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A REPORT ON THE LANDSLIDE HAZARD ZONATION OF MADIKERE TOWN ON MESOSCALE, COORG DISTRICT, KARNATAKA

(Progress Report for the Field Season 2007-08 & 2008-09)
Code No.: LHZ/SR/KG/2007/045-062

BY

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(क्षेत्र सत्र 2007-08 एवं 2008-09 के प्रगति प्रतिवेदन)

कूट सं.: एल.एच.जेड/एस.आर./के.जी./2007/045-062

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सारांश

हाल ही कुछ वर्षों में, भूस्खलन आपदाओं से सार्वभौमिक जनता संपत्ति एवं मानव जीवन की अपरिमित हानि से अवगत हुई है. मडिकेरी शहर कर्नाटक राज्य के कूर्ग जिले का जिला मुख्यालय है. यह सघन रूप से लोगों से भरा है एवं पश्चिमी घाट के उच्च पर्वतों में स्थित है. पिछले दो सदियों से पर्वतों के संवर्द्धित जमीन उपयोग प्रतिमान के साथ शहर के अनियोजित विस्तार से क्षेत्र के ढालों के प्राकृतिक संतुलन को हानि पहुँची है. मानसून के समय निरंतर वर्षा के साथ इन घटकों से क्षेत्र में कई लघु स्खलन उत्पन्न होते है. यद्यपि इन भूस्खलनों का विमा बहुत ही लघु है, इससे संपत्ति को हानि पहुँची है एवं दुर्घटना भी हुए है. उक्त अध्ययन का उद्देश्यों में थिमैटिक मानचित्रों का निर्माण जिसमें भूविज्ञान, जमीन का उपयोग, जमीन कवर, ढाल आकृति आदि, भूस्खलन तालिका को तैयार करना एवं भूस्खलन जोखिम न्यूनीकरण मानचित्र को तैयार करना आदि शामिल है. यह अन्वेषण जी.आई.एस. प्लैटफार्म पर जी.आई.एस. के प्रस्तावित मार्गनिर्देशों जिसमें डी.ई.एम. का निर्माण, ढाल फलक मानचित्र, ढाल आकारमिति, अश्म विज्ञान, संरचना, जमीन का उपयोग, जमीन कवर, तुलनात्मक उच्चावच, ढाल अपरदन स्थिति, भूस्खलन आपात, औसत वार्षिक वर्षा, भूकम्पनीयता आदि शामिल है, के अनुसार किया गया. भूस्खलन के लिए उत्तरदायी घटक एवं मार्गनिर्देशों के अनुसार उनकी श्रेणी कुल अनुमानित आपदा मूल्य (टी.ई.एच.डी.) को आकलित करने के लिए एवं संस्तरों को वर्गीकृत करने के लिए डटे हुए थे. अन्वेषण के दौरान यह देखा गया कि ज्यादातर स्खलन मलबे स्खलन या अवसर्पण है जो सडक निर्माण के लिए प्राकृतिक ढालों को काटने से उत्पन्न हुए है. अन्वेषण के दौरान यह देखा गया कि घाट अनुभागों में भारी वर्षा के कारण अर्ध्वाधर कट ढाल में कुछ कमियाँ आई है. अध्ययन क्षेत्र में एक लघु ढाल है जिसका ढाल कोण $< 15^{\circ}$ है. इस क्षेत्र का अश्म विज्ञान ग्रेनाइट, नाइस एवं मेटाबेसाल्ट है. अध्ययन क्षेत्र में जमीन के उपयोग पर्टेन में प्राकृतिक एवं मानवीय हस्तक्षेप देखे गए है. प्राकृतिक घटकों में स्थलाकृति, वर्षा एवं मौसम, ढाल कोण, मृदा कवर आदि शामिल है, जमीन के उपयोग का पर्टेन एवं मानवीय हस्तक्षेप का पता चलता है जो मुख्यतया जनसंख्या की सघनता, लोगों के पेशा, तकनीकी विकासों के विस्तार एवं सामाजिक-आर्थिक घटक आदि के कारण है. चूंकि इस क्षेत्र के ज्यादातर स्खलन कर्नाटक राज्य के पश्चिमी घाट के विकास कार्यक्रमों के कारण है. कट ढाल कोण एवं ऊँचाई सभी स्खलनों में मुख्य भूमिका अदा करती है.

कुल अनुमानित आपद मूल्य के अनुसार चार जोखिम संस्तरों का पता लगाया गया है. डाटा के विश्लेषण एवं आई. एल. डब्ल्यू.आई.एस 3.4 का प्रयोग करके मॉडल निर्माण से सबसे कम मूल्य वाले जोखिम संस्तर 17.5 वर्ग किमी का है (कुल अन्वेषित क्षेत्र का 21%), कम मूल्य वाले जोखिम संस्तर 62.3 वर्ग किमी का है (अन्वेषित क्षेत्र का 74%), सामान्य मूल्य वाले जोखिम संस्तर 5.41 वर्ग किमी (अन्वेषित क्षेत्र का 6%) एवं उच्च मूल्य वाले जोखिम संस्तर 0.2 वर्ग किमी (अन्वेषित क्षेत्र का 0.27%) मिला है.

सिफारिशों में कुछ स्खलनों के अस्थाई क्रौण भाग को निकालना, तलों के श्रेणीयन के द्वारा ढाल का भूज्यामितीय संवर्द्धन,ढाल के संरक्षण का जैव तकनीकी उपाय एवं उचित जलनिकास आदि दिए जाते है.

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ABSTRACT

In recent years, a number of major landslide disasters have made the global community aware of the immense loss of property and human lives. Madikere town, being the district headquarters of Coorg district, Karnataka, is densely populated and lies in the high hills of Western Ghats. For the past two centuries unplanned expansion of the town along with modified land use pattern in the hills have disturbed the natural equilibrium of the slopes of the area. These factors together with continuous heavy rainfall during monsoons trigger many small slides in the area. The landslides even though have small dimensions have destroyed property and caused casualties. The objectives of the present study includes preparation of thematic maps covering themes such as geology, land use, land cover, slope, aspect etc., preparation of landslide inventory and preparation of Landslide Hazard Zonation map. The investigation was carried out in GIS platform using proposed guidelines of GIS which includes preparation of DEM, Slope facet map, slope morphometry, lithology, structure, land use, land cover, relative relief, slope erosion condition, landslide incidences, average annual rainfall, seismicity etc,. Factors responsible for landslides and their ratings as envisaged in the guidelines were adhered to calculate the Total Estimated Hazard (TEHD) value and classifying the zones. During investigation it is observed that majority of the slides are debris slides occurred due to cutting of the natural slope for making roads. The vertical cut slopes have failed due to heavy rain in the ghat section during monsoon. The maximum portion of the study area has a very gentle slope with general slope angle <15º. Lithology of the area is granite, gneiss and meta basalt**.** Both the natural and human interference factors in land use pattern are noticed in the study area. The natural factors include topography, rainfall and climate, slope angle, soil cover as it defines the pattern of land use and the human interference is mainly due to the population density, occupation of people, extent of technological development and socio-economic factors as majority of the slides in this area and the Western Ghats of Karnataka are due to slope cut for developmental activities. Cut slope angle and height play a major role in all the slides

Four hazard zones are identified as per the total estimated hazard value viz. Very Low Hazard zone covering an area of 17.5 Sq.km (21% of the total area investigated), Low Hazard zone covering 62.3Sq.km (74% of the total area), Moderate Hazard zone covering 5.41Sq.km (6% of the area) and the high hazard zone covering 0.2Sq.km (0.27% of the area) as per the analysis of data and creation of the model using ILWIS 3.4.

The recommendations suggested include, removal of the unstable crown part in some slides, geometrical modification of the slope by grading by benches, bio-technical measures of slope protection and proper drainage.

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1. INTRODUCTION

1.1. **Background:** Coorg or Kodagu (originally called Kodaimalenadu) means 'dense forest on steep hill'. Dubbed as the Scotland of India, Madikeri, the district headquarters of Coorg, is situated at an elevation of 1525m from msl and was founded in 1681 by Muddu Raja, the prince of the Haleri dynasty and was hence named as Muddurajakeri, which later became Madikeri. The town emancipated from the rustic trade center to a marketing hub for tea, coffee and spices. The aroma of the township not only lies in the valor of its people but also the beauty bestowed upon it by the nature.

The Madikere town, being the district headquarters of Coorg district, Karnataka, is thickly populated and lies in the high hills of Western Ghats. For the past two centuries the unplanned expansion of the town along with modified land use pattern in the hills have disturbed the natural equilibrium of the slopes of the area. Hence the continuous heavy rainfall during monsoons triggers many small slides in the area. The landslides even though have small dimensions have destroyed properties and recorded casualties.

Geological Survey of India after being declared as the nodal agency for Landslides in 2004-05, decided to prepare meso scale (on 1:10,000 scale) landslide hazard zonation maps for major townships in the hilly regions of the country.

The 4th July 2006 landslide that occurred along Madikere-Murnad road caused death of six persons including four children. The Deputy Commissioner of Madikere (vide letter no PV(ND)/292/06/07 dated 05.03.2007) requested GSI to take up for Landslide hazard Zonation of Madikere town to mitigate the continuing problem year after year. Keeping in view the said request, the vulnerability to the trade center and the popular tourist destination, it was proposed to take up Land slide hazard zonation of the Madikere town in meso scale (1:10,000 scale).

In view of the small dimensions of the slides a meso-scale mapping on 1:10,000 scale was proposed to make more accurate models. Non-availability of the required topographic maps on 1:10,000 scale for the area was a hindrance, as there was no base map to carry out the investigation. Hence the CARTOSAT - I stereo images were used to derive the DEM (Digital Elevation Model) and calculating the slope components. The image procurement, processing was carried out at PGRS Division, GSI, SR, Hyderabad. The ortho rectified image was used to provide the base map. The accuracy of the map required for 1:10,000 scale map could not be enhanced for the X, Y and Z component by hand held GPS or the RPCs. Though DGPS Survey was suggested it could not be carried out due to non availability of the DGPS. Therefore, during MTR meeting 2008, it was decided to complete the project on 1:25,000 scale. Hence the work was taken up on 1:25,000 scale during the next field season.

The present study includes preparation of a landslide hazard zonation map for the area in and around Madikere town on 1:25,000 scale using a GIS platform. The DEM was created from CARTOSAT - I image, slope and aspect was created from the same and other layers were prepared from the available 1:25,000 scale toposheets and field work was carried out based on these base maps.

1.2. Scope and objectives of the investigation: The landslide hazard zonation (LHZ) of an area aims at identifying the landslide potential zones and ranking them in order of the degree of hazard from landslides. Landslides in Western Ghats has been a continuing problem for years, causing disruption in communication routes, damaging property and killing people. The menace of this hazard has been restricted to the monsoon season only. The ever increasing population, developmental activities and greed & need of people has changed the face of the stable slopes of the mountainous regions. The present study will give insight to the factors responsible for landslides in such a terrain. It will also help to know whether the methodology adopted for other terrains is suitable to deal with zonation in Western Ghats and throw light on the multi faceted challenge of zonation.
The objectives of the present study are:

1. Preparation of thematic maps covering themes such as geology, land use, land cover, slope, aspects, hydrology, landslide incidence etc.
2. Preparation of landslide inventory
3. Preparation of Landslide Hazard Zonation map.

1.3. Location and accessibility: The study area, located in the Malnad (central highlands) region of the Western Ghats (eastern part of Ghats), lies in the toposheet nos 48P/11/NE and 48P/15/NW and is bounded by latitudes 12º 27' 56" & 12º 24' 10" N and longitudes 75º 41' 22" & 75º 45' 59" E. It is well connected by several road networks from Bangalore, Mangalore, Chikmagalur, Mysore, Virajpet, Siddapura and Somwarpet. by SH-88, SH-89 and SH-27. The nearest railhead is Mysore which is 120 kms away from Madikere town.

1.4. Flora & fauna: A rich biodiversity is encompassed by the misty hills, imposing mountains and teak wood forests. The lush green vegetation, vast extents of tea and coffee plantation, variety of spices and a numerous species of plants dots the Malnad. Evergreen and semi-evergreen forests constitute the core of the Malnad in Western Ghats. Coorg district Consists of more than 8.8% of floral diversity of India and 37% of Karnataka amounting to 1332 species. The special distribution of all the species are distributed within the dense mixed jungles and the high shade trees in coffee, tea and other plantation areas.

The Asian Elephant, Tiger, Panther, Indian gaur, Leopard, Sambar, Four Horned Antelope, Spotted deer, Mouse deer, Leopard Cat, Small Indian Civet, Clawless Other, Common Giant Flying, Squirrel, Flying Fox are some of the important animals sheltered in the forest. 350 species of birds and thousand of insect species, 25 varieties of snakes including cobra, vipers and kraits make a lively combination of animal kingdom.

1.5. Physiography and drainage: The Kottupuzha River is the main river in the study area on which Abbey falls is located drains in the NW corner of the area, other major streams runs towards SE direction. The drainage pattern of the area is mainly dendritic, subdendritic and trellis.

1.6. Climate and rainfall: The area receives rainfall during June to September with an average annual rainfall of nearly 2700mm. The area experiences a mild summer with maximum temperature of 30°C and minimum of 20°C and winter with maximum temperature

of 20°C and minimum of 16°C.According to the Thronthwaite's classification the regions lies in per-humid i.e. those having moisture index of 100% and above. The monsoon rainfall is heavy.

