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GOVERNMENT OF INDIA
GEOLOGICAL SURVEY OF INDIA

कर्नाटक राज्य के उत्तर कन्नड़ जिले में भूआकृति संख्या 48 जे / 5 और 48 जे / 9 के कुछ हिस्सों में वृहद पैमाने पर (1: 50,000) भूस्खलन संवेदनशीलता का मानचित्रण I
(कोड सं: एल एस एम / एस आर / के और जी / 2015/098)
(कार्य सत्र २०१५-१६)

MACRO-SCALE (1:50,000) LANDSLIDE SUSCEPTIBILITY MAPPING IN PARTS OF TOPOSHEET NO. 48 J/5 & J/9, UTTAR KANNADA DISTRICT, KARNATAKA

(CODE NO : LSM/SR/K&G/2015/098)
(Field Season 2015-16)

द्वारा/*BY*

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Project

भूस्खलन संवेदनशीलता मानचित्रण
NLSM

राज्य इकाई: कर्नाटक व गोवा, दक्षिणी क्षेत्र

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2016

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PROJECT: NLSM
STATE UNIT: KARNATAKA & GOA
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द्वारा

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सारांश

भूआकृति सं 48 जे / 5 और 48 जे / 9 के कुछ हिस्सों में भूस्खलन संवेदनशीलता का मानचित्रण व स्थानिक (जीआईएस आधारित) भूस्खलन डेटाबेस (50000 पैमाने पर), पर्याप्त सुदूर संवेदन और क्षेत्र आदानों का उपयोग करते हुए बनाया गया I जिसमे आर्क जीआईएस सॉफ्टवेर की मदद से बहु-सामयिक गूगल चित्रों के दृश्य व्याख्या के माध्यम से विषयगत लेयर जैसे भूमि उपयोग व भूमि आवरण नक्शा , सड़क, भू-आकृति विज्ञान, ढाल उतराई, ढाल वक्रता और ढलान पहलू नक़्शे तैयार किए गए।

भूस्खलन संवेदनशीलता मानचित्रण, किसी क्षेत्र में ढलान विफलताओं पर भूस्खलन के लिए अतिसंवेदनशील क्षेत्रों की पहचान करने पर इन्हें कम, मध्यम और उच्च पैमाने पर वर्गीकृत करने का एक गुणात्मक अध्ययन है। विषयगत परतों के रूप में विभिन्न कारक नक्शे जीआईएस मंच पर भारित सूचकांक बहुश्रेणी ओवरले का उपयोग करते हुए भूस्खलन संवेदनशीलता को मान्य करने के लिए इस्तेमाल किया जा रहा है।

प्री फील्ड के कार्यकलापों के अन्तर्गत भूमि उपयोग व भूमि आवरण नक्शा , सड़क, भू-आकृति विज्ञान, ढलान के गठन की सामग्री, जलनिकास, ढाल उतराई, ढाल वक्रता और ढलान पहलू नक़्शे आईआरएस लिस 3 डेटा और बहु लौकिक गूगल चित्रों के दृश्य व्याख्या के माध्यम से आर्क जीआईएस में तैयार किए गए।

भूमि उपयोग व भूमि आवरण नक्शा बंजर चट्टानी ढलानों, बस्तियों, कम वनस्पति क्षेत्रों, मध्यम वनस्पति क्षेत्रों घनी वनस्पति क्षेत्रों, कम ऊंचाई वृक्षारोपण, उच्च ऊंचाई वृक्षारोपण, व्यापक कटौती ढलानों, नदी, और परती भूमि में विभाजित किया जा सकता है।

कार्य क्षेत्र का प्रमुख हिस्सा घनी वनस्पति / वन से आच्छादित है। नदी किनारे के क्षेत्र जलोढ़ मृदा है जो कई स्थानों पर कृषि गतिविधियों से आच्छादित हो रखी है , जबकि कम ऊंचाई वाली घाटियां अधिभार सामग्री के साथ आच्छादित है। अध्ययन क्षेत्र में व्यापक कटौती ढलान भूस्खलन को देखने के बिंदु से उन्मुख स्थान है क्योंकि वे बरसात के मौसम के दौरान भूस्खलन में बदल सकते हैं। अध्ययन क्षेत्र, भू-आकृति विज्ञान के संदर्भ में, पहाड़ी, जलोढ़ मैदान, कोल्लुवीएल फुट ढाल, उच्च / मध्यम / कम विच्छेदित ढाल, पेडिमेंट-पेनिप्लेन समूह, पठार शीर्ष, चोटी शीर्ष, रोलिंग मैदान और घाटी तलछट में बांटा गया है। प्री फील्ड कार्यकलापों के अन्तर्गत ढलान के गठन की सामग्री नक्शा (एस ऍफ़ एम्), गूगल चित्रों का उपयोग कर और विवेकपूर्ण तरीके से ढाल भूविज्ञान, भूमि उपयोग व भूमि आवरण नक्शा और भू-आकृति नक्शे को एकीकृत करके तैयार किया गया था। यह बाद में क्षेत्र डेटा के साथ अद्यतन किया गया था। क्षेत्र में ढलान के गठन की सामग्री नक्शा , चट्टान, अपक्षय चट्टान एवं इंसीटू मिट्टी में वर्गीकृत किया जा सकता है। क्षेत्र की ढलान मोरफोमेट्री ढाल उतराई, ढाल पहलू और वक्रता द्वारा परिभाषित किया गया है। इन कारकों के लिए डेटा जी एच आर एम् सेल, केंद्रीय मुख्यालय से उत्पादित डीईएम से निकाला गया था। डीईएम के व्युत्पन्न के रूप में ढाल उतराई नक्शा, <15° से >45° के बीच पांच वर्गों में वर्गीकृत किया गया था। ऐसा देखा गया है की अधिकांश भूस्खलन 25 डिग्री से 45 डिग्री के कोण के बीच हुआ है । वक्रता नक्शा < -0.1, -0.1 to 0.1 और >0.1, 3 वर्गों 'अर्थात उत्तल, फ्लैट और अवतल ढलानों में वर्गीकृत किया गया है।

डीईएम के व्युत्पन्न के रूप में ढाल उतराई नक्शा, <15° से >45° के बीच पांच वर्गों में वर्गीकृत किया गया था। ऐसा देखा गया है की अधिकांश भूस्खलन 25 डिग्री से 45 डिग्री के कोण के बीच हुआ है । वक्रता नक्शा < -0.1, -0.1 to 0.1 और >0.1, 3 वर्गों 'अर्थात उत्तल, फ्लैट और अवतल ढलानों में वर्गीकृत किया गया है।

