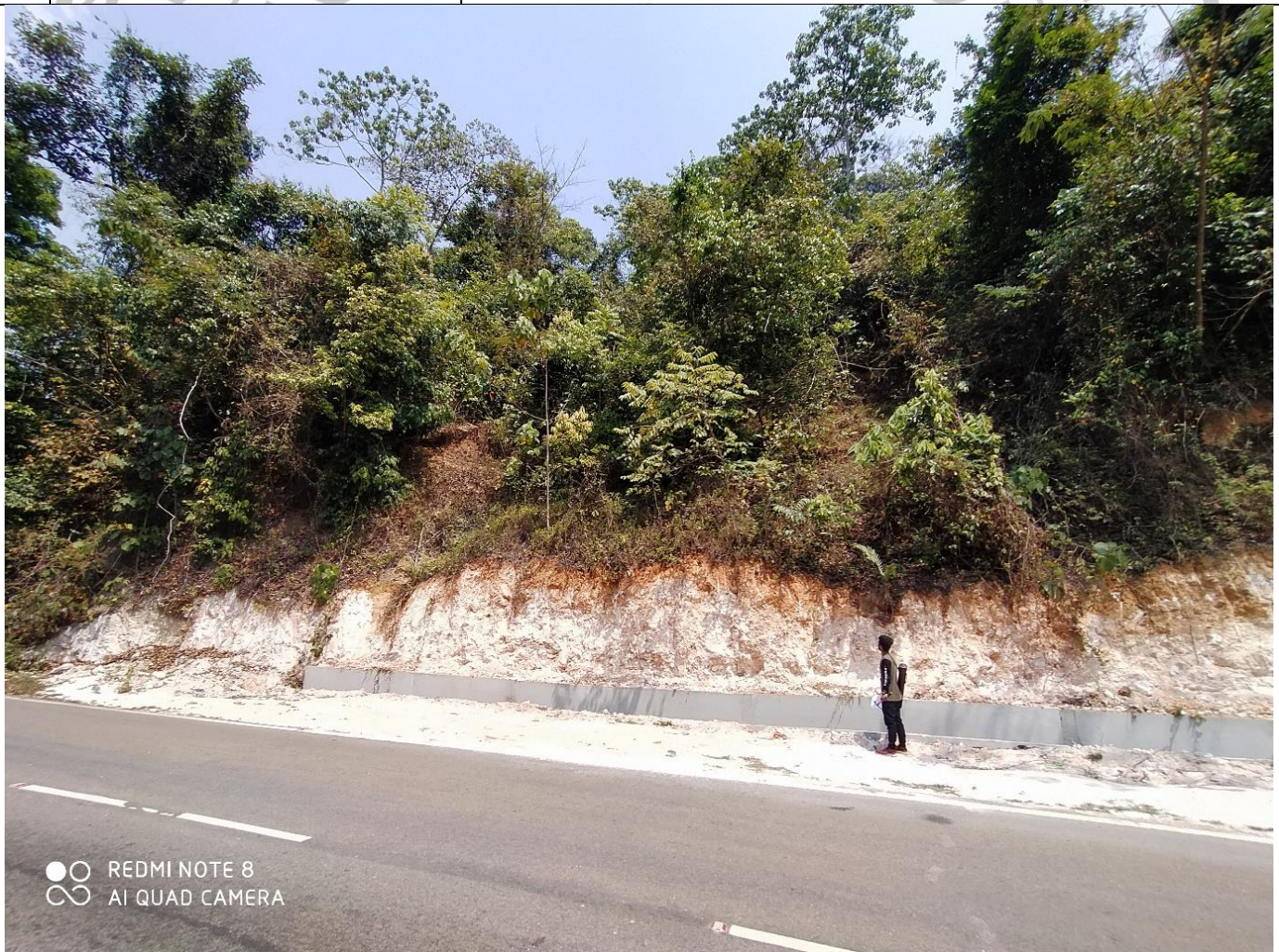
1	SLIDE_NO	KA/KOD/48P11/2020/17
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NIL
7	Latitude	12.44876
8	Long	75.64497
9	LENGTH	40
10	WIDTH	40
11	HEIGHT	20
12	LS_AREA	1600
13	DEPTH	>5m
14	LS_VOLUME	0
15	RUNOUT_DISTANCE	0
16	MATERIAL_TYPE	Soil
17	MOVEMENT_TYPE	Creep
18	MOVEMENT_RATE	Extremely slow
19	ACTIVITY	Active
20	DISTRIBUTION	moving
21	STYLE	Single
22	FAILURE_MECHANISM	Deep planar failure
23	History	2018
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite Gneiss
26	STRUCTURE	
27	LANDUSE_LANDCOVER	Road, settlement
28	HYDROLOGICAL_CONDITION	Damp
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Agriculture
36	GEOSCIENTIFIC_CAUSE	Steep slope with thick overburden cover, toe erosion by stream water action
37	PREL_REMEDIAL_MEASUR	Proper lined drainage arrangements, water-resistance toe support at