1.7. Nature and quantum of work done

Sl. No.	Nature of Work	Total work envisaged	Total work completed	Remarks
1	Landslide hazard zonation/ Susceptibility mapping on mesoscale (1: 10,000 scale) using GSI proposed guidelines which includes preparation of DEM, Slope facet map, slope morphometry, Lithology, structure, Land use, Land cover, Relative Relief, Slope Erosion condition ,Landslide incidences, Average annual rainfall, seismicity etc,	80sq.km.	80Sq.km	Due to non availability of 1:10,000 scale topographic maps, the investigation was carried out in combination with 1:10,000 scale Cartosat images and 1:25,000 scale toposheets
2	Landslide inventory	AN	72	

1.8. Acknowledgements: The authors are thankful to Shri R.Panduranga, Director, Engineering Geology Division, Operations: Karnataka and Goa for his technical guidance and scrutiny of the report. They are thankful to Dy. Director General, Op: Karnataka and Goa, Geological Survey of India, Bangalore, for his guidance and support. They are also thankful to the Director, PGRS Division, SR, Hyderabad for providing the PGRS inputs necessary for the work. They are also thankful to Shri B.K.Sahoo, Senior Geologist of Training Institute Hyderabad for constructive discussion and other related GIS inputs.

2. GEOLOGY

The area exposes sequence of NW-SE trending metapelites (schist rock) of Mercara Group. The foliation strike NNW-SSE to WNW-ESE with steep SW dip. Deeply weathered residual soil profile in the area consists of debris and clayey soil (top), followed by coarse gravelly soil and lateritic clayey soil on the mid part and lithomarge clay at the bottom. The area comprises of the lithounits of Archaean, Palaeoproterozoic and Cenozoic age. The lithounits include biotite gneiss, granite gneiss, garnet-silliminite-graphite schist, garnet sillimanite kyanite gneiss of Archean age, amphibolite, charnockite and pyroxene granulite of Archean age, granite, basic intrusives (dolerite) and acid intrusives (pegmatites) of Palaeoproterozoic age, laterite of Cenozoic age.

2.1. REGIONAL GEOLOGY

The area exposes the rocks belonging to Sargur Group, Peninsular Gneiss-I of PGC and Charnockite Group, which are intruded by granites, pegmatites and dolerite dykes. (Dey and Gourishankar 1949-50, Dey et al., 1954-55). The Sargur Group comprises garnet-sillimanite schist, kyanite bearing gneiss and amphibolites. The highly metamorphosed sediments, forming the garnet-sillimanite schist and kyanite gneiss occurs as narrow and discontinuous bands in the biotite gneiss. They are exposed at number of places in the northern part, northwest of Mercara, southwest of Mercara, north and east of Bhagamandala. Small outcrops of kyanite gneiss are exposed north of Appangala and east of Tattamane. Enclaves of narrow amphibolite bands trending NW-SE are exposed in the Peninsular gneiss.

PG-I of PGC consists of biotite gneiss and migmatites characterised by compositional banding and are well exposed over a large area. Biotite gneiss is exposed in the north and eastern part. It is coarse grained, light coloured and comprises quartz, plagioclase and biotite. Pyroxene granulites and charnockites constitute another major rock suite in the area. The pyroxene granulite shows invariably a granulitic texture and banding consisting of hornblende, diopside, augite and plagioclase feldspar. The charnockites which are closely interbanded with the granulites are generally light coloured, with medium grained texture. Around Bettageri and northwest of Kodamburu in the eastern part a granite body is found intrusive into the biotite gneiss. The granite body is about 15 km in length and 2 km in width trending NW-SE. This rock found as massive boulders and consists of quartz, feldspar and biotite (Ponnuswamy, 1971).

The regional trend of the foliation in biotite gneiss is NW-SE with dip of 50^{o}-60^{o} towards south. The granites, gneiss and pyroxene-granulite in the area are used as building stones and road materials. Occurrence of mica is reported from southwest of Hosuru in the northwestern part of the area. Occurrence of kyanite is reported from north of Jodpar in the northern part and 1.5 km SE of Mercara.

Charnockite group of rocks comprise of charnockite and pyroxenite granulites. Charnockite is well exposed in the south of Kushalnagar over a large area as lenticular body found interbanded with biotite gneisses and shows clear gradations towards the latter. They are light to dark grey in colour. Generally they are of intermediate variety made essentially of quartz, intermediate plagioclase, hypersthene and hornblende. The accessory minerals include biotite, apatite, zircon and iron ore. Pyroxene granulites are well exposed as narrow linear bands trending NNW-SSE in the northern part within the PGC. The bands are 5 to 100 m wide and the strike length ranges from 1-3 km. The rock is dark coloured, medium to coarse grained and consists hypersthene, diopside, plagioclase feldspar and biotite.

A body of younger granite intrusive into the biotite gneisses is seen around Murnad in southwestern part. The rock is found as massive boulders and generally consists of quartz, feldspar and biotite. Few pegmatite veins are seen intruding into the gneisses in the

southwestern part. They are very small in dimension trending NW-SE. Thin capping of laterite measuring 5-8 m in thickness, occurs over the gneisses in the southwestern part. They are dark brown in colour and contain hematite, limonite, goethite and numerous quartz grains.

The gneisses show well developed foliations. The strike of the foliation is varying from N65^{o}W-S65^{o}E to E-W with steep northerly dips of 60^o-70^o. The gneisses show lineation trending N-S with plunge of 30^o-40^o towards south. Minor antiforms plunging 20^o-40^o towards SW recorded within PGC in the northcentral part of the area

3. METHODOLOGY

The identified location surrounding the Madikere town has been taken from the Madikere town planning map. The anticipated future developmental area has been fixed as per the type of land and its usability. Orthomap from the CARTOSAT - I stereo image on 1:10,000 scale was generated with the help of triangulation points of Survey of India toposheets on 1:25,000 scale.

As topographic maps on 1:10,000 scale was not available with Survey of India, it was decided to procure CARTOSAT - I stereo images from which DEM and Derivative maps were generated. Accuracy assessment of the data was carried out by using RPC (Rational Polynomial Coefficient) which is supplied along with the CARTOSAT - I data and the triangulation points from toposheet of 1:25,000 scale and data collected by the hand held GPS during identification of the Ground Control Points. 20 GCP (Ground control points) were selected for preparation of Orthomap from the CARTOSAT - I stereo image. As DGPS survey could not be conducted in the proposed area, and 1:10,000 scale map was not available, all the data gathered were on 1:25,000 scale toposheet with some modification incorporated using the CARTOSAT - I imagery.

The DEM generation was done using Leica Photogrammetric Suite (LPS) Module of ERDAS 9.0 software while slope and aspect maps were generated from DEM using ILWIS 3.3 software the other layers such as the landslide inventory, lithology, structure, landuse, landcover, slope erosion, average annual rainfall were created and analyzed in ILWIS 3.3 software. For the present study UTM projection (Zone 43) with WGS84 spheroid and datum has been used. Data collected for Ground Water from1975-2007 (25years) and data collected for Average annual rainfall and daily rainfall from 1970-2007(30years) were synthesized and utilized in the hazard interpretation.

The rectification and the investigation include preparation of thematic maps on lithology, structure, Hydrogeology, Slope Morphometry, Land use, Land cover and Landslide Incidences. These thematic maps will be utilized to generate a landslide susceptibility map. This will be prepared following the BIS / modified BIS Code (GSI). It also includes demarcation of Landslide incidences and preparation of their inventory along with derivation of landslide prone and susceptible areas of the Madikere town for the planners to save life and property in future.

3.1. Compilation/ preparation of pre-field thematic maps

Various thematic maps on lithology, structure, hydrogeology, slope morphometry, land use and land cover were prepared as a part of this component of the work.

3.1.1 Compilation of geological map/Lithological map

The existing geological map of the area was used with cross verification of different units in the field and as per the litholological classification provided by the guidelines. The field observations of different lithounits in the study area were incorporated. The geological

set up vis a vis development of landforms play a major role in slope development and insitu slope characteristics by which the behavior of a slope mass stability can be predicted in a broad range.

3.1.2 Preparation of slope morphometry maps

Creation of slope morphometry map involved the following steps.

1) Creation of Digital Elevation Model from the CARTOSAT-I stereo images
2) Creation of slope angle map and
2) Creation of slope aspect (slope direction) map

In slope angle map, the hill slopes of the study area were divided into five classes as per BIS classification and the aspect map was prepared by calculating height differences in X-direction and Y-direction with filter operation on the Digital Elevation Model as the input map and aspect map in radians was calculated from these maps and reclassification of the groups was done as per BIS classification.

3.1.3. Preparation of Land use and Land cover maps

Land-use and Land cover maps were prepared from the Survey of India (SOI) toposheets 48P/11/NE and 48P/15/NW, along with Cartosat image.

3.2. Field studies

The field studies includes the study of geology, structures, weathering, landslide inventory, analysis of ground slope with reference to the observed landslide incidences, effect of various geoenvironmental parameters.

3.3. Landslide inventory

During the FS 2007-08 and 2008-09, landslide inventory was carried out in the proposed study area along ghat roads and in slope area (Annexure – I, Plate – 12). A total of 80 sq km area was covered on 1:25,000 scale and 72 incidences of landslides were studied. The following ghat sections, NH and SH roads were covered during the investigation.

a) Landslides recorded along Madikere - Suliya Ghat road section SH88: 24 landslides are recorded in this ghat section in between nearly 30 km stretch. The majority of slides were found to be debris slumps and earth slumps mainly due to toe cutting of the slope for making road. The lithology is mainly granite and gneisses. The vertical cut slopes have failed due to heavy rain in the Ghat section during monsoon. It was observed that the slopes are moderately to thickly vegetated and covered by tea, coffee and spices plantations .General slope angle varies from 10° to 20°. The depth of overburden consisting of soil and weathered rock varies from 0.5 to 2.0 m. The cut slope angle is 70° to 80° in most of the slides. The slides are shallow with <2m depth. Three complex slides which consist of both debris and rock slide and one rock slide with planar failures are also observed. The planes exposed by road cuttings have slipped due to heavy rain.

b) Landslides recorded along Madikere - Siddapur Ghat road section SH89 and SH88B: 15 landslides are recorded in this ghat section in between nearly 25 km stretch. The majority of slides were found to be debris slumps and earth slumps mainly due to toe cutting of the slope for making road. The lithology is mainly granite and gneisses. The vertical cut slopes have failed due to heavy rain in the ghat section during monsoon. It was observed that the slopes are moderately to thickly vegetated and covered by tea, coffee and spices plantations .General slope angle varies from 10° to 20°. The depth of overburden consisting of soil and weathered rock varies from 0.5 to 5.0 m. The cut slope angle is 70°to 80°in most of the

slides. The slides are shallow with <2 m depth. Two complex slides which consist of both debris and rock slide and one rock slide with planner failure is also observed. The planes day lighted by road cuttings has slipped along these weak planes due to heavy rain.

c) Landslides recorded along Madikere-Virajpet road section SH27: 33 landslides are recorded in this ghat section in between nearly 15 km stretch. The majority of slides were found to be debris slides and due to tampering of the natural slope for making road. The lithology is mainly granite and gneisses. The vertical cut slopes have failed due to increase in pore water pressure during heavy rain in the ghat section in monsoon. It was observed that the slopes are moderately to thickly vegetated and general slope angle varies from 10° to 20°. The depth of overburden consisting of soil and weathered rock varies from 0.5 to 2.0 m. The cut slope angle is 70° to 80° in most of the slides. The slides are shallow with <2 m depth.

4. MACROSCALE LANDSLIDE HAZARD ZONATION

4.1. General: Landslide Hazard Zonation (LHZ) indicates the susceptibility of the defined sample slope units of an area to landslides in space and time. The spatial distribution of the landslides produces a susceptibility map which divides all the similar sample units into various classes.

The landslide hazard assessment can be done either qualitatively (relative) or quantitatively (absolute). In the qualitative assessment, the relative hazard assessment techniques differentiate the likelihood of occurrence of mass movements for different areas on the map but without assigning exact values. On the contrary, the quantitative landslide hazard assessment displays an absolute value for the hazard (e.g. factor of safety or probability of occurrence) for different areas on the map (Misri et al., 2009).

The concept of Landslide Hazard Zonation starts with a definite boundary of the slope units which will fail due to the effect of combination of different geoenvironmental factors. The geoenvironmental factors with various combinations, overlays, statistics and weightage systems have evolved with time, persons and applicability because of the high degree of uncertainty involved while quantifying the effects of each factor on a slope. According to Carrara et al., (1992) main factors controlling slope stability and the degree of uncertainty associated with their data collection are tabulated below:

Factors	**Degree of uncertainty**
Geodynamic setting	High
Rock composition	Low
Rock structure	Intermediate
Ground water conditions	High
Surface water conditions	Low
Slope geometry	Low
Geomorphic processes	High/ Intermediate
Land use	Low
Human activity	Intermediate
Present climatic conditions	Intermediate
Past climatic conditions	Intermediate/ High

4.2. BIS and modified BIS code (by GSI) for macro scale Landslide Hazard Zonation

In 1998, the BIS published guidelines for preparation of Landslide Hazard Zonation maps in mountainous terrains (Code No. IS 14496 (Part 2), 1998) and the modified BIS code was circulated by GSI incorporating the few factors that were necessary to be included.
The BIS guidelines and modified BIS guidelines by GSI for macro level Landslide Hazard Zonation mapping on 1:25,000/50,000 scales are tabulated below.