कुल क्षेत्र में सत्रह ढलान विफलताओं की पहचान की गई। अधिकांश स्लाइड्स सड़क मार्ग के किनारे स्थित हैं, प्रमुख रूप से मगोड प्रपात की जैसे कुछ पर्यटन स्थलों पर ये अधिकांशतः मिलती है । क्षेत्र में स्लाइड्स उथले ट्रांसलेशनल प्रकृति के हैं और ज्यादातर सड़कों के किनारे तक ही सीमित हैं। येल्लापुर -अरबिल (एनएच 63) सड़क मार्ग में स्लाइड बरसात के मौसम के दौरान बहुत सक्रिय हैं और व्यापक कटौती ढलान से ज्यादातर उत्पन्न हो रही हैं । कार्य क्षेत्र में लगभग 90-95% स्लाइड डेब्रीज़ प्रकार के उथले ट्रांसलेशनल फेलियर रहे हैं। क्षेत्र में डेब्रीज़ स्लाइड मानवीय गतिविधियों और वर्षा के संयुक्त प्रभाव के कारण हो सकती है। इसके अलावा, राष्ट्रीय राजमार्ग 63 के किनारे यातायात प्रेरित कंपन भी ढीला तलछट के संचलन में वृद्धि कर सकता है ।

क्षेत्र भूस्खलन / ढलान विफलताओं की पर्याप्त संख्या के अभाव में, क्षेत्र की संवेदनशीलता मॉडलिंग विश्लेषणात्मक पदानुक्रम प्रक्रिया (ऐ एच पी) का उपयोग करके की गयी है जिसमें व्यक्तिगत कारकों की रेटिंग और अंतर-भविष्यवाणी महत्व विशेषज्ञ या ज्ञान संचालित तकनीक पर ही आधारित है। यह ज्ञान आधारित रेटिंग / मात्रात्मक मीट्रिक, विभिन्न भू कारक कक्षाओं के लिए गुणात्मक जोड़ो में महत्व मैट्रिक्स पर निर्णय लेने और अंतर-भविष्यवाणी वजन के लिए अलग-अलग भू कारकों के बीच, चर्चा और स्थानीय विशेषज्ञों और इस क्षेत्र में भूस्खलन के अध्ययन में लगे हुए भूस्खलन वैज्ञानिकों से प्राप्त टिप्पणियों के माध्यम से प्राप्त करने के बाद विश्लेषणात्मक पदानुक्रम प्रक्रिया (ऐ एच पी) का उपयोग कर गणितीय विधि से आसानी से निर्धारित किया जा सकता है। लगभग 5% (लगभग 74 वर्ग किमी) क्षेत्र की उच्च संवेदनशीलता क्षेत्रों में गिर रही है, जबकि लगभग 12% (178 वर्ग किमी) क्षेत्र मध्यम संवेदनशीलता क्षेत्र में गिर रही है। क्षेत्र के बाकी हिस्से कम संवेदनशीलता क्षेत्र में पड़ते है। उच्च अतिसंवेदनशील क्षेत्रों में से अधिकांश भूआकृति सं 48 जे / 5 में आ रहे हैं ।

Macro - scale (1:50,000) Landslide Susceptibility Mapping in parts of Toposheet nos. 48 J/5 and 48 J/9, Uttar Kannada district, Karnataka.

CODE: LSM/SR/KG/2015/098

(Field Season 2015-16)

By

Zameer Ahmad Shah, Geologist

Kapil Singh, Geologist

ABSTRACT

Landslide Susceptibility Mapping in parts of Toposheets no. 48J/5 and J/9, was carried out on 1:50000 scale using adequate remote sensing data and thematic layers like Land use/ Land Cover (LULC), Roads, Geomorphology, Slope Forming Material, Slope gradient and Slope Curvature in Arc GIS through visual interpretation of multi-temporal Google Imageries.

Landslide Susceptibility Mapping is a qualitative study of slope failures in an area with focus on identifying zones susceptible to landslides on low, moderate and high scale. Various factor maps in the form of thematic layers are being used to validate landslide susceptibility using weighted multiclass index overlay on GIS platform.

Pre-field maps for Land use/ Land Cover (LULC), Roads, Geomorphology, Slope Forming Material, Drainage, Slope gradient, Slope Curvature and Slope aspect were prepared in Arc GIS through visual interpretation of IRS LISS III data and multi-temporal Google Imageries.

The area in terms of LULC is divided into: Barren, Barren Sand, Cultivation, Extensive Slope Cut, Fallow Land, Moderate Vegetation, High Height Plantation (HHP), Low Height Plantation (LHP), Quarry, Settlement, Sparse Vegetation, Swamp, Thick Vegetation and Water Body.

Major part of the area is covered with thick vegetation/forest. The areas along river banks are covered with alluvial material which is covered by agricultural activities at many places whereas along low lying valleys is covered with overburden material. Extensive cut slopes in the study area are the hot spots from landslide point of view as they transform into landslides during rainy seasons. Gemorphologically, the area is divided into Hilltop, Alluvial Plain, Colluvial Foot Slope, Highly/Moderately/Low Dissected Slope, Pediment-Peneplain Complex, Plateau Top, Ridge Top, Rolling Plain and Valley Fill. Pre field Slope Forming Material map (SFM) of the area was prepared using Google imageries and judiciously predicting slope forming material by integrating geology, LULC and geomorphology maps and updated with field data. Slope Forming Material in the area can be classified into rock, weathered rock and In-situ soil. Slope morphometry defined by slope gradient and curvature were derived from Digital Elevation Moldel (DEM) provided by GHRM Cell, CHQ. Most of the slides are observed to have occurred between 25° and 45° angle. Curvature map is classified into 3 classes i.e., convex, flat and concave slopes corresponding to curvatures < -0.1, -0.1 to 0.1 and >0.1.

A total of seventeen slope failures were identified in the area. Most of the slides are located along the roads leading to some tourist spots like that of Magod Falls. The slides in

the area are of shallow translational nature and are mostly confined to road sides. Slides along Yellapur-Arabail (NH-63) are very active during rainy season and originate mostly from extensive cut slopes. About 90-95 % slides occurring in the area are shallow translational failure of debris type. Debris slides in the area may be due to the combined effect of anthropogenic activities and triggered by rainfall. In addition, traffic induced vibrations along NH-63 also enhance the movement of loose material along the road sides.

Due to insufficient landslide data in the area, the susceptibility modelling is carried out by Analytical Hierarchy Process (AHP) method wherein ratings and inter-predictor weights were given to individual factors using expert or knowledge driven techniques. This knowledge-driven ratings/weights in quantitative metrices can easily be determined mathematically using AHP, after preparing/deciding on the qualitative pair-wise importance matrix for different geo factor classes and comments received from local experts and landslide scientists engaged in landslide studies in the area. Approximately, 5 % (about 74 sq. km's) area is falling in high susceptibility zones while about 12 % (178 sq. km's) area is falling in moderate susceptibility zone. Rest of the area falls in low susceptibility zone. Most of the high susceptible zones are covered in T.S. No. 48 J/5.

Macro - scale (1:50,000) Landslide Susceptibility Mapping in parts of Toposheet nos. 48 J/5 and 48 J/9, Uttar Kannada district, Karnataka.