	ES	the foot.
38	REMARKS	The slope is involved in creep movement and is a critical slope having highway passing and settlement houses. Monitor the slope during rainfall period round the clock and necessary relocate the settlement houses to safer places as and when possible.
39	PHOTOS	Attached
40	ABSTRACT	The slope is under creep movement covering a large area with high elements at risk. The creep movement is manifested by bending of tree trunks, surface cracks, and tilting of trees, electric poles, settlement houses. It is not precisely known that whether there is block movement or the slope material is moving on hard rock contact but it may be downward movement of slope material due to more or less periodic toe erosion of slope by stream water action.
41	ENTRY_DATE	02-03-2021
42	ALERT	I



1	SLIDE_NO	KA/KOD/48P11/2020/18
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	
6	NH_SH_LOCATION	NH-275
7	Latitude	12.4682
8	Long	75.6109
9	LENGTH	12
10	WIDTH	8
11	HEIGHT	10
12	LS_AREA	96
13	DEPTH	1.5
14	LS_VOLUME	144
15	RUNOUT_DISTANCE	NIL
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Slide
18	MOVEMENT_RATE	Rapid
19	ACTIVITY	Active
20	DISTRIBUTION	Retrogressive
21	STYLE	Single
22	FAILURE_MECHANISM	shallow planar failure
23	History	NIL
24	GEOMORPHOLOGY	Spur
25	GEOLOGY	Dolerite
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Forest cover
28	HYDROLOGICAL_CONDITION	Dry
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	NIL
34	INFRASTRUCTURE_AFFECTED	NIL
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Cut-slope having considerable height, loose weathered rock material, an increase of unit mass of hanging material, and gravity pull

37	PREL_REMEDIAL_MEASURES	Give a site suitable and proper dimensional reinforcement by appropriate concrete measures.
38	REMARKS	Cut-slopes may be avoided but if given then do not leave these untreated.
39	PHOTOS	Attached
40	ABSTRACT	It is a small dimensional landslide that occurred due to cut-slope during the widening of the NH-275. This type of failure has experienced to occur at the initial periods of prolonged rainfall along road, river, and settlement cut-slopes. Initially, the infiltration rate remains high and the upper overburden cover gets more and more weight day by day. During this process, the cut slope portions that are left untreated become vulnerable to landslides.
41	ENTRY_DATE	02-03-2021
42	ALERT	II



1	SLIDE_NO	KA/KOD/48P11/2020/19
2	STATE	Karnataka
3	DISTRICT	Kodagu
4	TOPOSHEET	48P11
5	SLIDE_NAME	Koyanad
6	NH_SH_LOCATION	NH-275
7	Latitude	12.4682
8	Long	75.6109
9	LENGTH	80
10	WIDTH	200
11	HEIGHT	20
12	LS_AREA	0
13	DEPTH	>5m
14	LS_VOLUME	0
15	RUNOUT_DISTANCE	0
16	MATERIAL_TYPE	Debris
17	MOVEMENT_TYPE	Subsidence
18	MOVEMENT_RATE	Moderate
19	ACTIVITY	Active
20	DISTRIBUTION	Nil
21	STYLE	Single
22	FAILURE_MECHANISM	Nil
23	History	2013
24	GEOMORPHOLOGY	Slope
25	GEOLOGY	Granite gneiss
26	STRUCTURE	NIL
27	LANDUSE_LANDCOVER	Road
28	HYDROLOGICAL_CONDITION	wet
29	TRIGGERING	Rainfall
30	PERSONS_DEATH	NIL
31	PEOPLE_AFFECTED	NIL
32	LIVESTOCK_AFFECTED	NIL
33	COMMUNICATION_AFFECTED	Yes
34	INFRASTRUCTURE_AFFECTED	Road
35	LANDUSE_AFFECTED	Forest
36	GEOSCIENTIFIC_CAUSE	Toe erosion by stream water action
37	PREL_REMEDIAL_MEASURES	Proper lined drainage arrangements, water-resistance toe support at the foot.