A.BIS guidelines for Macrozonation (1:25,000 to 1:50,000 scale)

Sl no	***Causative factors***	***Maximum LHEF rating***
1	Lithology	2
2	Structure	2
3	Slope Morphometry	2
4	Relative relief	1
5	Land use and Land cover	2
6	Hydrological condition	1
	Total	*10*

B. Modified BIS guidelines by GSI for Macrozonation (1:25,000 to 1:50,000 scale)

Sl no	***Causative factors***	***Maximum LHEF rating***
1	Slope Morphometry	2
2	Lithology	2
3	Structure	2
4	Relative relief	1
5	Land cover	1
6	Land use	1
7	Rainfall	1
8	Hydrological condition	1
9	Landslide incidence	2
10	Slope erosion	1
	Total	*14*

As per the maximum LHEF rating the various types of Landslide hazard zones defined by the BIS guideline and modified BIS guidelines are as follows

A.BIS guidelines (1989)

Zone	*THED Value*	*Description of zone*
I	<3.5	Very Low Hazard Zone(VLHZ)
II	3.5-5.0	Low Hazard Zone(LHZ)
III	5.1-6.0	Moderate Hazard Zone(MHZ)
IV	6.1-7.5	High Hazard Zone(HHZ)
V	>7.5	Very High Hazard Zone(VHHZ)

B.GSI modified guidelines

Zone	*THED Value*	*Description of zone*
I	<4.9	Very Low Hazard Zone(VLHZ)
II	4.91-7.0	Low Hazard Zone(LHZ)
III	7.1-8.4	Moderate Hazard Zone(MHZ)
IV	8.41-10.5	High Hazard Zone(HHZ)
V	>10.5	Very High Hazard Zone(VHHZ)

5. MODIFIED BIS CODE BY GSI FOR LANDSLIDE HAZARD ZONATION IN MACROSCALE

5.1. Geoenvironmental parameters: The Landslide Hazard Zonation in and around Madikere town as per modified BIS guidelines by GSI for macro level Landslide Hazard Zonation mapping on 1:25,000/50,000 scale.The map units for data collection may have regular geometric shapes having specified dimensions or they may have irregular shapes having varied dimensions. The BIS defines the smallest map unit for zonation as "facet". A facet is a part of the hill slope which has more or less similar characters of slope showing consistent direction and inclination. The facets are generally delimited by ridges, spurs, gullies and rivers. Total ten geoenvironmental parameters considered for the study which are as follows

Sl no	***Causative factors***	***Maximum LHEF rating***
1	Slope Morphometry	2
2	Lithology	2
3	Structure	2
4	Relative relief	1
5	Landcover	1
6	Landuse	1
7	Rainfall	1
8	Hydrological condition	1
9	Landslide incidence	2
10	Slope erosion	1

5.2. Description and sub categorization of Geoenvironmental parameters: Details of the ten geoenvironmental parameters and distribution of landslide hazard evaluation factor values for subcategories of each geoenvironmental parameters as proposed by modified BIS by GSI are as follows.

5.2.1. Slope Morphometry (LHEF rating-2)

Description	*Category*	*Rating*	*Remarks (No. of contour lines of 20m interval over 100m length on 1:50,000)*	*Slope angle*
i. Escarpment/cliff	>45°	2.0	>25	>45°
ii. Steep slope	36°-45°	1.7	19-25	36°-45°
iii. Moderately steep slope	26°-35°	1.2	13-18	26°-35°
iv. Gentle slope	16°-25°	0.8	8-12	16°-25°
v. Very Gentle slope	<15°	0.5	<7	<15°

5.2.2. Lithology (LHEF rating-2)

Description		*Category*	*Rating*	*Remarks (Correcting factor for weathering)*
1.Type of rock	Type I	i. Quartzite/Limestone/BHQ etc	0.2	i. Highly weathered rock, discolored, joints open with weathered
		ii. Granite/Basalt/Charnokite etc	0.3	
		iii. Gneiss	0.4	

	Type II	i. Well cemented terrigenous sedimentary rocks dominantly sandstone with minor beds of claystone	1.0	products *Correction Factor C1* ii. Moderately weathered rock discolored with fresh rock patches, weathering more along joint planes, but rock intact in nature. *Correction Factor C2* iii. Slightly weathered rock slightly discoloured along joint planes but intact in nature *Correction Factor C3* *For rock type I-* C1=4, C2=3,C3=2 *For rock type II* C1=1.5, C2=1.25,C3=1.0
		ii. Poorly cemented terrigenous sedimentary rocks dominantly sand rock with minor clay shale beds	1.3	
	Type III	i. Slate and Phyllite	1.2	
		ii. Schist	1.3	
		iii. Shale with inter bedded clayey and non clayey rocks	1.8	
		iv. Highly weathered shale, phyllite and schist	2.0	
2. Soil type		i. Older well compacted alluvial fill material(Old river terraces	0.6	
		ii. Clayey soil over bedrock	0.8	
		iii. Sandy soil over bedrock	1.2	
		iv. Older compacted colluvial material	1.4	
		v. Poorly compacted younger loose material or slide debris	2.0	

5.2.3. Structure (LHEF rating -2)

Description	*Category*	*Rating*	*Remarks*
Relationship of structural discontinuity with slope			Discontinuity refers to the planar discontinuity or line of intersection of two planar discontinuities which ever is important from point of view of stability Œj- Dip direction of joint Œi- Direction of intersection of two discontinuities Œs-Direction of slope inclination ßj-Dip of joint ßi-Plunge of line of two
i. Relationship of parallelism between slope and discontinuity(RS) Planar(œj-œ3) Wedge(œi-œ3) œ	I.>30°	0.20	
	II. 15°-30°	0.30	
	III. 5°-15°	0.40	
	IV. <5°	0.50	
ii. Relationship of discontinuity and inclination of	I.>15°	0.3	
	II. 0°-15°	0.5	
	III. -1°-(-15)°	0.8	

slope(RI) Planar(ßj-ßs) Wedge(ßi-ßs)	IV. >(-15)°	1.0	discontinuities ßs-Inclination of slope
iii.Dip of discontinuity Planar(ßj)(DP) Wedge(ßi)	I.<15°	0.20	
	II. 16°-30°	0.25	
	III. 31°-45°	0.35	
	IV. >45°	0.50	
Depth of soil cover	<5m	0.65	*Category I* Very favourable
	6-10m	0.85	*Category II* favourable
	11-15m	1.20	*Category III* Fair
	16-20m	1.50	*Category IV* Unfavourable
	>20m	2.0	*Category V* Very unfavourable

5.2.4. Relative relief (LHEF rating-1)

Description	*Category*	*Rating*	*Remarks*
i. Low	<100m	0.3	In seismic zone II & III the maximum rating for relative relief be multiplied by 0.5.It is also considered 5.No correction is required for Zones IV &V
ii. Medium	101-300m	0.6	
iii. High	>300m	1.0	

5.2.5. Land cover (LHEF rating-1)

Description	*Category*	*Rating*	*Remarks*
i. Thickly vegetated forest area		0.4	
ii. Moderately vegetated area		0.6	
iii. Sparsely vegetated area with lesser ground cover		0.8	
iv. Barren land		1.0	

5.2.6. Land use (LHEF rating-1)

Description	*Category*	*Rating*
i. Agricultural land/populated flat land		0.2
ii. Moderately populated slope/village roads		0.5
iii. Thickly populated slope modified by large scale excavation		0.7
iv. Major communication routes involving extensive slope cutting		1.0

5.2.7. Hydrology (LHEF rating-1)

Description	*Category*	*Rating*	*Remarks*
i. Dry		0.2	
ii. Wet		0.5	
iii. Flowing/spring		1.0	

5.2.8. Average annual rainfall (LHEF rating-1)

Description	*Category*	*Rating*	*Remarks*
i. Low	<500mm	0.2	
ii. Medium	500-2000mm	0.4	
iii. High	>2000mm	0.6	
iv. History of cloud bursts		1.0	

5.2.9. Slope erosion condition (LHEF rating-1)

Description	*Category*	*Rating*	*Remarks*
i.	Deep gully erosion/rill erosion of hill slope	0.5	
ii.	Severe toe erosion by nala and river	1.0	

5.2.10. Landslide incidence (LHEF rating-2)

Description	*Category*	*Rating*	*Remarks*
i.	No landslide	0	
ii.	Dormant landslide	0.5	
iii.	One active landslide	1.0	
iv.	More than one slide or one very large active slide(material dislodged>100 cu.m)	2.0	

5.2.11. Total Estimated Hazard (THED) of each facet

Zone	*THED Value*	*Description of zone*
I	<4.9	Very Low Hazard Zone(VLHZ)
II	4.91-7.0	Low Hazard Zone(LHZ)
III	7.1-8.4	Moderate Hazard Zone(MHZ)
IV	8.41-10.5	High Hazard Zone(HHZ)
V	>10.5	Very High Hazard Zone(VHHZ)

6. ASSESSMENT OF GEOENVIRONMENTAL PARAMETRES AND LANDSLIDE HAZARD ZONATION OF THE STUDY AREA

6.1. Aspect map and facet map: The aspect map of the area shows the direction of the slope of facets. A total of 6703 facets were identified in the whole area and the majority of the slopes face either North-East or South (Fig.1).

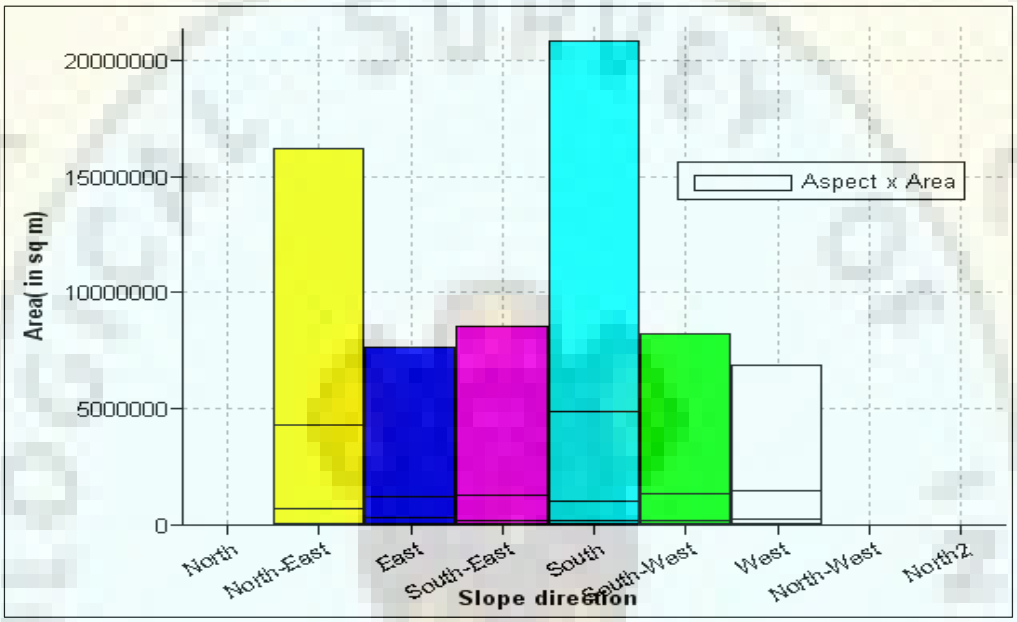
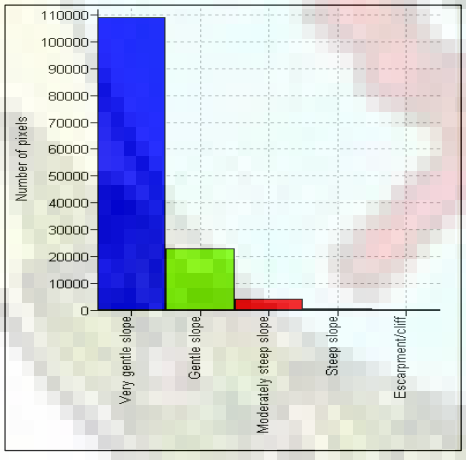


Fig 1: Distribution pattern of slope aspect

6.2. Slope morphometry (LHEF rating-2)

The slope map of the area was created from the DEM and was reclassified as per modified BIS code. The major portion of the study area has a very gentle slope with general slope angle <15º (Fig. 2). As the study area lies in the eastern fringe of Western Ghats, the denudational landforms spread across this area do not have steep gradient. The NNW-SSE trending hillock south of Madikere town has a higher slope angle than the rest of the area (Plate-4).

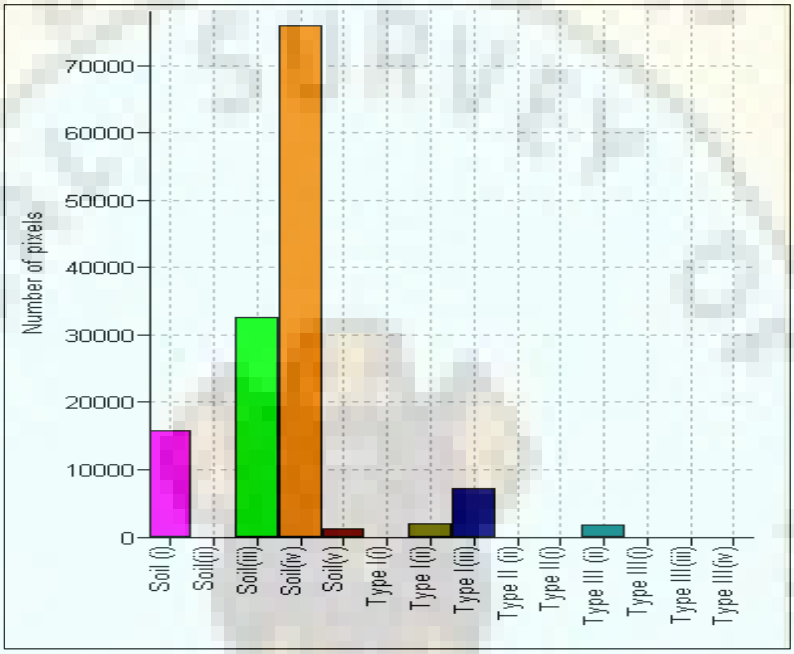


	npix	npixpct	Area
Very gentle slope	109246	79.91	68278750
Gentle slope	22967	16.80	14354375
Moderately steep slope	4154	3.04	2596250
Steep slope	333	0.24	208125
Escarpment/cliff	4	0.00	2500
Min	4	0.00	2500
Max	109246	79.91	68278750
Avg	27341	20.00	17088000
StD	46749	34.20	29218234
Sum	136704	99.99	85440000

Fig 2: The slope class distribution in the study area

6.3. Lithology (LHEF rating-2)

The lithological classification of the area has been carried out with the available geological maps and field checks during investigation (Fig. 3). The soil is generally dark brown to dark reddish brown and black in colour due to the accumulation of high organic matter under the forest cover.