CODE: LSM/SR/KG/2015/098
(Field Season 2015-16)
By
Zameer Ahmad Shah, Geologist
Kapil Singh, Geologist

I. INTRODUCTION

1.1 Background:

Landslides in Western Ghats is a recurring problem for years, causing disruption in communication routes, damaging properties and killing people. The road development, the shifting of agricultural practice from orthodox seasonal crops to cash crops has put tremendous pressure on the natural slopes of the Western Ghats. With passage of time the modification of slopes due to human interference in the natural slope has deteriorated the equilibrium attained by nature. While not every landslide results in catastrophe, the damage from many small ones may equal or exceed the impact of a single major failure. Thus, both large and small landslides are capable of causing significant damage and loss of life. With every passing monsoon over the Western Ghats, a number of landslides are triggered. The blockade, damage and disruption of traffic along important roads linking the major cities create lot of inconvenience for the public.

Geological Survey of India, being the Nodal Agency for Landslides in India since 2004, vigorously and swiftly started integrated approach towards landslide hazard studies which included site specific landslide studies, landslide hazard zonation along important road corridors, around townships and preparation of landslide inventory.

Geological Survey of India (GSI) has been carrying out landslide susceptibility Zonation/mapping on macro scale (1:50,000/ 25,000) since last 3 to 4 decades. However, compared to the available landslide-prone areas in India (~0.42 Million sq. Km's spreading over 1112 Survey of India 1:50,000 scale Topographic Sheets), the target achieved so far by GSI (~60,000 sq. km's) is quite lesser. This warrants GSI, being the nodal agency for landslide studies in India, to impart maximum stress towards completion of this basic data generation work on landslides by aiming to complete the remaining task much at a faster pace than what has been followed by GSI so far. This matter was deliberated in detail at the Regional Workshop on Landslide Disaster Management at Shillong on 22-23 November, 2014 and the Joint Secretary, Ministry of Mines has also directed GSI to revamp and fasten its endeavour for this important task for completing the remaining targets of landslide susceptibility mapping/zonation as early as possible.

Accordingly, since FS 2014-15, GSI undertook a national programme on landslide susceptibility mapping – **Macro scale (1:50,000) National Landslide Susceptibility Mapping (NLSM)** with an aim to cover the remaining targets expeditiously. This national programme was formally launched by Shri Dinsha Patel, Hon'ble Minister of Mines, Government of India on 5th February, 2014 at the 53rd Central Geological Programming Board Meeting, New Delhi.

Landslide Susceptibility Mapping in parts of Toposheets no. 48 J/5 and J/9, parts of Uttar Kannada District, Karnataka was carried out to prepare a seamless landslide susceptibility map and spatial (GIS-based) landslide database on 1:50000 scale using adequate remote sensing and field inputs. (CODE NO: LSM/SR/KG/2015/098).

1.2 Present Work:

The present work was carried out with following objectives:

i) To prepare landslide inventory database using high-resolution remote sensing data and field inputs.

ii) To prepare Toposheet wise 1:50000 scale spatial database for geofactors of landslides for use as input thematic maps.

iii) To prepare landslide susceptibility map using Multi class index overlay method in GIS platform.

The nature and target of work envisaged for field season programme of 2015-16 and the achievements are given in Table 1.

Table 1: Nature of work, quantum and achievements.

Nature of work	Total Work Load envisaged	Target for FS 2015-16	Cummulative for FS 2015-16 Since Commencement
1.Pre-field preparation			
i) Preparation of Thematic maps (in GIS on scale 1:50,000)	1487 sq. km	1487 sq. km	-
a) Slope Forming Material map		1487 sq. km	1487 sq. km
b) Geomorphology & Lineament map		1487 sq. km	1487 sq. km
c) Slope Morphometry (slope, aspect & curvature) map		1487 sq. km	1487 sq. km
d) Landuse / Landcover map		1487 sq. km	1487 sq. km
e) Drainage map		1487 sq. km	1487 sq. km
f) Regolith depth/thickness map		1487 sq. km	1487 sq. km
ii) Preparation of Landslide Inventory Map		1487 sq. km	1487 sq. km
1. Field-based studies			
i) Field-checking of all thematic maps	1487 sq. km	1487 sq. km	1487 sq. km
ii) Field validation of landslide inventory and collection of		1487 sq. km	1487 sq. km

recent and historic landslides (using archives, old reports, road register etc)			
iii) Collection of landslide inventory and damage data as per 41 point geo parametric data sheet	As necessary	As necessary	1487 sq. km
iv) Validation of landslide susceptibility map at important locations	1487 sq. km	1487 sq. km	1487 sq. km
2. Post-field studies & modeling			
i) Updation of thematic and inventory maps in GIS	1487 sq. km	1487 sq. km	1487 sq. km
ii) Preparation of Landslide Susceptibility Map in GIS		1487 sq. km	1487 sq. km
3. Collection of rainfall data from available rain stations	Collected Rainfall data from Tehsil Office, Yellapur.		
Integration for hazard and risk analyses after carrying out necessary consequence analysis	As necessary	As necessary	1487 sq. km

Table 2 Details of the man-days spent in the filed

	Sep-15	**Oct-15**	**Nov-15**	**Dec-15**	**Jan-16**	**Feb-16**	**Mar-16**	**Total Days**
Zameer Ahmad Shah	-	10	10	20	20	11	09	80
Kapil Singh	02	10	10	18	20	11	09	80
J. Srihari								02

Table 2 gives details of total man-days spent in the field. A total of 82 man-days were spent in the field, which also include two days of field inspection by Director, Shri J. Srihari.

1.3 Study Area:

The area forms the part of Karnataka State, is bounded by latitudes 14° 45'00" and 15°00"00" N and longitudes 74°15'00" and 74°45'00" E falling in Survey of India Toposheet No's 48 J/5 and 9 in parts of Uttar Kannada district. The area is well connected to Yellapur, Karwar and Kaigha Nuclear Power Plant (Figure 1). Most of the villages and towns of the area are well connected by metalled and non-metalled roads. The administrative offices of the area are located at Yellapur. The Hubballi Railway Junction (South Central Railway main line) is the nearest railway station in the area. Yellapur, Arabail, Ramnagar and Heggumballi are some of the major town in toposheet no. 48 J/9 while Kadra, Anashi and Bahire are the major towns present in toposheet no. 48 J/5. The study area can be approached by Hubballi – Karwar N National Highway (NH-63) and many other state roads. The nearest airport to the study area is at Mangalore.