38	REMARKS	NIL
39	PHOTOS	Attached
40	ABSTRACT	The area is involved in subsidence type of landslide. It happened 1 st in the year 2013 and this subsidence damaged the NH-275 due to which the road was blocked for 2 months.
41	ENTRY_DATE	02-03-2021
42	ALERT	I



Slide No.	KA/KOD/48P11/2021/20
State	Karnataka
District	Kodagu
Toposheet	48P11
NH/SH/Locality	NH-275 Abbikolli Waterfall
Latitude	12°26'26.32" N
Longitude	75°39'03.24" E
Length x Width x Height	10m x 10m x 6m
Volume	600m ³
Run out distance	NA
Type of Material	Rock
Type of Movement	Slide
Activity	Active
Failure Mechanism	Wedge failure in the upslope side
History	Old slide, now reactivated on 4 th September 2021
Geomorphology/Landform	Rock escarpment
Geology	Granite Gneiss
Geological Structure	Foliated and jointed rock
Landuse	Forest cover
Hydrological Condition	Dripping
Triggering Factor	Rainfall
Loss of Life/Infrastructure	No
Geo-scientific Causes	i. The presence of discontinuity planes (joint and foliation planes) in the rock and their interference pattern form wedges. ii. The lubrication along discontinuity planes in the rainfall period. iii. Lack of reinforcement to upslope side.
Remedial Measures	Appropriate reinforcement to the upslope side (maybe breast-wall and anchoring); Lined drainage in the upslope side.
Risk Category	I
Remarks if any	The rocky slope was predicted as highly susceptible in Meso-scale mapping 2020-21. A suitable treatment dimension may be selected in consultation

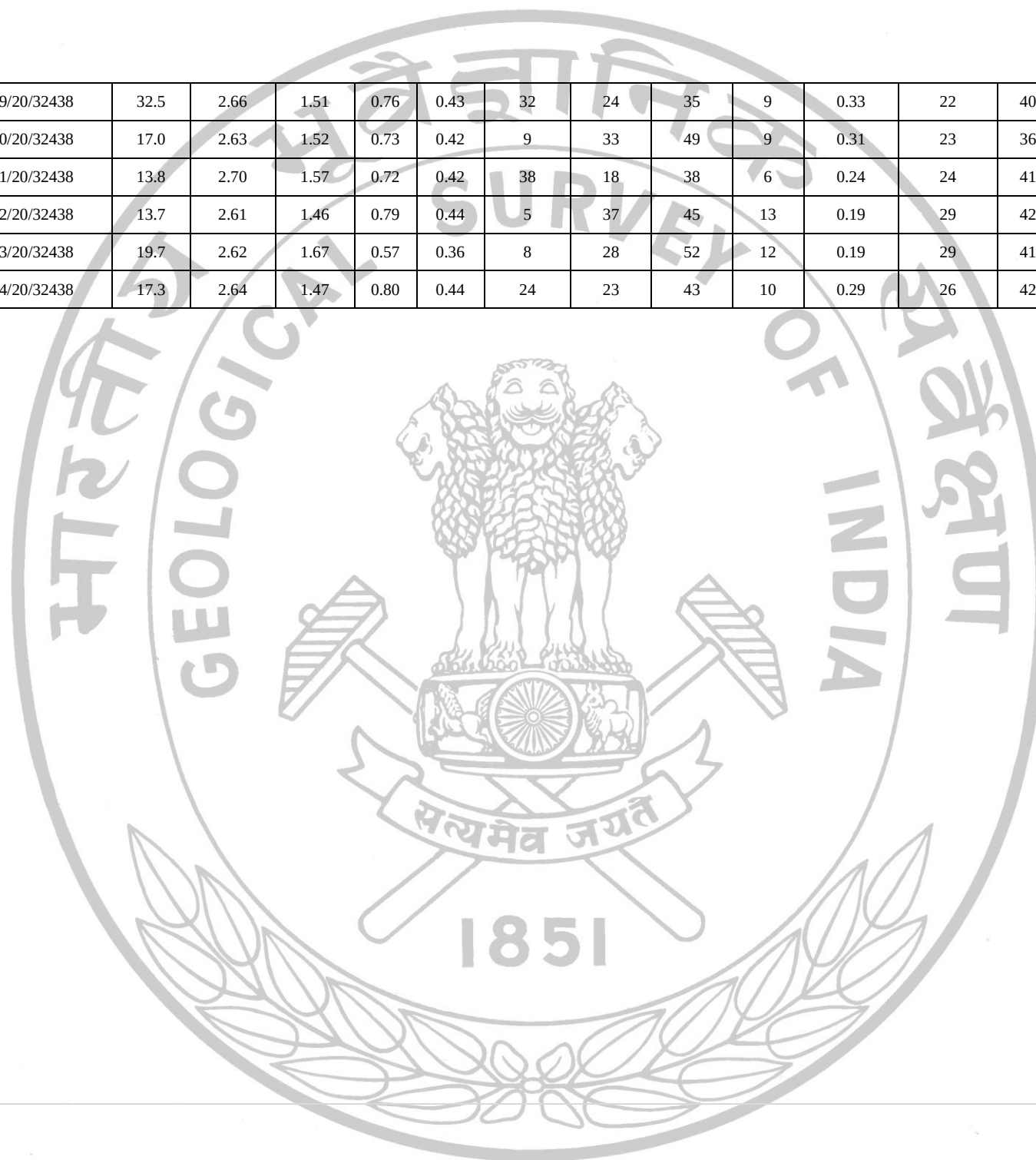
with a civil engineer. The commercial shops located to the foot of the upslope side may be relocated to safer places. The waterfall site scene viewpoint limit may be moved away from the zone of rockfall to avoid any loss of life or infrastructure. The viewpoint may be developed either on the surface or from an airlifted bridge.