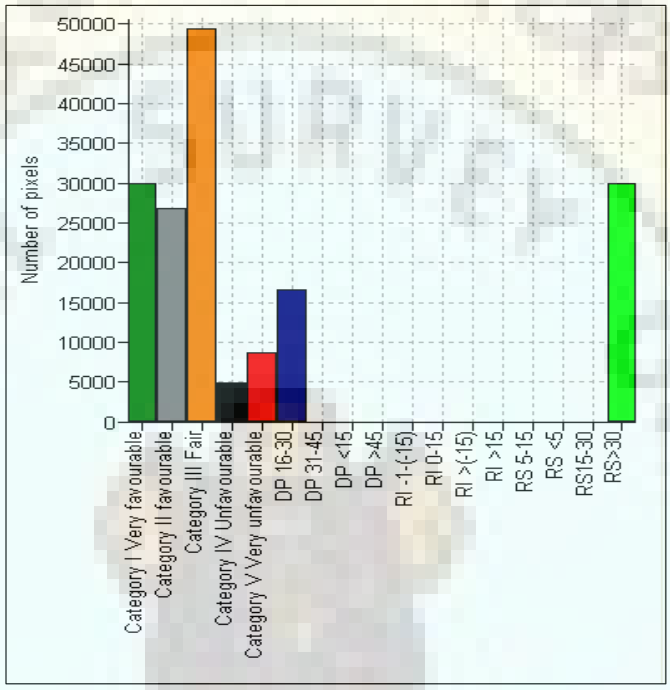
	npix	npixpct	pctnotund	Area
Soil (i)	15746	11.52	11.54	9841250
Soil(ii)	0	0.00	0.00	0
Soil(iii)	32623	23.86	23.91	20389375
Soil(iv)	75970	55.57	55.67	47481250
Soil(v)	1273	0.93	0.93	795625
Type I(i)	0	0.00	0.00	0
Type I(ii)	1874	1.37	1.37	1171250
Type I(iii)	7128	5.21	5.22	4455000
Type II (ii)	0	0.00	0.00	0
Type II(i)	0	0.00	0.00	0
Type III (ii)	1840	1.35	1.35	1150000
Type III(i)	0	0.00	0.00	0
Type III(iii)	0	0.00	0.00	0
Type III(iv)	0	0.00	0.00	0

Fig 3: Distribution of different lithological parameters in the study area

6.4. Structure (LHEF rating -2)

The structure has been defined as per the orientation of discontinuities in rock slopes and soil depth where ever it is soil covered. Discontinuity refers to the planar discontinuity or line of intersection of two planar discontinuities whichever is important from point of view of stability. For the rock slopes the disposition of discontinuities with respects to the slope orientation, parallelism between slope and discontinuity and relationship of discontinuity and inclination of slope has been evaluated to ascertain the rating. Majority slopes are found to be covered with soil. The soil cover in the flat lands has been included in the very favourable

(Category I) even though the depth of soil is >10m at many places taking into consideration that there will be no slide in these flat lands. Rest all areas has been assigned values as per the modified BIS ratings provided by GSI (Fig. 4).



	npix	npixpct	pctnotund	Area
Category I Very favourable	29861	21.84	21.94	18663125
Category II favourable	26859	19.65	19.74	16786875
Category III Fair	49295	36.06	36.22	30809375
Category IV Unfavourable	4889	3.58	3.59	3055625
Category V Very unfavourable	8613	6.30	6.33	5383125
DP 16-30	16564	12.12	12.17	10352500
DP 31-45	0	0.00	0.00	0
DP <15	0	0.00	0.00	0
DP >45	0	0.00	0.00	0
RI -1-(-15)	0	0.00	0.00	0
RI 0-15	0	0.00	0.00	0
RI >(-15)	0	0.00	0.00	0
RI >15	0	0.00	0.00	0
RS 5-15	0	0.00	0.00	0
RS <5	0	0.00	0.00	0
RS15-30	0	0.00	0.00	0
RS>30	29861	21.84	21.94	18663125
Min	0	0.00	0.00	0
Max	49295	36.06	36.22	30809375
Avg	8005	5.86	5.88	5002978
StD	14418	10.55	10.59	9011492
Sum	136081	99.55	99.99	85050625

Fig 4: Distribution of different structural parameters in the study area

6.5. Relative relief (LHEF rating-1)

The relative relief of each slope unit i.e facet has been derived from the 1:25,000 scale toposheet nos. 48P/11/NE and 48P/15/NW. The relief of the area even though reaches up to

1215 m above msl, the relative relief of each facet does not cross 100m. Hence the relative relief of the slopes in the study area lies in category I (low relative relief with <100 m height). No map for relative relief is essential. The modified BIS code envisages that the influence due to seismicity is to be included into the relative relief factor. As the area lies in seismic zone III the rating for the whole area has been given 0.3X0.5=0.15.

6.6. Land cover (LHEF rating-1):

The land cover in the studied area includes dense scrub, open scrub, cardamom plantation, coffee plantation, open jungle, eucalyptus plantation and fairly dense mixed jungle. As per the BIS guideline the code fairly inadequate to bracket the land cover type in its fold. Since the coffee and cardamom plantations require high shadows, the thickly forested areas have been modified to accommodate the plantation. Even though the plantation in this case could have been retained in type ii (i.e. moderately vegetated area), the coffee and cardamom plantations cover large areas, thus protecting the slope rather than destabilizing it. Therefore the thickly covered slopes due to coffee and cardamom plantation have been put in the thickly vegetated forest area. The eucalyptus plantation has been put in type ii i.e. moderately vegetated area (Fig. 5&5A). The predominant land cover of the area is thickly vegetated forest area and the sparsely vegetated area with lesser ground cover occupies the least area.

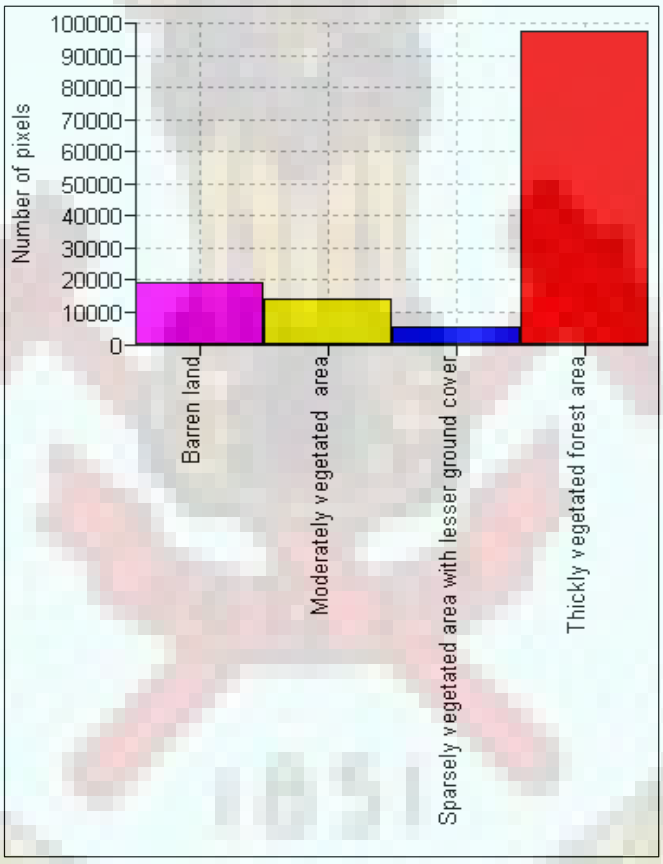


Fig 5: Distribution of different land cover types in the study area

	npix	npixpct	pctnotund	Area
Barren land	19105	13.98	14.01	11940625
Moderately vegetated area	13975	10.22	10.25	8734375
Sparsely vegetated area with lesser ground cover	5594	4.09	4.10	3496250
Thickly vegetated forest area	97650	71.43	71.63	61031250
Min	5594	4.09	4.10	3496250
Max	97650	71.43	71.63	61031250
Avg	34081	24.93	25.00	21300625
StD	42744	31.27	31.36	26714781
Sum	136324	99.72	99.99	85202500

Fig 5A: Statistical distribution of different land cover types in the study area

6.7. Land use (LHEF rating-1)

The land use pattern of an area depends on two factors viz. the natural set up and the human interference. The natural factors include topography, rainfall and climate, slope angle, soil cover as it defines the pattern of land use and the human interference is mainly due to the density, occupation of people, extent of technological development and socio-economic factors. Physical factors and human activity influences land use pattern. The Agricultural land/populated flat land are mainly restricted to the valleys and the modified stream banks. The roads into the coffee and tea estates have been also included in moderately populated slope/village roads class. Thickly populated slopes modified by large scale excavations are few. The major state highways and few areas in the Madikere town have been kept in the category “major communication routes involving extensive slope cutting” (Fig. 6&6A)

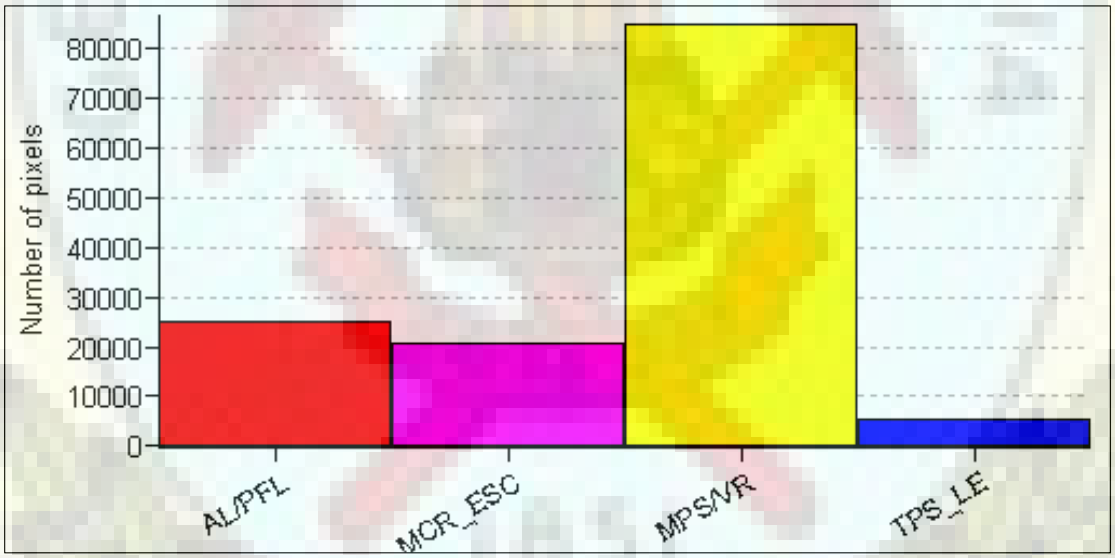


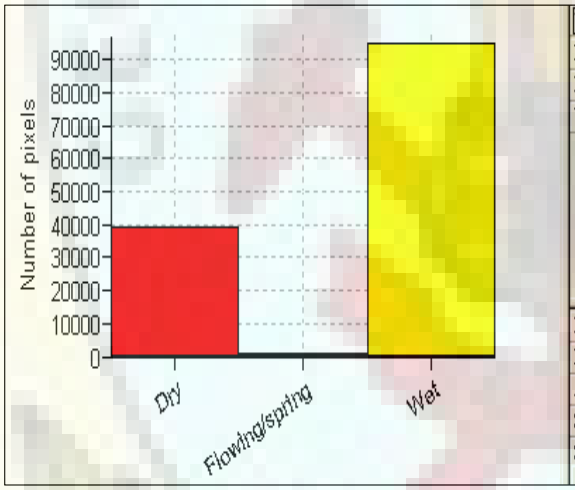
Fig 6: Distribution of different landuse types in the study area

	npix	npixpct	pctnotund	Area
Agricultural land/populated flat land	24936	18.24	18.31	15585000
Major communication routes involving extensive slope cutting	20767	15.19	15.25	12979375
Moderately populated slope/village roads	84924	62.12	62.37	53077500
Thickly populated slope modified by large scale excavation	5541	4.05	4.07	3463125
Min	5541	4.05	4.07	3463125
Max	84924	62.12	62.37	53077500
Avg	34042	24.90	25.00	21276250
StD	34931	25.55	25.65	21831593
Sum	136168	99.60	100.00	85105000

Fig 6A: Statistical distribution of different land cover types in the study area

6.8. Hydrology (LHEF rating-1)

It is difficult to define the hydrological parameters of a given slope for the whole length of the year, as during the monsoon all the slopes are wet to flowing condition in Western ghats. The ratings have been provided (Fig. 7) as per the data collected during the field work (January and February months). As all the landslide incidences recorded in the study area occurred only during monsoon the dry parameter cannot be used for the monsoon period. It will give a better result/model if the rating for hydrological condition is given for whole area for the monsoon period and dry seasons and separate models prepared based on these parameters for monsoon and dry seasons



	npix	npixpct	pctnotund	Area
Dry	39404	28.82	29.16	24627500
Flowing/spring	991	0.72	0.73	619375
Wet	94726	69.29	70.10	59203750
Min	991	0.72	0.73	619375
Max	94726	69.29	70.10	59203750
Avg	45040	32.94	33.33	28150208
StD	47121	34.47	34.87	29450626
Sum	135121	98.83	99.99	84450625

Fig 7: Distribution of different hydrological units in the study area

6.9. Average annual rainfall (LHEF rating-1)

As Madikere lies in Malnad region it receives heavy rainfall with average annual rainfall exceeding 2000 mm. The rainfall data has been collected from the rain gauge stations in Madikere district for comparison (Annexure -II). The comparative figures for the rain gauge station at Madikere (agricultural research station) shows that the study area receives average annual rainfall exceeding 2000 mm (Annexure – III). As per the BIS rating the whole area has been kept in high category with a rating of 0.6.