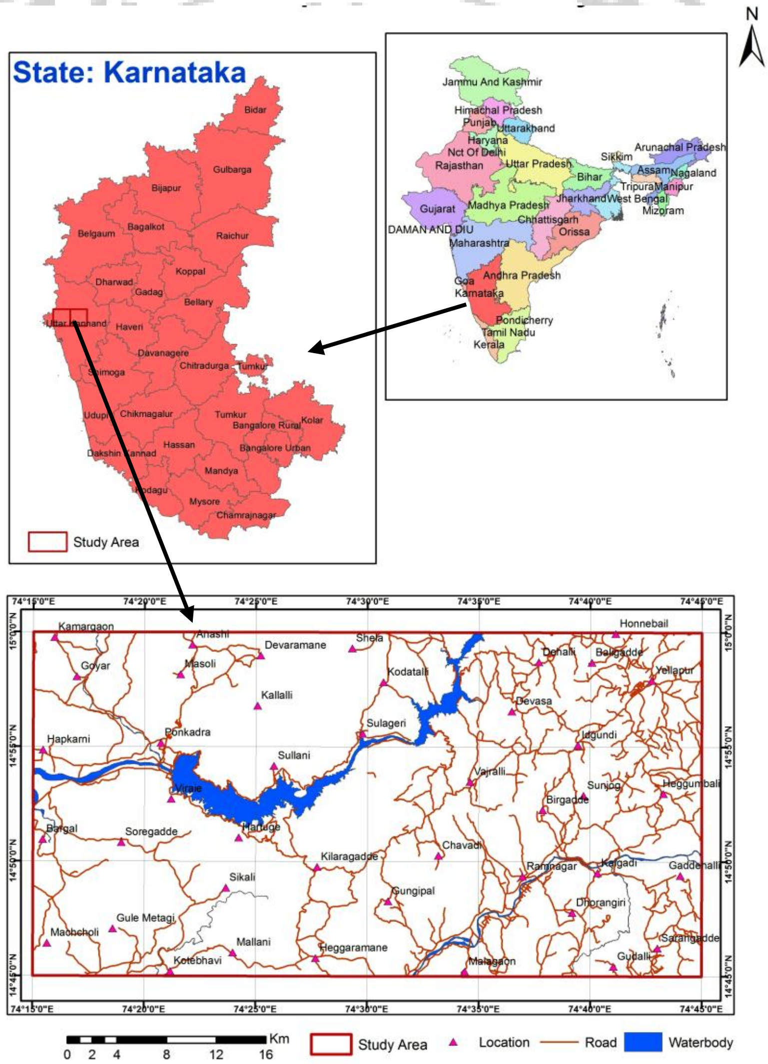

Figure 1 Location map of the study area (48 J/5 and 48 J/9).

1.4 Physiography:

The study area has an undulating topography with higher peaks found near Baligadde in the North-East and Masoli in the North-West. The area shows an elevation of 132 to 785 above mean sea level. The area has temperate climate and the forest type is semi evergreen forest.

The major river in the study area is Kali-Nadi flowing from West to East direction running across the study area from Katar in the west to north-west of Ganesh-gudi. The drainage pattern of the area is mainly dendritic, sub-dendritic and trellis (Plate 9).

1.5 General Geology and Geomorphology:

The area under investigation forms a part of Western Ghats that grade into a plateau towards east. Geologically the area exposes Late Archean rocks (<3000 ma), Peninsular gneiss-I of Tonalite-Trondjhemite-Granodiorite composition, Middle Archean (>3000 ma) Sargur Group, with ultramafic-mafic intrusive complex, serpentinised komatitic and amphibolites, etc. and lower to Middle Archean (~3400 ma) older Gneisses. Western Ghat belt preserves an ideal succession of Bababudan Group, which is exposed in the mountainous region of Kudremukh, Agumbe and Kodchadri. The Sargur Group is represented by a number of enclaves within gneisses and granites and the enclaves are quartzite, amphibolite, iron formation, garnetiferous mica schist, kyanite-staurolite schist, silimanite-garnet schist, calc-silicate rock and ultramafics. The Peninsular Gneiss of this region is a complex of migmatitic gneiss and granitoids and includes biotite gneiss, hornblende-biotite gneisses and hornblende gneiss. The Peninsular Gneiss is unconformably overlain by the Dharwar Supergroup (Bababudan Group). Bababudan Group is represented by four formations, namely (a) Walkunje Formation, (b) Kudremukh Formation, (c) Kodchadri Formation, and d) Narasiparvata Formation. The Walkunje Formation represents the lower arenaceous and argillaceous member of the Bababudan Group. Other rock units associated with it are quartzites, quartz-sericite schist, greywacke, arkose and quartz-biotite-chlorite schist. Kudremukh Formation comprises amygdular metavolcanics, amphibolite, actinolite-chlorite schist, meta-gabbro and ultramafics with interbeds of quartzites, quartz-sericite schist and chlorite schist. Kodchadri Formation comprises of Banded magnetite quartzite and quartz-chlorite-sericite schist. The Narasiparvata Formation comprises of acid porphyries, chlorite quartz schist and iron stones. Numerous dykes, varying in texture from coarse to fine grained, are reported from various localities. The laterite cover is extensive in the area between the coastal plains and the intermediate range of hills below the Western Ghats (Awasthi, 1981; Davay, 1968; Gopal Reddy et.al 1984; Jagnnathan et.al 1983).

Uttar Kannada district in particular is occupied by rocks of Sargur Group, Peninsular Gneissic complex (PGC), older Granitoids and Chitradurga Group of Dharwar Supergroup of Archean age. Dolerite dykes of Palaeoproterozoic age are intruding these rocks (Plate 1). The older metamorphics of Sargur Group are represented by amphibolite occurring as enclaves within granite. The rocks belonging to PGC are represented by granitic gneiss and granodiorite. The granite gneiss at places is migmatitic in nature. The Dharwar Supergroup of rocks and PGC-I are intruded by older granitoids reffered as 'Karwar Granite'. The granite is massive, generally coarse grained, porphyritic found in shades of grey and pink consisting of quartz, K-feldspars, plagioclase and biotite. The Goa belt represented by Chitradurga Group is exposed in the area as 'Barcem Formation' consisting of metabasalt (Schistose), BMQ and acid volcanics. The area is also intruded by numerous swarms of dolerite dykes. The majority of the rock sequences are lateritised that occur as extrusive cappings in the Western Ghats and in coastal plains. Their thickness ranges from a few cm to 60 m. (Chalpathi Rao, 1968; Chalpathi Rao and Kannan, 1970; Davay, 1968; Gopal Rao, 1968; Pazhamalainathan et. Al, 1982; Ramakrishna, 1967; Shafeeq Ahmed, 1990; Subramanian, 1968; Subramanian, 1969).

1.6 Land use and Land cover:

The Landuse/cover pattern of a region is an outcome of natural and socio-economic factors and their utilization by man in time and space. The increase in density of population is directly proportional to the Landuse and Landcover. Land Use & Land Cover map was prepared in ArcGIS through visual interpretation of IRS LISS III data and multi-temporal Google Imageries of the area. The area in terms of LULC can be divided in to following classes: Barren, Barren Sand, Cultivation, Extensive Slope Cut, Fallow Land, Moderate Vegetation, High Height Plantation (HHP), Low Height Plantation (LHP), Quarry, Settlement, Sparse Vegetation, Swamp, Thick Vegetation and Water Body. The areas along river banks is covered with alluvial material and along low lying valleys is covered with overburden material and are being used for cultivation. Major part of the area is covered with moderate to thick vegetation/forest. Steep cut slopes in the study area are most affected by slope failures as far as land use /land cover is concerned.