Annexure-II: Geotechnical Results of Undisturbed Slope Overburden Samples (UDS)

Sr. No.	Sample Number/Code	Moisture content %	Specific gravity	Density gm/cm ³	Void ratio (e)	Porosity (n)	Grain Size				Cohesion (Kg/cm ²)	Angle of Internal friction (Ø)	Liquid Limit %	Plastic Limit %	Plasticity Index	Shrinkage Limit %
							Gravel %	Sand %	Silt %	Clay %						
1	KAR/KOD/48P11/UDS/G01/20/32438	19.7	2.63	1.74	0.51	0.34	7	26	57	10	0.31	22	39	29	10	15
2	KAR/KOD/48P11/UDS/G01A/20/32438	23.6	2.67	1.66	0.61	0.38	11	20	63	6	0.24	25	38	29	9	17
3	KAR/KOD/48P11/UDS/G01B/20/32438	23.0	2.68	1.62	0.65	0.39	8	16	66	10	0.31	23	41	31	10	20
4	KAR/KOD/48P11/UDS/G02/20/32438	18.8	2.58	1.42	0.82	0.45	12	12	67	9	0.32	22	42	30	12	19
5	KAR/KOD/48P11/UDS/G03/20/32438	17.6	2.65	1.49	0.78	0.44	4	35	53	8	0.29	21	40	29	11	20
6	KAR/KOD/48P11/UDS/G04/20/32438	18.7	2.68	1.75	0.53	0.35	15	39	40	6	0.24	26	35	25	10	17
7	KAR/KOD/48P11/UDS/G05/20/32438	13.9	2.66	1.63	0.63	0.39	11	37	43	9	0.33	22	38	30	8	13
8	KAR/KOD/48P11/UDS/G06/20/32438	14.9	2.65	1.67	0.59	0.37	11	40	44	5	0.24	23	40	31	9	15
9	KAR/KOD/48P11/UDS/G07/20/32438	20.4	2.62	1.67	0.57	0.36	12	12	70	6	0.26	24	41	31	10	19
10	KAR/KOD/48P11/UDS/G08/20/32438	19.5	2.64	1.78	0.48	0.32	31	32	28	9	0.29	21	42	31	11	14
11	KAR/KOD/48P11/UDS/G09/20/32438	14.3	2.67	1.70	0.57	0.36	6	39	45	10	0.29	21	36	28	8	17
12	KAR/KOD/48P11/UDS/G10/20/32438	12.2	2.64	1.58	0.67	0.40	17	33	41	9	0.30	22	40	30	10	16
13	KAR/KOD/48P11/UDS/G11/20/32438	31.0	2.75	1.62	0.70	0.41	16	26	48	10	0.30	23	38	30	8	18
14	KAR/KOD/48P11/UDS/G12/20/32438	17.9	2.61	1.78	0.47	0.32	18	37	36	9	0.32	22	43	34	9	15
15	KAR/KOD/48P11/UDS/G12A/20/32438	26.5	2.64	1.69	0.56	0.36	17	27	50	6	0.23	25	39	31	8	12
16	KAR/KOD/48P11/UDS/G13/20/32438	23.3	2.52	1.79	0.41	0.29	13	36	46	5	0.24	23	38	27	11	17
17	KAR/KOD/48P11/UDS/G14/20/32438	14.7	2.62	1.78	0.47	0.32	16	44	34	6	0.24	23	36	26	10	14
18	KAR/KOD/48P11/UDS/G15/20/32438	13.3	2.67	1.57	0.70	0.41	19	34	36	11	0.28	25	40	31	9	17
19	KAR/KOD/48P11/UDS/G16/20/32438	16.4	2.70	1.57	0.72	0.42	6	46	36	12	0.19	29	36	25	11	18
20	KAR/KOD/48P11/UDS/G17/20/32438	18.7	2.61	1.53	0.71	0.42	8	29	52	11	0.27	25	40	31	9	21
21	KAR/KOD/48P11/UDS/G18/20/32438	14.8	2.63	1.46	0.80	0.44	16	34	40	10	0.27	25	36	28	8	18