6.10. Slope erosion condition (LHEF rating-1)

The Western Ghats are relict mountains having very low relative relief; deep gully/rill erosion of the slope is quite uncommon in such a matured hilly terrain with high land cover of the slopes. As Madikere town lies in the highest part of the Western Ghats, all the major streams and *nalas* originate in the study area. With a moderate relative relief the severe toe erosion by nala or river is uncommon. Hence the whole area has been kept in the category (i) Deep gully erosion/rill erosion of hill slope and has been assigned rating of 0.5.

6.11. Landslide incidence (LHEF rating-2):

The landslides in the study area have small dimensions. With the present scale of mapping the landslide boundaries could not be reproduced in the map. Hence the landslide incidence map is a point map in place of a segment map. The landslides in the area are restricted to the cut slopes and as per the landslide characteristics it is found during the study that all the slides have lateral widening in the cut slopes and thus has been included in the category (More than one slide or one very large active slide (material dislodged>100 cu.m). Hence only two ratings has been provided for the whole area where ever there was a slide the area has been given rating 2 and no landslide areas has been assigned 0.

Description	Category	Rating	Remarks
i.	No landslide	0	
ii.	Dormant landslide	0.5	
iii.	One active landslide	1.0	
iv.	More than one slide or one very large active slide(material dislodged>100 cu.m)	2.0	

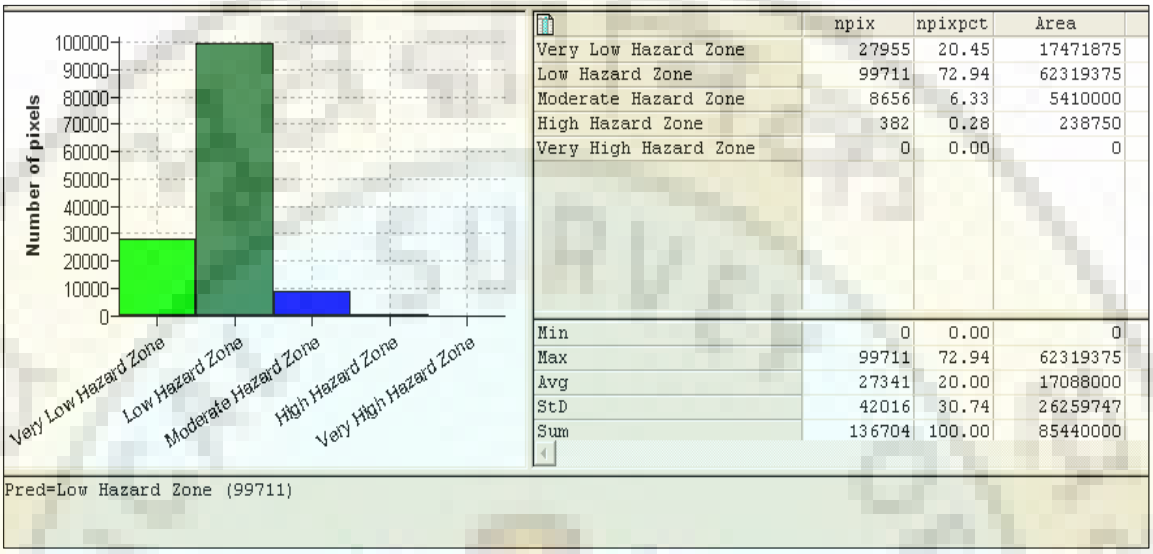
6.12. Landslide hazard susceptibility Map for the Area in and around Madikere town

All the thematic maps after being assigned LHEF ratings for different factors as per the modified GSI code "Total Estimated Hazard value (TEHD value)" was calculated by adding ratings of individual causative factors facet wise.

The TEHD values are indicative of susceptibility of a slope to failure. The TEHD values were regrouped to classify the investigated area into 1) very low, 2) low and 3) moderate hazard Zones and the final output Landslide Hazard zonation map. (Plate-12)

The characteristics of different zones are described below (Fig 8 and 9)

a. **Very Low Hazard zone**: Very low hazard zone covers an area of 17.5 Sq.km which is 21% of the total area investigated. This area is distributed all over and mainly includes the flat agricultural lands in the valleys and the low lying areas having very low relative relief.
b. **Low Hazard zone**: Low Hazard Zone covering 62.3Sq.km area constituting about 74% of the total area lies scattered in major part of the investigated area.
c. **Moderate Hazard zone**: 6% of the area covering an area of 5.41 Sq.km lies in Moderate Hazard Zone. The Moderate hazard zone lies towards south and NNW of Madikere town along the NNW-SSE trending hillock, along which the state highway connecting Madikere and Mangalore (SH-88) runs. It also includes the area of Indira Nagar and Chamundeswari Nagar lying east of Raja's seat.
d. **High Hazard zone**: High hazard zone, restricted to 0.2 Sq.km, accounts for 0.27% of the area. This zone is restricted to the slope cutting areas of the SH-88 and the road leading to the waste disposal site of the Madikere town.
e. **Very High Hazard Zone**: This zone is not found in this area.



	npix	npixpct	Area
Very Low Hazard Zone	27955	20.45	17471875
Low Hazard Zone	99711	72.94	62319375
Moderate Hazard Zone	8656	6.33	5410000
High Hazard Zone	382	0.28	238750
Very High Hazard Zone	0	0.00	0
Min	0	0.00	0
Max	99711	72.94	62319375
Avg	27341	20.00	17088000
StD	42016	30.74	26259747
Sum	136704	100.00	85440000

Fig. 8: Distribution of Landslide susceptibility zones in and Madikere town

Area covered by different susceptibility classes in the investigated area

Type of Hazard zones	Area covered (in Sq Km)	% of total area investigated
Very Low Hazard Zone(VLHZ)	17.471875	20.4492919
Low Hazard Zone(LHZ)	62.319375	73.9393434
Moderate Hazard Zone(MHZ)	5.41	6.331928839
High Hazard Zone(HHZ)	0.23875	0.279435861
Very High Hazard Zone(VHHZ)	0	

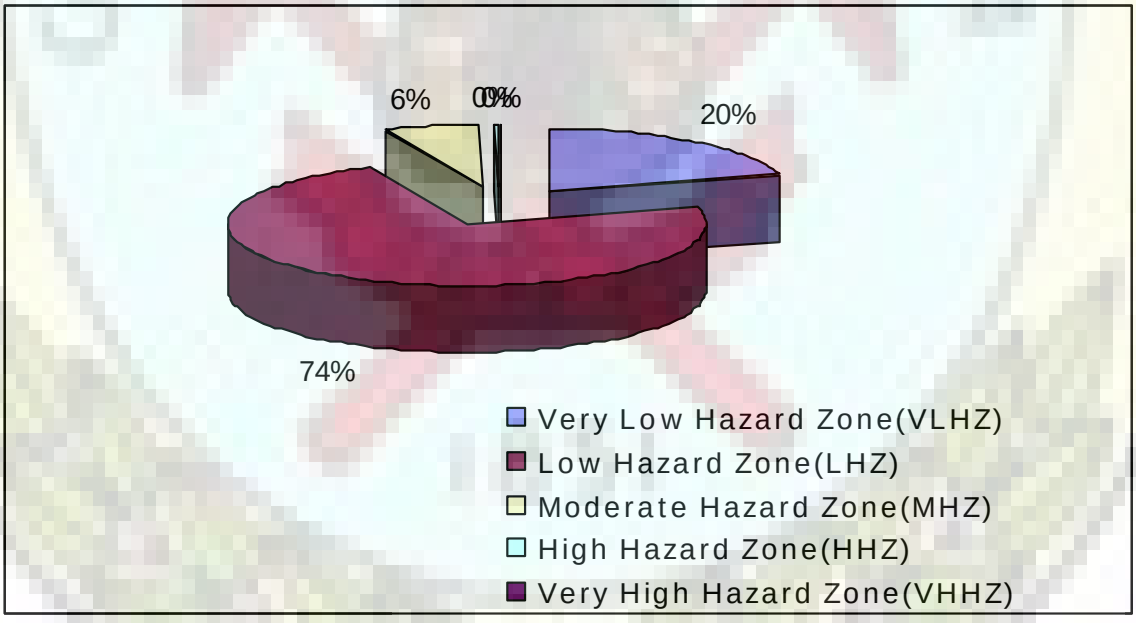


Fig 9: Pie diagram showing the hazard zone distribution in percent of the total area

7. CONCLUSIONS

The landslide hazards, in general cannot be completely prevented, however, the intensity and severity of their impact can be minimized if the problem is recognized before taking up the development activity. The present study was carried out to bring out the susceptibility of the slopes to failure in and around Madikere town which will help the town planners and public to work out the modalities prior to start any developmental activities.

The thematic layers prepared were on the basis of the BIS code modified by GSI. The analysis of data and creation of the model was prepared in ILWIS 3.4. Accordingly four zones were identified as per the total estimated hazard value viz. Very Low Hazard zone covering an area of 17.5 Sq.km (21% of the total area investigated), Low Hazard zone covering 62.3Sq.km (74% of the total area), Moderate Hazard zone covering 5.41Sq.km (6% of the area) and the High hazard zone covering 0.2Sq.km (0.27% of the area).

The scheme of the preparation of susceptibility map in Western Ghats needs a relook as many of the parameters that have been derived from the experience in Himalayan terrain do not hold good to the slope dynamics of the Western Ghats. Majority of the slides in Western Ghats in general, and Madikere town in particular, are due to slope cutting for developmental activities. Cut slope angle and height play a major role in all the slides. Cut slope height was included as a factor as this is found to be a major cause of the slides. The landslides are restricted mainly to the cut slopes. The toe and crown of the slides lie between the top cut and bottom cut of the slopes. The factors responsible for landslides are mainly the cut slope height, cut slope angle, heavy construction and high rainfall.

Spatial prediction of landslide potential slopes through landslide hazard zonation mapping is an important issue for disaster management. The different methods have their own merits and demerits. Since the landslide contributing factors vary from region to region, uniform rating criteria can not be applied to different geo-environmental condition. The scheme of classifying factors responsible for landslides in Western Ghats should be worked out prior to taking up other landslide zonation projects in these areas.

8. RECOMMENDATIONS

Based on the studies carried out, the following recommendations are made for consideration prior to taking up developmental activity by the town planners.

1. Proper drainage should be maintained. The water from the hill may be diverted in the following ways in order to minimize the slide
   i. Making contour drainage at the top of the slopes
   ii. The catch water drains in the sections
   iii. Inserting horizontal perforated pipes in to the slopes will act as weep holes in the vertical slopes and thus reducing the pore pressure by draining out the excess water. This is to be given at suitable interval as per the site condition.
2. Vertical cut slopes should be avoided in future as it does not give stability in such terrain.
3. Retaining structures like retaining wall, stone pitching and gabions are recommended as per the site condition.
4. Geometrical modification of the slope by grading and benching
5. Biotechnical measure of slope protection.

Sd/- A.K. MISHRA Geologist	Sd/- U.K.PRADHAN Geologist	Sd/- L.P.SINGH Senior Geologist

Scrutunised By
Sd/-
(R. PANDURANGA)
Director

LOCALITY INDEX

Sl No	Location	Longitude			Latitude			Toposheet No
		Degree	Min	Sec	Degree	Min	Sec	
1	Appangala	75	43	05.71	12	23	20.41	48P11NE
2	Raja's tomb	75	44	26.58	12	25	57.41	48P11 NE
3	Raja seat	75	44	13.83	12	24	49.21	48P11 NE
4	Kalakerinidagane	75	42	50.34	12	27	05.88	48P11 NE
5	Karanangeri	75	44	39.40	12	25	40.25	48P11 NE
6	Madikere	75	44	26	12	25	57	48P11 NE
7	Makkandur	75	46	01.97	12	27	27.21	48P15 NE
8.	Boyrkeri	75	47	11.23	12	25	52.59	48P15 NE
9.	Jodpar	75	39	40	12	26	00	
10.	Hosuru	75	31	20	12	28	30	

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SYNOPSIS OF WORK DONE

1.	Title of the report	A report on the Landslide Hazard Zonation of Madikere town on mesoscale, Coorg district, Karnataka	
2.	Item No.	LHZ/SR/KG/2007/045-06	
3	Field Season	2007-08 &2008-09	
4	Officers associated with investigation and no. of days spent in the field	A.K. Mishra, Geologist U.K.Pradhan, Geologist Dr. L.P.Singh, Senior Geologist	30 days 30 days 6 days
5	Quantum of work done	80 Sq.km area, Landslide hazard zonation/ Susceptibility mapping on mesoscale (1: 10,000 scale) using GSI proposed guidelines **Due to non availability of 1:10,000 scale map the study was carried out in combination with 1:10,000 scale CARTOSAT-I images and 1:25,000 scale toposheets	
6	Expenditure (1) POL (2) Wages (3) Misc.	 Rs 20,000.00 Rs 5,000.00 Rs 4,000.00	
7	Other information if any		

Sd/- A.K. MISHRA Geologist	Sd/- U.K.PRADHAN Geologist	Sd/- L.P.SINGH Senior Geologist
Scrutunised By Sd/- (R. PANDURANGA) Director		