1.7 Methodology:

The method employed in the present study is primarily landslide dependent following a raster-based GIS modelling approach for integration of all selected and weighted thematic maps to prepare 1:50,000 scale landslide susceptibility maps. Areas having scarce prior landslide information, any one of the following approaches can be taken into consideration as per the preferences or the conditions of the terrain or even discussion with the local experts/workers.

a) An investigation in the nearby area with frequent landslide data will serve as base for individual ratings for geofactor classes and weights of geofactors. Later such ratings and weights will be used for the entire study area for model integration using the same multiclass index overlay method. In case of availability of similar research work in adjacent and similar terrain nearby, the ratings and weights developed and used in such work may also be used after due discussion with the local experts.

b) Individual ratings for geofactor classes and weights of geofactors will be determined using Analytical Hierarchy Process (AHP) after preparing the pair wise qualitative comparison matrix of all factors (Saaty, 1977) after due discussion with local experts and workers. The methodology used pertains to the method b).

Methodology adopted can be broadly grouped as follows:

- A total of seven factor maps, viz., Slope curvature, slope gradient and drainage maps (derived from 30m ASTER DEM), Geomorphology and Landuse/Landcover (prepared using Google Earth as base maps in ESRI ArcGIS 10.2), Slope Forming Material and Regolith thickness maps (field based and GSI Geology map) were prepared for susceptibility analysis.

- All maps except drainage map have been used for the assessment of factor class ratings, map weights and validation of the landslide susceptibility map (LSM) for the study area.

- Pair-wise comparison ratings obtained from experts and application of analytical Hierarchy Process is obtained to calculate ratings of all the geofactors.

- Preparation of Landslide Occurrence Favorability Score (LOFS) maps.
- Factor map (LOFS) integration using Weighted Multiple Index Overlay and preparation of Landslide Susceptibility Score map.
- Determination of classification/break pixel values for classification of Susceptibility Score map.

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II. PREVIOUS WORK ON LANDSLIDE STUDIES

In India, preliminary studies in the field of landslide zonation were initiated by Oldham (1880), Middlemiss (1890) and Holland (1897). Seshagiri et.al. (1982) considering five parameters carried out landslide hazard zonation by categorizing each parameters and assigning Landslide Susceptibility Index (LSI) on the basis of percentage of Landslides in each category. Anbalagan (1992) used Lithology, structure, slope, relief, land use, land cover and ground water condition to prepare zonation. In Karnataka, Mishra et al. (2010) carried out zonation in a Geographical Information system (GIS) environment of Madikeri Township. Mishra et al. (2010)[1] also carried out a zonation in GIS environment of road corridor of Charmudi Ghat section from Charmudi to Kotigehara, Kotigehara to Kalasa and Shiradi Ghat section from Sakleshpur to Uppinangadi. Maruthi and Chandran (2013) has carried out zonation on Macro-scale using modified BIS guidelines between Virajpet-Madikeri-Sulya road corridor. There was no systematic approach for landslide studies in the state of Goa till 2005. Few scattered landslide investigation were carried out by GSI. During the monsoon of 2005, R. Dharuman (2005) carried out the preliminary post disaster landslide investigation of the landslide at Decarpoli village, Quepem Taluk, South Goa district where 11 people died. Two landslide investigations, one for south western railway in Doodhsagar and one at Cabo hill were carried out by R.Panduranga and R.Dharuman during field season 2004 and 2002-04 as sponsored items to stabilize those slopes. Few slides such as Zuari landslide and the slides at Altinho hillock were reported in Goa seminar volume. During FS 2007-08 a total no 35 landslide incidences were recorded along Anmod Ghat Section of NH 4A-, part of NH-17, SH connecting Valpoy-Chaverde, NH17A-Vasco-da-Gama and SH connecting Pernem –Morjim-Mapusa in North Goa and South Goa districts covering parts of Toposheet nos. 48 I/2 & 3; 48 E/14, 15, 16 & J/1.

Landslide inventory was carried out by K.V.Maruthi & K.V.Chandran during F.S-2012-13 along the road-sections of the Western Ghat in North Goa and South Goa districts covering parts of Toposheet nos. 48 I/2 & 4; 48 E/13,14 & 15.The following Ghat sections (SH and NH roads and main district roads) were covered during the FS 2012-13.

2.1 Landslide Issues of the Study area:

As per the literature almost all landslides in the area appear to have been caused due to the human inference in modifying the existing natural slopes. The specific causes of landslide in Western Ghats in general are removal of support by toe cutting of hill slopes for the construction of road, for human settlement, presence of weathered and loose rock mas, heavy and frequent rain etc. Studies in the area have been carried out only along transportation corridors (NH & SH) in the Western Ghats. Temporal data for these slides is not available as far as the study area is concerned. Landslides in the study area generally occur frequently from untreated cut slopes. These are usually small in size but pose considerable risk to life and property. Several landslides are reported along roads (Highways) every year during the monsoons indicating that the triggering factor for these slides may be rainfall besides anthropogenic activities. Overall, landslides studied in the area are few and small in size, but are mostly confined to roads and seem to be triggered by anthropogenic activities in addition to the role of rainfall in the area. They are mostly of shallow translational type and are confined to areas having very steep slopes and thick overburden. Some of the slides have been observed along interior roads which mostly lead to some tourist places and thus seem to be anthropogenic.

III. LANDSLIDE INVENTORY

A landslide inventory map records the location and, where known, the date of occurrence and the types of mass movements that have left discernable traces in an area (Guzzetti et al., 2000). Generation of such inventory is a difficult task as landslides occur individually and have to be identified, mapped and inventoried. A Landslide inventory contain basic information about landslides such as location, classification, morphology, volume, run-out distance, activity and date of occurrence/activity etc. and can be prepared through various methods such as detailed geomorphologic fieldwork, mapping from remote sensing data and topographic maps, historical archive studies and interview. In this study, satellite images are used as the main source for obtaining a multi-temporal landslide inventory.

3.1 Data source:

Landslides leave discernible signs on slopes, most of which can be recognized, classified and mapped in the field or from photo-interpretation (Varnes, 1978). These signatures are mostly visible as morphological changes such as changes in slope type, breaks in slopes, hummocky surfaces, etc. These morphological signs are interpreted here to determine important landslide information such as type of failure, the surface area, cause and the run-out distance. Detailed and systematic field work was carried out to generate the 41-point attribute data for landslides. Preparation of the landslide inventory commenced with the search of archival data sources, particularly published and unpublished reports of GSI.