22	KAR/KOD/48P11/UDS/G19/20/32438	32.5	2.66	1.51	0.76	0.43	32	24	35	9	0.33	22	40	29	11	14
23	KAR/KOD/48P11/UDS/G20/20/32438	17.0	2.63	1.52	0.73	0.42	9	33	49	9	0.31	23	36	28	8	20
24	KAR/KOD/48P11/UDS/G21/20/32438	13.8	2.70	1.57	0.72	0.42	38	18	38	6	0.24	24	41	29	12	18
25	KAR/KOD/48P11/UDS/G22/20/32438	13.7	2.61	1.46	0.79	0.44	5	37	45	13	0.19	29	42	32	10	21
26	KAR/KOD/48P11/UDS/G23/20/32438	19.7	2.62	1.67	0.57	0.36	8	28	52	12	0.19	29	41	32	9	22
27	KAR/KOD/48P11/UDS/G24/20/32438	17.3	2.64	1.47	0.80	0.44	24	23	43	10	0.29	26	42	31	11	19



Annexure-III: Geotechnical Results of Disturbed Slope Overburden Samples (DS)

Sr. No.	Sample Number/Code	Specific gravity	Grain Size			
			Gravel %	Sand %	Silt %	Clay %
1	KAR/KOD/48P11/DS/G01/20/32438	2.63	3	40	48	9
2	KAR/KOD/48P11/DS/G01A/20/32438	2.61	4	42	44	10
3	KAR/KOD/48P11/DS/G03/20/32438	2.65	10	45	39	6
4	KAR/KOD/48P11/DS/G04/20/32438	2.63	5	41	44	10
5	KAR/KOD/48P11/DS/G05/20/32438	2.65	5	45	39	11
6	KAR/KOD/48P11/DS/G06/20/32438	2.66	2	50	39	9
7	KAR/KOD/48P11/DS/G09/20/32438	2.67	1	39	49	11
8	KAR/KOD/48P11/DS/G10/20/32438	2.65	12	51	30	7
9	KAR/KOD/48P11/DS/G11/20/32438	2.69	5	45	41	9
10	KAR/KOD/48P11/DS/G12/20/32438	2.63	10	38	42	10
11	KAR/KOD/48P11/DS/G12A/20/32438	2.64	5	42	47	6
12	KAR/KOD/48P11/DS/G14/20/32438	2.66	6	33	50	11
13	KAR/KOD/48P11/DS/G15/20/32438	2.67	5	43	41	11
14	KAR/KOD/48P11/DS/G16/20/32438	2.70	0	38	50	12
15	KAR/KOD/48P11/DS/G17/20/32438	2.65	5	41	44	10
16	KAR/KOD/48P11/DS/G18/20/32438	2.66	3	35	51	11
17	KAR/KOD/48P11/DS/G19/20/32438	2.67	5	37	47	11
18	KAR/KOD/48P11/DS/G20/20/32438	2.69	8	49	36	7
19	KAR/KOD/48P11/DS/G21/20/32438	2.65	8	41	40	11
20	KAR/KOD/48P11/DS/G24/20/32438	2.67	8	43	41	8





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