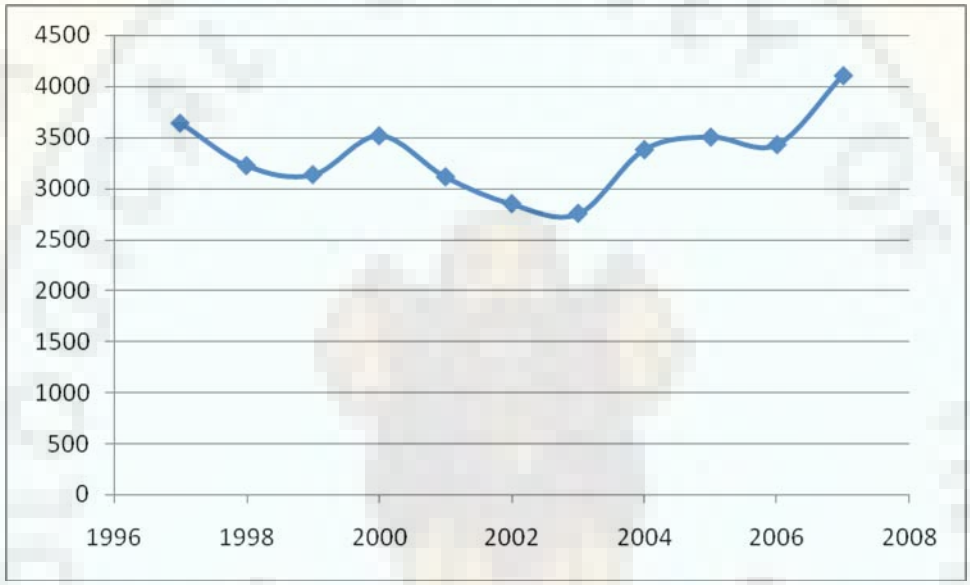
Annexure - II

Annual rainfall data recorded at different places in Madikere district. (Surrounding the study area)

Year	Raingauge stations												
	Madikere (Sudarsan guest house)	**Madikere Agricultural Research Station**	**Avandur**	**Baghamandla**	**Galibeedu**	**Karike**	**Mundroot**	**Napoklu**	**Naladi**	**Sampaji**	**Talcauvery**	**Moornadu**	**Dabadka**
Lat	12 25	12 25	12 23	12 22	12 29	12 28	12 18	12 15	12 15	12 29	12 23	12 19	12 26
Long	75 42	75 45	75 46	75 32	75 40	75 23	75 27	75 40	75 35	75 35	75 29	75 45	75 35
Elevation			**910**	**1181**	**990.1**	**390.1**	**210**		**1200**	**750**	**1355.4**	**914.6**	
1997	2678.2	3641.5	4017.2	5989.5	4162	9244	5484	3578.6	6245	4532	7259	2819	
1998		3223.1	2897.7	5500.3	4565.6	6011.6		3006.2	5800	3498.3	6877.5	2496.8	
1999		3135.4	2700.4	5311.3	3578.2	8512	5550	2964	5035	3274	6301	2170.6	
2000		3517	2754	5135	3419		4077	2703.9	5512.2	3308	6435.8		
2001		3113.1	2495.8	4533.3	3645	8325.2	3133	2174.8	4151.1	3868.8	5284.7	1835.2	5528.8
2002	2422.2	2849.3	2293.4	3337.7	3048	5749.4	4211	2094.3	3751.9	3137.2	4462	1961.6	2894
2003	1874.6	2754.2	2214.3	3861.3	3702.5	6011.6	4195.8	3060.9	3605.4	3356.1	4592.4	1606.3	3371.2
2004	3515	3380.9	2582.2	4412.9	4375	4925	4772	2672	4282.1	3416.8	5488.8	2092.8	3264.8
2005	3201.4	3504.5	3446.7	6330.3	4769	5923.9	5829.3	3202.4		4251.9	8433.9	3176.3	4741.8
2006	2860.4	3429.8	3156.2	6101.2	4554.1	5646.3	6203	2974.6	7470.7	4209	7336.8	2619.5	4492.4
2007	3519.6	4109.4	4095.6	7083.1	5002.8	4626.2	6659.7	3695.7	7903.6	4053.6	8439.9	2891.6	3212.9
Average	**2867.342857**	**3332.56364**	**2968.5**	**5235.99091**	**4074.654545**	**6497.52**	**5011.48**	**2920.67**	**5375.7**	**3718.7**	**6446.5273**	**2366.97**	**3929.414**

Annexure - III

Annual rainfall recorded at **Madikere (Agricultural Research Station) rain gauge station, Madikere**



A Note on

LANDSLIDE HAZARD ZONATION AND RISK MITIGATION OF MADIKERE TOWN

1 Background Information

Madikere is the district headquarters of Coorg district, Karnataka located in the high hills of Western Ghats. The continuous heavy rainfall during monsoons triggers many small landslides in the area. The unplanned expansion of the town on the vulnerable slopes has disturbed the natural slopes leading to frequent landslides resulting in loss of life and property. In order to help the planners for sustainable development of the area landslide hazard zonation mapping of 80 sq. km area on 1:10,000 scale was taken up by Operation Karnataka and Goa, GSI, Bangalore in collaboration with PGRS Division, GSI, SR as per Item No. 062/LHZ/SR/KG/2007/045 during F. S. P. 2007-2008.

As per the FSP, Engineering Geology Division, Geological Survey of India, Op. Karnataka & Goa had to carry out the LHZ mapping on 1:10,000 scale based on mapping of landslide causative factors and assigning weights to each parameter class of each causative factors and finally combining all the weight maps to generate landslide susceptibility map.

2 Sope of study at PGRS Division

The responsibility of PGRS Division was to prepare DEM and derivative maps such as slope and aspect maps from stereo satellite images and provide these maps to the Engineering Geology Division, Geological Survey of India, Op. Karnataka & Goa for further studies. Base Map of the study area on the desired scale of 1:10,000 was not available. Therefore the cartosat-1 stereo data was procured as an alternative for preparation of DEM and derivative maps. The following outputs were generated from Cartosat1 stero images.

1. DEM
2. Slope and Aspect maps from DEM
3. Orthophoto map

3 Input Data

- Cartosat1 stereo
- GCPs from Hand-held GPS
- Topographic maps of 1:50.000 and 1:25,00 scale.

4 Generation of DEM and Derivative Maps

The generation of accurate DEM from high resolution satellite images requires precise Ground Control Points derived from Differential GPS (DGPS) survey. Since DGPS survey data was not provided for the present study the DEM and derivative maps have been generated using the Rational Polynomial Coefficient (RPC) which is supplied along with the cartosat-1 data. However, the positional

and height accuracies of the RPC-derived DEM is in the order of 100 to 250 m which is not suitable for mapping on 1:10,000 scale. It is therefore important that this fact about accuracy should be mentioned in the final report.

The DEM generation was done using Leica Photogrammetric Suite (LPS) Module of ERDAS9.0 software while slope and aspect maps were generated from DEM using ILWIS 3.3 software. For the present study UTM projection (Zone 43) with WGS84 spheroid and datum has been used. DEM, slope and aspect maps and orthophoto map are shown in Figure1.

Slope map has been classified into 5 classes: 0 to 10^0, 10 to 25^0, 25 to 35^0, 35 to 45^0 and >45^0 as shown

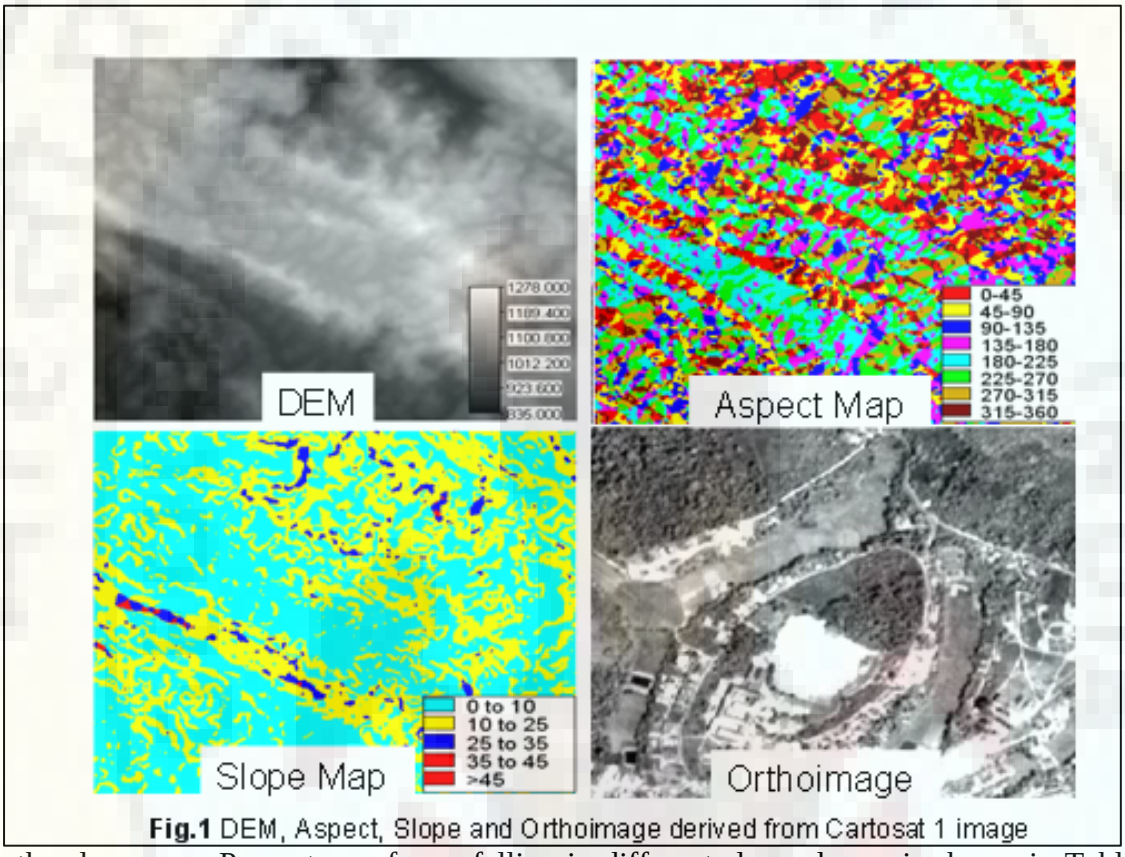


Fig.1 DEM, Aspect, Slope and Orthoimage derived from Cartosat 1 image

in the slope map. Percentage of area falling in different slope classes is shown in Table1. The aspect map has been classified into eight classes of 45^0 interval each, starting from 0^0 north and moving clockwise. Overlay of Slope and aspect maps in GIS environment can be used to get unique slope facet pixels and the resulting map can be used for calculating the per pixel aggregated weights of all the causative factors of occurrence of landslides.

The DEM generated from Cartosat1 stereo was used to orthorectify the cartosat image so that it can be used as updated base map for the study area because 1:10,000 scale topographic maps are not available.

5. Accuracy Assessment

As mentioned earlier the positional and height accuracies of the RPC-derived DEM are in the order of 100 to 250 m which is not suitable for mapping at 1:10,000 scale and therefore accurate GCPs from DGPS Survey are required to improve accuracy.

The accuracy of a DEM is usually represented by the horizontal and vertical (height) accuracy. Various methods of quality checks are reported in literature(Zhu and Wei, 2003):

i. point examination
ii. visual checking

iii. random sampling
iv. joint map checking
v. section method
vi. auto examination, &
vii. image examining.

The method employed depends on the purpose for which the DEM is to be used. The focus of the present study is to assess the quality of DEM derived from high resolution stereo images for terrain characterisation in the form of slope rather than the absolute horizontal and vertical height accuracy. For the present study area no reference DEM is available for comparison because DGPS survey could not be conducted due to reasons beyond our control and therefore GCPs collected from hand-held GPS was used as an alternative to see if the accuracy is improved. For this purpose the DEM and slope map generated using RPC was compared with the DEM and slope map generated by refining RPC using GCPs collected from hand-held GPS. The accuracy process adopted in the present study include:

i. comparision of elevation difference by subtracting RPC DEM from GPSTOPO DEM and
ii. comparison of slope maps derived from the above DEMs.

5.1 Elevation Difference

The histograms and statistics of elevation difference are given in Figure 2. The comparison of elevation indicates that in more than 85% of the total area in the two DEMs the elevation differs from -25 m to +25 m. In rest 15% area the variation of 50 m or more is observed.

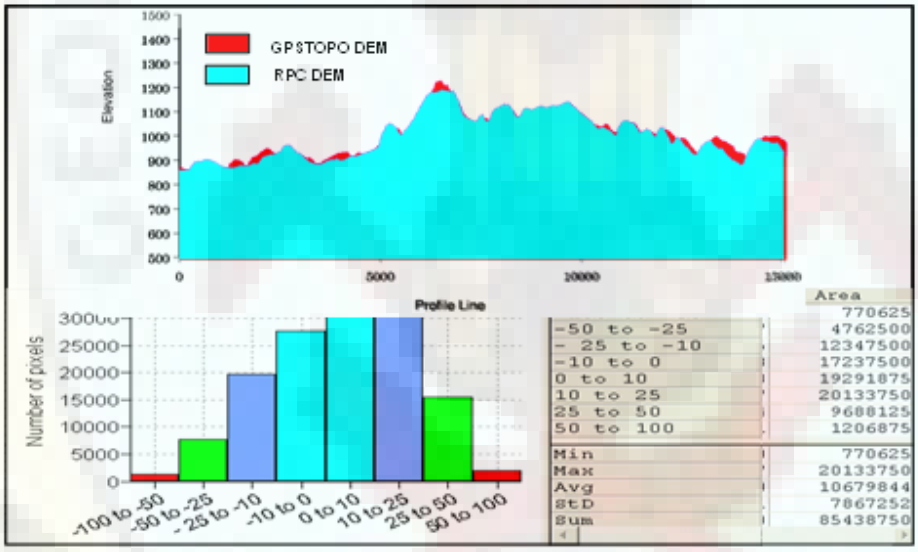


Fig.2 Comparison of DEMs generated from RPC and Hand-held GPS

5.2 Slope Difference

Slope is a very critical parameter in landslide susceptibility zonation. Therefore, accuracy in characterization of slopes is very important. In the present study, comparison of slope maps derived from the two DEMs has been made. Slope maps (in Degree) were generated from both the DEMs mentioned in the previous section and have been named as Slope_GPSTopo and Slope_RPC. The area under different

Table1: Comparison of Slopes

Slope Class	Area (sq. km)	
	Slope_GPSTopo	Slope_RPC
0 to 10	49.234375	46.105625
10 to 25	33.40375	35.918125
25 to 35	2.5925	3.15375
35 to 45	0.2075	0.253125
>45	0.001875	0.009375

slope classes in both the slope maps is shown in Table1.