In the present study, it was not possible to identify landslides from Google Earth as the area is thickly vegetated and if any landslide of recordable dimension is present is masked by the canopy in the area. Around 15 landslides were identified in the present investigation.

3.2 Inventory mapping:

The following steps were used for mapping a landslide in the field and building its inventory attribute.

1. For each landslide identified in the field, the attributes such as name, state, district, taluka, toposheet number, initiation), slide type, slide material, length, width, surface area, cause, land use and element at risk were recorded. Archival data were used for naming and defining the cause of the landslides.

2. The morphological signatures left by landslides on slopes were used to identify the shape of landslides.

3. After identifying the landslides in the field, the morphological parameters (landslide scar length, width and depth) were noted carefully after measuring them in the field using a meter tape. Additional data such as landslide type, run-out distance, present land use, regolith thickness, probable cause, and damage details were also added to the inventory.

3.3 Landslide in the Area:

During field only 17 Landslides or rather slope failures identified in the study area are concentrated mainly along roads and other transportation corridors (Plate 10). Overall landslides studied in the area are few and small in size, but are mostly confined to roads and seem to be triggered by anthropogenic activities in addition to the role of rainfall in the area. Most of the landslides affecting the road originate from cut slopes, which are left unsupported and become prone to failure during rains. They are mostly of shallow translational type and are confined to areas having very steep slopes and thick overburden. Recording these slope failures which are a result of anthropogenic activities and considering them for susceptibility zonation of the study area would be highly biased. Since very few, almost negligible amount of slides are observed in the area, the usually applied method of modelling cannot be used here. In this situation, ratings and inter-predictor weights can only be determined using expert or knowledge driven techniques by implementing one of the following alternatives or by combining knowledge derived from attempting all the alternatives.

Most of the slides were recorded along NH-63 leading towards Ankola and Karwar. The area with frequent cut slope failures lies near toYellapur township. All mapped landslides are debris/earth slides triggered by extensive slope cutting followed by spells of rain. The slided material mostly consists of younger loose debris mixed with debris of weathered rock. Failures are common during rains when the exposed overburden mass resting on the cut slopes slips downslope.

The spatial distribution of mapped landslides is shown in **Annexure-I**, which gives detailed inventory of 17 landslides for which 41-point inventory data were prepared. Cut slope failures are very much wide spread along Kaigha-Yellapur road (Photos 1 to 4). Some of the cut slopes show prominent undercutting which can be attributed to the root exposure and rain percolation leading to the removal of underlying material (Photo 1). Many of the cut slope failures transform into landslides during rainy season in the area.

IV. LANDSLIDE SUSCEPTIBILITY ANALYSIS

This chapter deals with the material and methods of landslide susceptibility analysis using Analytical Hierarchy Process method.

4.1 Background:

A quantitative or qualitative assessment of the spatial distribution of landslides in an area depicts the landslide susceptibility of that area. Generally, landsliding is expected to occur in the most susceptible areas. One of the drawback of the landslide susceptibility analysis is that it does not take time frame and magnitude into consideration. A susceptibility map therefore gives only the qualitative or quantitative estimation that the mapping unit (e.g., a pixel, slope unit or facet) will be affected by a future landslide source. Therefore, using the term “landslide hazard analysis” instead of “landslide susceptibility analysis”, for methods of spatial prediction of landslide-prone areas may not be correct.

In GIS-based data-driven methods such as Weighted Multiclass Index Overlay, spatial factors (or layers of evidence) are integrated with a landslide inventory map (target) using various mathematical/statistical integration techniques (Bi-variate, Multivariate, Artificial Neural Network etc) that can model relationships among layers of evidence with respect to targets (Bonham-Carter, 1994).

4.2 Selection of preparatory factors:

For susceptibility mapping, the selection of preparatory factors for landslides depends on the scale of analysis, the characteristics of the study area, the landslide type, the failure mechanisms and the priori knowledge of the main causes of landslides (Guzzetti et al., 1999). A prior knowledge of the main causes of landslides in the area of interest is essential in selecting the most relevant factors out of the many known preparatory factors that can “theoretically” cause landslides (Ghosh et al., 2010).

In the study area, landslides are mostly debris slides affecting natural slopes and are smaller in size. Keeping in consideration the landslide characteristics, seven factor maps were prepared that are considered to be the main spatial causal factors for landslides in the area. Out of the eight maps, three are related to terrain morphometry derived from DEM and four are field based maps prepared from remote sensing data. A brief description of the significance and mapping techniques for each factor is given below.

4.3 Geo-factor Themes:

Landslides occur when the shearing stress along the failure plane exceeds the shearing strength of rock/debris mass (Varnes, 1978). This can be controlled by the dynamic nature of various parameters such as i) physical state of slope such as slope gradient, slope aspect, and slope curvature, ii) lithology or physical characteristics of slope forming mass, iii) spatial variation in depth of slope forming mass, iv) geomorphological forms and processes, v) rock structure: orientation of planar/linear discontinuities in the rock mass in relation to topography, vi) geo-hydrology and vii) land use/cover including road and other physical features mappable on 1:50,000 scale. Based on the estimation of above pre-disposing geo-factors, the following factors and its possible factor classes are considered for preparation of geo-factor databases for the GIS-based analysis of susceptibility to landsliding. These spatial factor maps are prepared using various source data and employing different mapping techniques which are detailed below.

4.3.1 Slope Morphometry:

Slope morphometry is evaluated through Slope gradient, Slope aspect and Slope curvature (Plate 2, 3 and 7). In the present investigation, Slope aspect was not taken into consideration keeping in view its least significance.

4.3.1a Slope gradient:

Slope gradient is an essential component of slope stability analysis. As the slope gradient increases, the level of gravitation-induced shear stress in the colluviums or residual soils increases as well. Gentle hillslopes are expected to have a low frequency of landslides because of the generally lower shear stresses associated with low gradients. Slope gradient, the maximum rate of change of elevation of the surface, was then reclassified into five classes: <15º, 16 –25 º, 26–35º, 36–45 º and > 46°.

The slope angle maps were derived from the 30m ASTER DEM using ArcGIS 10.2. Slope gradient varies between 0° and 51°. In general, landslide frequency increases with the slope gradient until the maximum frequency is reached in the 35–40° categories, followed by a decrease (Plate 2).

Steep slopes (>45°) generally form the escarpment rocky slopes around Soregadi, Sonjog, Gadihalli and mostly along Kaigha-Asiwan road in the north-west of the study area. About 90% of the area exhibit slope gradient up to 25°.

4.3.1b Slope Curvature:

Slope Curvature (Profile curvature) shows the curvature of the surface perpendicular to the slope direction for each cell, and thus determines the shape of a slope in profile, Slope shape was also derived from 30m ASTER DEM using ArcGIS 10.2. A positive curvature represents upwardly convex surface, while a negative curvature indicates that the surface is upwardly concave at a given pixel. The concave hill slopes are having high soil moisture content and receive more surface run-off. Failures can be expected to occur more frequently in those areas than the slopes that are convex along the contour. The curvature maps were reclassified into three classes viz, concave, flat and convex (Plate 3).

4.3.2 Landuse and Landcover:

Mapping or delineating areas prone to landsliding is very essential for land-use activities and management decision making in hilly or mountainous regions.The land use and land cover (LULC) map was prepared from the Google Earth data considering 2012 data. Following the generally used mapping procedure in Google Earth, first the polylines of different land use/cover were drawn and the same were imported in Arc GIS through kml to feature conversion. In Arc GIS the features were converted into polygons and then again exported to Google Earth through layer to kml conversion. Each polygon was named as per its LULC class and reconverted into a shape file through kml to layer conversion. Finally the boundary of the individual LULC class was corrected from SPOT images available as base map in Arc GIS 10.2. The obtained pre-field LULC map was checked in the field in all accessible locations and all necessary modifications in the boundary and name of the LULC class were incorporated. Plate 4 shows the LULC map for parts of toposheets 48 J/5 and 48 J/9. The area in terms of LU/LC can be divided into following classes: Barren, Barren sand, Cultivation, extensive slope cut (Photo 5), Fallow land, Moderate vegetation, HHP, LHP, Quarry (Photo 6), Settlement, Sparse Vegetation, Swamp, Thick Vegetation (Photo 7) and Water Body. Most part of the area is covered with thick vegetation/forest. Extensive cut slopes in the study area are most affected by slope failures as far as land use /land cover is concerned.

4.3.3 Geomorphology:

The present landscape of the study area under consideration is viewed as the manifestation of a chain of interactions between fluvial and denudational processes operating on underlying geology that has been subjected to past vertical tectonics. Field and laboratory studies indicate that the geomorphology of the study area is marked by ridges with steep slopes, denuded surfaces and sinuous valleys suggesting the considerable period has elapsed during the development of the landforms. Each landform signifies the processes operated in the evolution of the landforms.

Geomorphological map was prepared in ArcGIS through visual interpretation of multi-temporal Google Imageries of the area. NGLM data supplied by GHRM cell was also taken into account while preparing the geomorphology map of the study area. Gemorphologically, the area can be divided into Hill-top, Alluvial Plain, Colluvial foot slope, Highly/Moderately/Lowly dissected slope, Pediment-peneplain complex, Plateau top, Ridge top, Rolling plain and Valley fill.

The method used for geomorphology mapping is the same as that of LULC map. The obtained pre-field geomorphology map was checked in the field at all accessible locations and related necessary modifications in the boundary and name of the geomorphology class were incorporated. Plate 5 shows the geomorphology map of parts of toposheets 48 J/5 and 48 J/9. Most part of the area is covered by lowly dissected slope followed by moderately dissected and rolling plains respectively. The details of geomorphic features are given as follows:

Ridge: This is the topmost part of the hills/mountains which is formed by the intersection of two escarpments from the opposite directions. (NGLM Manual, 2010)

Pediment – Pediplain Complex: A complex landform where both pediplain and pediments occur and it is difficult to separate them (Photo 9).

Alluvial Plain: A level or gently sloping tract or a slightly undulating land surface produced by extensive deposition of alluvium, usually adjacent to a river that periodically overflows its banks; (Photo 12). (NGLM Manual, 2010).

Lowly/Moderately Dissected Slopes: These slopes are defined by the intensity of linear features dissecting the landscape of the area (Photo 8).

Rolling Plain: Rolling plain is assigned to areas with hummocky appearance where most of the area is generally flat with some minor wavy undulations.

4.3.4 Slope Forming Material (SFM):

Slope Forming Material (SFM) map was prepared in ArcGIS 10.1 through visual interpretation of multi-temporal Google Imagery of the area and collection of data for material present on slopes. The study area in terms of Slope Forming Material (SFM) can be classified in to following classes: Rock, weathered rock and In-situ soil (Plate 6).

Areas with visible soil profile were categorized under in-situ soil category. On slopes, barren rock is present at places where the slope angle in general is more than 35 degrees, most of the study area is covered by In-situ, soil of granitic origin (Photo 11). Fresh outcrops were observed along Kaigha-Anashi road (Photo 10). Weathered exposures were observed on Kaigha-Yellaur road with blackish and reddish soil representing the underlying lithology i.e charnockites and granites.

4.3.5 Regolith Thickness/Depth:

The regolith thickness depends on a large variety of factors, one important being the local variation in terrain morphology; and therefore prediction of the thickness of regolith over a large area is extremely difficult. Ideally, for thickness modelling, a large number of observations (such as drill holes, outcrops or geophysical measurements) are required. However, on a catchment scale, this approach is difficult to implement. Given the above limitations, regolith thickness map was prepared based on field observations and value observations. Assessment of depth of regolith cover at different sites was made by studying the exposures along the road, streams and landslide scars. Depth of Overburden is directly controlled by slope forming material (SFM), geomorphology, land use & land cover and slope gradient. An attempt is made to get the approximate overburden depth and it is observed that in low dissected hill slope with low slope gradient, the overburden depth is relatively more (approx. 2-5 m or >5m) where as in low dissected slopes having steeper slope gradient, the overburden depth varies from 1-2m to occasionally up to 5m. In the study area it can be classified into two classes: <0.5 m and 0.5m to 5 m (Plate 8). Along the moderate & steep slopes depth of overburden in general is less while along major weathered profiles regolith thickness is more, these areas are more prone for landslides. Regolith depth of <0.5m depth is observed on rocky, steep slopes (Photo 13). Areas with comparatively gentle slope with weathered outcrops exhibit overburden of 0.5 to 5 (Photo 14).

4.4 Landslide Susceptibility Analysis:

Landslides or rather slope failures in the study area are concentrated mainly along roads and other transportation corridors. Recording these slope failures which are a result of anthropogenic activities and considering them for susceptibility zonation of the study area would be highly biased. Since very few, almost negligible amount of slides are observed elsewhere in the area, the generally used method of modeling cannot be used here. In this situation, ratings and inter-predictor weights can only be determined using expert or knowledge driven techniques by implementing one of the following alternatives or by combining knowledge derived from attempting all the alternatives.

Alternative 1: Finalisation of ratings and weights in a smaller neighbouring area-

If landslide inventory data is available in a smaller catchment or road-corridor within or adjacent to the proposed study area (or Toposheet), attempts should be made to determine terrain-specific ratings and weights of geofactors through a pilot study in that particular pilot study area. This can be executed by employing different spatial association analysis such as determination of Yule's Co-efficient, Distance Distribution Analysis etc (Yule, 1912). The ratings and weights determined so far through that pilot study can then be utilised for the entire study area where landslide data is not available. Since NLSM aims to develop and utilise terrain-specific ratings and weights, this seems to be the best approximation of terrain-specific importance of geofactors.