6. Discussion and Conclusions

The comparison of DEMs and corresponding slope maps indicate the following: i} DEMs indicate minor variations in elevation, ii) slope maps derived from these DEMs do not indicate significant variations (Table1). From the above comparison it can be stated that there is not much improvement in the accuracy of DEM and derivative maps by using GCPs from topomap and hand-held GPS and therefore GCPs from DGPS survey is very essential for 1:10,000 scale mapping.

Landslide incidences in and around Madikere town

Sl.No	Slide No	Location	Toposheet no	Latitude			Longitude			ELEVATION(M)	Road section	Dimension slide(in m	
				D	M	S	D	M	S			L	W
MADIKERE TALUK (ALONG SH88 & SH89)													
1	KA-01	SH-88	48P/11	12	24	49	75	44	21	1088	Madikere-Sulya road	30	20
2	KA-02	SH-88	48P/11	12	24	44	75	44	4	1034	Madikere-Sulya road	60	9
3	KA-03	SH-88	48P/11	12	24	44	75	44	4	1033	Madikere-Sulya road	5+18	8
4	KA-04	SH-88	48P/11	12	24	44	75	44	4	1033	Madikere-Sulya road	2+27	10
5	KA-05	SH-88	48P/11	12	24	43	75	43	55	1031	Madikere-Sulya road	10	12
6	KA-06	SH-88	48P/11	12	24	45	75	43	49	1034	Madikere-Sulya road	15	21
7	KA-07	SH-88	48P/11	12	25	0	75	42	45	963	Madikere-Sulya road	12	7
8	KA-08	SH-88	48P/11	12	25	0	75	42	45	963	Madikere-Sulya road	10	5
9	KA-09	SH-88	48P/11	12	25	1	75	42	44	961	Madikere-Sulya road	12	30
10	KA-10	SH-88	48P/11	12	25	5	75	42	26	961	Madikere-Sulya road	10	12
11	KA-11	SH-88	48P/11	12	25	10	75	41	35	890	Madikere-	10	38
12	KA-12A	SH-88	48P/11	12	25	45	75	40	43	889	Madikere-	10	9
13	KA-12B	SH-88	48P/11	12	25	45	75	40	43	889	Madikere-	10	
14	KA-13	SH-88	48P/11	12	25	43	75	40	37	871	Madikere-Sulya road	6	
15	KA-14	SH-88	48P/11	12	26	26	75	39	5	686	Madikere-Sulya road	20	7.5
16	KA-15	SH-88	48P/11	12	26	13	75	39	34	643	Madikere-Sulya road	20	7
17	KA-16	SH-88	48P/11	12	26	14	75	39	33	645	Madikere-Sulya road	20	7
18	KA-17	SH-88	48P/11	12	26	16	75	39	31	655	Madikere-Sulya road	20	50
19	KA-18	SH-88	48P/11	12	26	12	75	40	8	723	Madikere-Sulya road	14	10
20	KA-18A	SH-88	48P/11	12	26	12	75	40	8	723	Madikere-Sulya road	10	5
21	KA-19	SH-88	48P/11	12	25	59	75	40	18	772	Madikere-Sulya road	25	20
22	KA-20	SH-88	48P/11	12	25	56	75	40	24	772	Madikere-Sulya road	15	10
23	KA-21	SH-88	48P/11	12	24	54	75	44	24	1140	Madikere-Sulya road	23	10
24	KA-22	SH-88	48P/11	12	24	42	75	44	20	1075	Madikere-Sulya road	25	20

Landslide incidences in and around Madikere town

25	**KA-23**	SH-88	48P/11	12	24	40	75	44	17	1060	Madikere-Sulya road	21.5	12
26	**KA-24**	SH-88	48P/11	12	24	44	75	44	13	1061	Madikere-Sulya road	25	15
27	**KA-24A**	SH-88	48P/11	12	24	44	75	44	13	1061	Madikere-Sulya road	25	7
28	**KA-25**	SH-88	48P/11	12	24	45	75	44	12	1062	Madikere-Sulya road	10	12
29	**KA-25A**	SH-88	48P/12	12	24	45	75	44	12	1062	Madikere-Sulya road	10	7
30	**KA-26**	SH-88	48P/11	12	25	12	75	41	41	1062	Madikere-Sulya road	17	10
31	**KA-27**	SH-89	48P/15	12	24	37	75	45	29	1155	Madikere-Siddapura	7	15
32	**KA-28**	SH-89	48P/15	12	24	52	75	45	26	1153	Madikere-Siddapura	8	10
33	**KA-29**	SH-89	48P/15	12	24	56	75	45	24	1153	Madikere-Siddapura road	7	14
MADIKERE-SULIYA ROAD SECTION,SH-88(From Jodpal)													
34	**KA-175**	2-3 km from Jodpal towards suliya, on SH-88	48P/11	12	26	37	75	38	54.7	557	On SH-88	10.00	8.00
35	**KA-176**	Madikere-suliya road,SH-88	48P/11	12	26	45.7	75	38	49.2	554	On SH-88	8.00	14.00
36	**KA-177**	Near Glencoorg estate, Madikere-suliya road,SH-	48P/11	12	26	1.5	75	38	38.1	546	On SH-88	18.00	26.00
37	**KA-178**	Near Glencoorg estate, Madikere-suliya road,SH-88	48P/11	12	27	4	75	38	38.4	544	On SH-88	12.00	12.00
38	**KA-179**	Near big curve of Glencoorg estate, Madikere suliya road,SH-88	48P/11	12	27	6.1	75	38	36.8	514	On SH-88	18.00	60.00
39	**KA-180**	50 mts from slide no KA-179,Madikere-suliya road,SH-88	48P/11	12	27	3.4	75	38	34.5	505	On SH-88	12.00	25.00
40	**KA-181**	200 mts from slide no KA-180 Madikere-suliya road,SH-88	48P/11	12	27	2.5	75	38	34.5	501	On SH-88	12.00	18.00
41	**KA-182**	50 mts from slide no KA-181,Madikere-suliya road,SH-88	48P/11	12	27	7.7	75	38	33.3	494	On SH-88	11.00	15.00
42	**KA-183**	180mts from slide no KA-182,Madikere-suliya road,SH-88	48P/11	12	26	57	75	38	30.9	483	On SH-88	11.00	11.00
43	**KA-184**	Madikere-suliya road,SH-88	48P/11	12	27	35.1	75	37	46.1	392	On SH-88	12.00	28.00
44	**KA-185**	7 km from sampaje towards madikere,Madikere-suliya road,SH-88	48P/11	12	27	53.1	75	37	0.8	299	On SH-88	10.00	18.00
45	**KA-186**	6 km from sampaje towards madikere,Madikere-suliya road,SH-88	48P/11	12	28	10.3	75	36	41.2	293	On SH-88	10.00	17.00
46	**KA-187**	5.5 km from sampaje towards madikere,Madikere suliya road,SH-88	48P/11	12	28	21.6	75	36	20.5	256	On SH-88	7.00	15.00
47	**KA-188**	4.5 km from sampaje towards madikere,Madikere suliya road,SH-88	48P/11	12	28	23.5	75	35	56.6	233	On SH-88	13.00	20.00
48	**KA-189**	4.0 km from sampaje towards madikere,Madikere suliya road,SH-88	48P/11	12	28	23	75	35	44.4	220	On SH-88	13.00	30.00
MADIKERE-SIDDAPUR ROAD SECTION,SH-89													

Landslide incidences in and around Madikere town

49	**KA-199**	on Madikere-Siddapur road SH-89	48P/15	12	24	43.5	75	45	27.6	1069	On SH-89	20.00	70.00
50	**KA-200**	100 mts from slide no KA-199,on Madikere-Siddapur road SH-89	48P/15	12	24	40.3	75	45	28	1135	On SH-89	15.00	10.00
51	**KA-201**	50 mts from Slide no KA-200,on Madikere-Siddapur road SH-89	48P/15	12	24	38.6	75	45	28.2	1144	On SH-89	11.00	13.00
52	**KA-202**	50 mts from Slide no KA-201,on Madikere-Siddapur road SH-89	48P/15	12	24	36.4	75	45	28.7	1140	On SH-89	8.00	25.00
53	**KA-203**	500 m from Kattalkad,on Madikere-Siddapur road SH-89	48P/15	12	23	37	75	47	45.8	1141	On SH-89	25.00	25.00
54	**KA-204**	50 mts from Slide no KA-203,on Madikere-Siddapur road SH-89	48P/15	12	23	36.5	75	47	46.4	1141	On SH-89	30.00	25.00
55	**KA-205**	on Madikere-Siddapur road SH-89	48P/15	12	23	28.8	75	47	52.2	1140	On SH-89	35.00	20.00
56	**KA-206**	on Madikere-Siddapur road SH-89	48P/15	12	23	24.9	75	47	57.9	1138	On SH-89	11.00	6.00
57	**KA-207**	on Madikere-Siddapur road SH-89	48P/15	12	23	23	75	47	58.2	1133	On SH-89	30.00	15.00
58	**KA-208**	50 mts from slide no KA-207,on Madikere-Siddapur road SH-89	48P/15	12	23	22.3	75	47	57.7	1135	On SH-89	32.00	35.00
59	**KA-209**	10 mts from slide no KA-208,on Madikere-Siddapur road SH-89	48P/15	12	23	20.6	75	47	58	1135	On SH-89	12.00	25.00
60	**KA-210**	100 mts from slide no KA-209,on Madikere-Siddapur road SH-89	48P/15	12	23	17.1	75	48	2.6	1134	On SH-89	12.00	11.00
61	**KA-211**	50mts from slide no KA-210,on Madikere-Siddapur road SH-89	48P/15	12	23	15.9	75	48	4.6	1136	On SH-89	16.00	10.00
62	**KA-212**	200mts from slide no KA-211,on Madikere-Siddapur road SH-89	48P/15	12	23	16.9	75	48	9.7	1136	On SH-89	40.00	70.00
63	**KA-213**	on Madikere-Siddapur road SH-89	48P/15	12	22	49.6	75	49	21.9	1134	On SH-89	10.00	12.00
MADIKERE-VIRAJPET ROAD SECTION,SH-27													
64	**KA-214**	250 mts from Madikere towards virajpet, on Madikere-Virajpeth, SH-27	48P/11	12	24	50.9	75	44	34.2	1084	On SH-27	5.70	25.00
65	**KA-215**	100 mts from Madikere towards virajpet, on Madikere-Virajpeth, SH-27	48P/11	12	24	47.1	75	44	34.6	1084	On SH-27	15.00	20.00
66	**KA-217**	600 mts from Madikere towards virajpet, on Madikere-Virajpeth, SH-27	48P/11	12	24	44.6	75	44	38.5	1080	On SH-27	12.00	7.00
67	**KA-218**	600 mts from Madikere towards virajpet, on Madikere-Virajpeth, SH-27	48P/11	12	24	44.2	75	44	38.5	1080	On SH-27	16.00	15.00
68	**KA-219**	600 mts from Madikere towards virajpet, on Madikere-Virajpeth, SH-27	48P/11	12	24	43.4	75	44	38.5	1078	On SH-27	25.00	25.00

Landslide incidences in and around Madikere town

69	**KA-220**	2 km from Madikere, 24 km towarrds Virajpet,on Madikere-Virajpeth, SH-27	48P/11	12	24	35.6	75	44	38.7	1079	On SH-27	17.00	26.00
70	**KA-221**	2.2 km from Madikere, 23.8 km towarrds Virajpet,on Madikere-Virajpeth, SH-27	48P/11	12	24	38.6	75	44	39	1079	On SH-27	15.00	30.00
71	**KA-222**	On Madikere-Virajpeth, SH-27	48P/11	12	24	23.5	75	44	31.3	1073	On SH-27	10.00	48.00
72	**KA-223**	On Madikere-Virajpeth, SH-27	48P/11	12	24	22	75	44	31.3	1078	On SH-27	15.00	5.00
73	**KA-224**	On Madikere-Virajpeth, SH-27	48P/11	12	24	19.6	75	44	32.2	1070	On SH-27	8.00	20.00

Landslide incidences in and around Madikere town

n of m)	Base length (Toe length)	Type of slide	History	Overburden		Material involved	Depth of weathering	whether road cutting	Structures affected
D				Type	depth				
5	25.75	Debris	New	soil	1 m	Weathered granite	10 mt	yes	Road Sh-88
3		Multiple Debris,6 source	New	soil	1m	Weathered granite	11 mt	yes	Road Sh-88
2		Debris,slump	New	soil	50 cm	Weathered granite	5 mt	yes	one house damaged
1	20	Debris,slump	New	soil	50 cm	Weathered granite	5 mt	yes	one mud house
2	13.1	Debris	New	soil	30 cm	Weathered granite	10 mt	yes	Road Sh-88
1	22.4	Debris,slump	New 2 slide)	soil	20 cm	Weathered granite	10 mt	yes	Road Sh-88
2	14.85	Debris	New	soil+weathered granite	25 cm	Weathered granite	7 mt	yes	Road Sh-88
0.5	7.5	Debris,slump	New	Soil	50cm	Weathered granite	8 mt	yes	Road Sh-88
1	32	Debris,slump	New,multiple	soil	50c-1m	Weathered granite	10	yes	Road Sh-88
1	16.75	Debris,slump	Reactivated	soil+weathered granite	30cm	Weathered granite	10	yes	Road Sh-88
1	40	Multiple Debris	New	soil	1m	Weathered granite		yes	Road Sh-
1	10	Debris	New	soil		Weathered granite		yes	Road Sh-
	9.1	Debris	New	soil		Weathered granite		yes	Road Sh-
1	17.52	Debris	New	soil	.50m	Weathered granite	10m	yes	Road Sh-88
1	9.6	Debris,planar	New	soil		Weathered granite		yes	Road Sh-88
1	14.25m	slump	New	soil	.30-.50m	Weathered granite	15m	yes	Road Sh-88
1	11.6	Debris slide	New	soil+weathered granite	3m	Weathered granite	15	yes	Road Sh-88
2	53	Multiple slide Debris/slump	New	soil+weathered granite	2m	Weathered granite	15	yes	Road Sh-88
0.5	14.03	Debris/slump	New	soil+weathered granite	1.5m	Weathered granite	10	yes	Road Sh-88
1	8.2	slump	New	soil	2m.	Weathered granite	10	yes	Road Sh-88
5	29.3	slip,Debris	New	soil	2m	Weathered granite	10	yes	Road Sh-88
2	15.84	slip,Debris	New	soil	2m	Weathered granite	10		
1		slump,Debris	old,reactivated	soil+weathered granite	0.5	Weathered granite	7	yes	Road Sh-88
3	21.5	slide,slip	old	soil+weathered granite	0.5	Weathered granite	5	yes	Road Sh-88

Landslide incidences in and around Madikere town

1	15	Rock fall	old	Nil		Rock	5	yes	Road Sh-88
2		slump,fall	old	soil+weathered	0.3	Weathered granite	5	yes	Road Sh-88
1	9	slump,fall	old	soil+weathered	0.3	Weathered granite		yes	Road Sh-88
1	14	slip,Debris	old	soil+Debris		Weathered granite		yes	Road Sh-88
1	7.5	slip,Debris	old,reactivated	soil+Debris		Weathered granite		yes	Road Sh-88
2		slip,Debris	old	soil+Debris		Weathered granite	10	No	House
1	15.8	Debris	old,reactivated	soil	2m	Weathered granite	5	yes	road,Sh-89
2	13.5	Debris	new	soil	4m	Weathered granite	10	yes	road,Sh-89
1	14	slump,	new	soil+weathered granite	4m	Weathered granite	10	yes	road,Sh-89
0.50	8	Slump	New	soil	1	Weathered granite	1	Yes	SH-88
0.50	17	Slump	New	soil	0.5	Weathered granite	0.5	Yes	SH-88
1.50	31	Complex slide(half Debriss half	New	soil	0.5	Weathered granite	8	Yes	SH-88
1.00	15.5	Slump	New	soil	1	Weathered granite	2	Yes	SH-88
1.00	62	Slump	New	soil	0.5	Weathered granite in the process of laterisation (limonitic patches senn rock highly fractured and	10	Yes	SH-88
1.00	28.5	Slump	Reactivated	soil	0.5	Weathered granite	5	Yes	SH-88
1.00	20	Slump	old	soil	1	Weathered granite	5	Yes	SH-88
1.00	18	Debriss slide	old	soil	1	Weathered granite	5	Yes	SH-88
1.00	12	Debriss slide	old	soil	1	Weathred granite	5	Yes	SH-88
1.00	32	Debriss slide	Reactivated	soil	1	Weathred granite	5	Yes	SH-88
1.00	20	Debriss slide	old	soil	1	Weathred granite	5	Yes	SH-88
0.50	18	Debriss slide	old	soil	1	Weathred granite	6	Yes	SH-88
1.00	18	Slump	old	soil	1	Weathred granite	5	Yes	SH-88
1.00	23	Slump	old	soil	1	Weathred granite (highly deformed and foliated , foliation plane- N55W/53SW)	3	Yes	SH-88
1.00	35	Slump	New	soil	3	Weathred granite	5	Yes	SH-88

Landslide incidences in and around Madikere town

1.50	72	Debriss slide	New	soil	2	Granite	4	Yes	SH-89
0.50	13	Earth slump	New	soil	2	Granite	2	Yes	SH-89
0.50	14	Earth slump	New	soil	3	Granite	3	Yes	SH-89
0.50	28	Earth slump	New	soil	5	Granite	10	Yes	SH-89
0.50	27.4	Earth slump	Reactivated	soil	5	Granite	25	Yes	SH-89
1.00	28 (crown length)	Earth slump	New	soil	3	Granite	10	Yes	SH-89
4.00	25	Complex slide(half Debriss half rock)	New	soil	0.5	Granite	2	Yes	SH-89
0.50	8	Slump	New	soil	2	Granite	5	Yes	SH-89
1.00	16	Slump	Reactivated	soil	3	Granite	5	Yes	SH-89
2.00	39	Complex slide(half Debriss half rock)	Reactivated	soil	2	Granite	12	Yes	SH-89
1.00	30	Rock fall	old	soil	0.5	Granite	2	Yes	SH-89
1.00	14	Slump	New	soil	1	Granite	10	Yes	SH-89
1.00	12	Slump	New	soil	2	Granite	10	Yes	SH-89
3.00	60	Debriss slide	New	soil	2	Granite	10	Yes	SH-89
0.50	13	Slump	New	soil	0.5	Granite	10	Yes	SH-89
0.50	25.7	Slump	New	soil	1	Weathered Gneiss	>10	Yes	SH-27
1.50	22.2	Slump	New	soil	1	Weathered Gneiss	>10	Yes	SH-27
1.00	8	Slump	New	soil	1	Weathered Gneiss	>10	Yes	SH-27
1.00	16.2	Slump	New	soil	1	Weathered Gneiss	>10	Yes	SH-27
3.00	24.6	Slump	New	soil	1	Weathered Gneiss	>10	Yes	SH-27

Landslide incidences in and around Madikere town

2.00	29	Debriss slide	New	soil	4	Weathered Gneiss	>10	Yes	SH-27
2.00	33	Debriss slide	Reactivated	soil	3	Weathered Gneiss	>10	Yes	SH-27
1.00	50	Debriss slide	New	soil	1.5	Weathered Gneiss	>10	Yes	SH-27
1.00	6	Debriss slide	New	soil	1.5	Weathered Gneiss	>10	Yes	SH-27
1.00	22.7	Debriss slide	old	soil	1	Weathered Gneiss	>10	Yes	SH-27

Landslide incidences in and around Madikere town

Casualities	***Type of Bedrock***	***Local geology***	***Regional geology***	***Structure***				***Cut slope height***	***Type of failure surface***
				Joint orientation	**spacing**	**opening**	**filling**		
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				15	convex & concave
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				15	slump
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				8	slump
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				8	slump
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				7	Slip
Nil	Weathered granite/gneis	Weathered granite/gneis	Weathered granite/gneiss	NA				5 m	slump,undulating,convex
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				8 m	slip
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				9 m	slip
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				7m	slip,slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				5m	slip
Nil	Weathered	Weathered	Weathered	NA				5m	slip,slump,un
Nil	Weathered	Weathered	Weathered	NA				8m	slip,slump,un
Nil	Weathered	Weathered	Weathered	NA					
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				8m	slip,slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	N32W/64NE	10cm	nil	nil	7m	slip,planar
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				15m	slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				15m	slip
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				6m	slump,slip
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				6m	slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				6m	slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				10	slip
	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				7	slip
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	N15E/57NW	.50m	tight	nil	5	slump
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				5	slip

Landslide incidences in and around Madikere town

Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				21.5	fall
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	N60E/60NW				25	concave
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss						
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				10	
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA					
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				6	concave
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				5	concave
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				5	circular,concave
Nil	Weathered granite/gneiss	Weathered granite/gneiss	Weathered granite/gneiss	NA				5	irregular,concave
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				10	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	J1-N80E/75S J2-N15E/23SE	J1-0.5 m	J1-Tight J2-Tight		14	Slump/planar
Nil	Weathered granite	Weathered granite	Weathered granite	J1-N20W/74E J2-N10E/38E (Debriss sliped on	J1-1.5 m J2-1.5 m	J1-Tight J2-Tight		12	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	J1-N35W/40NE (day lighted plane) J2-N15E/45W J3-N40W/58SW	J1-5 cm J2-20 cm J3-6 cm	J1-Tight J2-Tight J3-Tight		13	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				10	Slip
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slip
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slip
Nil	Weathered granite	Weathered granite	Weathered granite	NA				12	Slip
Nil	Weathered granite	Weathered granite	Weathered granite	NA				9	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	J1-N60W/81NE J2-N55W/53SW (Foliation plane)	J1-60 cm J2- -	J1-Tight J2-Tight		15	Slump
Nil	Weathered granite	Weathered granite	Weathered granite	NA				15	Slump

Landslide incidences in and around Madikere town

Nil	Granite	Granite	Granite	J1-N65E/77SE J2-NS/25W	J1-1.0 m J2- 1.0 m	J1-Tight J2-Tight		25	Slip
Nil	Granite	Granite	Granite	NA				20	Slump
Nil	Granite	Granite	Granite	NA				15	Slump
Nil	Granite	Granite	Granite	NA				10	Slump
Nil	Granite	Granite	Granite	NA				25	Slump
Nil	Granite	Granite	Granite	NA					Slump
Nil	Granite	Granite	Granite	J1-N50E/70SE J2-N30W/54SW J3-N30W/53NE	J1- 1 m J2-60 cm J3-80 cm	J1-Tight J2-Tight J3-Tight		30	Slump/planar
Nil	Granite	Granite	Granite	NA				10	Slump
Nil	Granite	Granite	Granite	NA				25	Slump
Nil	Granite	Granite	Granite	J1-N55W/50SW	J1-1.0 m	J1-Tight		30	Slump/planar
Nil	Granite	Granite	Granite	J1-N50E/Vertical J2-N30W/39SW (foliation plane)	J1- 10 cm-1 m J2-5-20 cm	J1-Tight J2-Tight		20	planar
Nil	Granite	Granite	Granite	NA				10	Slump
Nil	Granite	Granite	Granite	NA				12	Slump
Nil	Granite	Granite	Granite	NA				20	Slip
Nil	Granite	Granite	Granite	J1-N30W/39SW (foliation plane)				10	Slump
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				8	Slump
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				8	Slump
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				8	Slump
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				10	Slump
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				11	Slump

Landslide incidences in and around Madikere town

Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	J1-N65W/72NE (foliation plane)				5	Slip
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				8	Slip
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				10	Slip
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	NA				5	Slip
Nil	Weathered Gneiss	Weathered Gneiss	Weathered Gneiss	J1-N70E/62S (foliation plane)				8	Slip

Landslide incidences in and around Madikere town

Slope morphometry				*Remarks*
Slope prior to failure	**Slope after failure**	**Slide Direction**	**original slope angle**	
90	80	S60E	41	Moderate vegetation
90	80	S13E, S5W	40	Moderate vegetation
90	65	S18E	40	Moderate vegetation
90	65	S3W	40	Moderate vegetation
85	80	N55W	30	Moderate vegetation
90	80	S41E	40	
90	45	N74E	50	coffee planted
90	80	N80E	50	coffee planted
90	80	N30E	20	coffee planted
90	75	N14W	25	sparsh vegetation
90	75	S48W	25	sparsh vegetation
90	85	N80E	20	sparsh vegetation
90	85	N44E	15	sparsh vegetation
90	85	N45E	20	sparsh vegetation
90	80	N12E	20	sparsh vegetation
90	85	S65W	45	thick vegetation
90	75	S15W	25	thick vegetation
90	75	S25W	25	banana,pepper
90	80	N79E	25	thick vegetation
90	80	N33E	25	thick vegetation
90	60	N23E	40	thick vegetation,coffee
90	42	N78E	50	thick vegetation,ccoffee
90	75	S52E	50	thick vegetation,ccoffee
85	70	S42E	54	thick vegetation,ccoffee

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85	80	S62W	55	thick vegetation,ccoffee
85	80	S62W	55	thick vegetation,ccoffee
				thick vegetation,ccoffee
85	75	S24W	49	thick vegetation,ccoffee
		S26W	48	thick vegetation,ccoffee
90	39	S54W	25	The level has gone down 30 cm.
90	45	S55E,S76 E,N85E	20	moderate vegetation,ccoffee
90	66	N86E	20	moderate vegetation,ccoffee
90	47	N54E	20	moderate vegetation,ccoffee
90	85	S80E	20	Small Debriss slump
90	85	N25E	25	Small Debriss slump
80	50	Towards E	20	complex slide left side Debriss right side rock fall
85	50	N75E	30	Highly fractured granite difficult to distinguish between frature plane and joint two
80	70	N40E (varies according to the	25	Huge Debriss slump near the bend of the road
90	80	N20W	20	old Debriss slump reactivated
90	80	N80W	30	old slide may reactivate
90	80	N70W	30	old slide may reactivate as longitudinal cracks are developed on the flanks
90	80	N65W	25	old slide may reactivate as water stream is flowing on the Debriss
80	70	N10E	25	old slide may reactivate
80	70	N70E	25	old Debris slide
90	80	N30E	25	old Debris slide
80	70	N10E	10	old Debris slump cracks are seen due to deep penetration of roots
80	70	N25E	25	old Debris slump
80	70	N25E	30	Debriss slump with large scarp development

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80	70	Towards E	25	three adjacent slides are taken as one. At various places Granite is exposed. Some trees precaroiusly hanging on the crown part
80	70	N80E	25	small earth slump
80	70	N80E	25	small earth slump, the slide materail has benn converted to clay.
80	70	S80E	20	two small earth slumps taken as one
80	70	N45E	30	old slide reactivated
-	70	N45E	45	big Debriss slump on the other side of the road
80	65	N65E	45	complex slide both Debriss and rock fall
80	70	N70E	45	small slump
80	70	N75E	45	
90	70	N85E	40	
90	75	N78E	40	
90	75	N35E	35	
90	70	N50E	35	
85	70	towards N	30	earlier mud road washed away by huge slide. Gullies seen on Debriss.the material has been saturated by heavy rains
80	70	S80E	25	
90	80	S60W	20	
90	50	S60W	20	
90	65	S70W	30	three slides side by side
90	65	S70W	30	three slides side by side
90	65	S70W	30	three slides side by side

Landslide incidences in and around Madikere town

80	40	S45W	30	
80	45	S65W	30	
90	65	S25W	25	Multiple slide
90	65	N64W	25	
90	70	S70W	25	old slide