Alternative 2: Finalisation of ratings and weights using expert opinion and Analytical Hierarchy Process (AHP)-

In situation of complete non-availability of landslide inventory data, there is absolutely no remedy other than utilising complete expert or knowledge driven ratings and weights into susceptibility modeling despite its subjectivity. However, this knowledge-driven ratings/ weights in quantitative metrices can easily be determined mathematically using AHP (Saaty, 1977; Ghosh et al., 2011), after preparing/ deciding on the qualitative pairwise importance matrix for different geofactor classes and amongst different geofactors for inter-predictor weights, obtained so far through discussion and comments received from local experts and landslide scientists engaged in landslide investigation of the area. The procedures of application of AHP through some examples are demonstrated through some illustration below.

In line of the above proposition, for determining the terrain-specific knowledge-driven ratings and weights through application of AHP, a mandate form/ questionnaire is prepared, where all the concerned landslide scientists, other geologists working in similar terrain and all experts of the concerned Region may submit their mandate/ answer in a semi-quantitative term by rating each geofactor theme separately. While giving the semi-quantitative rating in a scale of 1-9 for each geofactor theme, the mutual relative importance for influencing/ causing a single proposition that is land sliding in this case should be taken into account. A particular geofactor class having higher rating would be considered as more instrumental in influencing land sliding. For example, if we classify our slopes into 5 classes say 0-15º, 16-25º, 26-35º, 36-45º and >45º and give semi-quantitative rating as 2, 4, 8, 6, 1 then it will be presumed that for land sliding, slope class 25-35 is the most important among all other classes.

Methodology: The Analytic Hierarchy Process (AHP), developed by Saaty (1977) is a method of structuring decision problems. The AHP consists of three levels of hierarchy. The first hierarchy level is the goal of the decision making, the second level involves how each of the existing criteria contributes to achievement of goal, and the third level is to find out how each of the alternatives contributes to each of the criteria.

The AHP method is appropriate to be used where decisions are to be assessed quantitatively. It is assumed that human beings' natural reaction when facing a complex decision making process, is by grouping the decision elements according to common characteristics. This involves ranking the decision elements, and then comparing between each pair in each group in a form of matrix. Then inconsistency ratio and weight for each element can be measured. This provides ease in testing the data consistency. The higher consistency ratio, the assessment result becomes more inconsistent. The acceptable consistency ratio is less than or equal to 10%.

According to Taylor, Consistency Index (CI) can be calculated by using the following formula:

CI= maks eigen value-n/n-1 Eq-1

$maks.eigenvalue = \sum_{\iota} wi.\mathrm{ci}$ Eq-2

The consistency ratio is then calculated as,

$CR = CI/RI$ Eq-3

Where, n is the amount of items compared, w*i* is the weight, ci is the sum of column, CR is the Consistency Ratio, CI is the Consistency Index and RI is the Random Consistency Index.

If CR ≥ 10%, the data acquired is inconsistent and If CR < 10%, the data acquired is consistent. The ratio-scale form is used as an input. The values in the ratio are organized in a matrix, which is called the pairwise comparison matrix. In the AHP method, the scale range 1–9 is assumed. It is limited to a ratio-scale 1–9 because according to the research conducted by Miller, human beings cannot simultaneously compare more than seven objects. The Standard Preference Scale used is shown in Table 3:

Preference Level	Numerical Value
Equally Preferred	1
Equally to Moderately Preferred	2
Moderately Preferred	3
Moderately to Strong Preferred	4
Strongly Preferred	5
Strongly to Very Strongly Preferred	6
Very Strongly Preferred	7
Very Strongly to Extremely Preferred	8
Extremely Preferred	9

Using the above Standard Preference Scale, a group of geoscientists from GSI engaged in landslide studies in India and in Western Ghats, in particular, were asked to rank the factor classes and the factor maps. The obtained score for individual factor class was used for determining the ratings for each factor class. The average score for the factor maps of the area ranked between 0 and 9. Matrix of pairwise ratings; estimated eigenvectors of pairwise rating matrix; and estimation of consistency vector (CV), consistency index (CI) and consistency ratio (CR) for judgment of consistency of pairwise ratings of factors, respectively for all maps was calculated.

Example of LULC for calculation of Landslide Occurrence Favorability Score (LOFS) is given below in Table 4:

Example-Calculation of LOFS For LULC

Barren (B)	1
Barrne Sand (BS)	0
Cultivation (CL)	2
Extensive Slope Cut (ESC)	9
Fallow Land (FL)	1
Moderate Vegetation (MV)	5
Plantation (HHP)	4
Plantation (LHP)	3
Quarry (QR)	5
Settlement (S)	1
Settlement on modified slope (SM)	7
Settlement with Cultivation (SC)	0
Settlement with Vegetation (SV)	0
Swamp (SW)	0
Thick Vegetation (TV)	4
Sparse Vegetation (SV)	7
Waterbody (WB)	0
Salt Pan (SP)	0

Table 3: Generic Table showing mutual comparison rank of LULC factor classes.

LULC	B	CL	ESC	FL	MV	HHP	LHP	QR	S	SM	TV	SV
B	1.00	0.50	0.11	1.00	0.20	0.25	0.33	0.20	1.00	0.14	0.25	0.14
CL	2.00	1.00	0.13	2.00	0.25	0.33	0.50	0.25	2.00	0.17	0.33	0.17
ESC	9.00	8.00	1.00	9.00	5.00	6.00	7.00	5.00	9.00	3.00	6.00	3.00
FL	1.00	0.50	0.11	1.00	0.20	0.25	0.33	0.20	1.00	0.14	0.25	0.14
MV	5.00	4.00	0.20	5.00	1.00	2.00	3.00	1.00	5.00	0.33	2.00	0.33
HHP	4.00	3.00	0.17	4.00	0.50	1.00	2.00	0.50	4.00	0.25	1.00	0.25
LHP	3.00	2.00	0.14	3.00	0.33	0.50	1.00	0.33	3.00	0.20	0.50	0.20
QR	5.00	4.00	0.20	5.00	1.00	2.00	3.00	1.00	5.00	0.33	2.00	0.33
S	1.00	0.50	0.11	1.00	0.20	0.25	0.33	0.50	1.00	0.14	0.25	0.14
SM	7.00	6.00	0.33	7.00	3.00	4.00	5.00	3.00	7.00	1.00	4.00	1.00
TV	4.00	3.00	0.17	4.00	0.50	1.00	2.00	0.50	4.00	0.25	1.00	0.25
SV	7.00	6.00	0.33	7.00	3.00	4.00	5.00	3.00	7.00	1.00	4.00	1.00
Sum Clm	49.00	38.50	3.00	49.00	15.18	21.58	29.50	15.48	49.00	6.96	21.58	6.96

Table 4: Table showing matrix of mutual comparison ranks of LULC classes given rank >0.

LULC	B	CL	ESC	FL	MV	HHP	LHP	QR	S	SM	TV	SV	Sum rows	Frac rate	LOFS
B	0.020	0.013	0.037	0.020	0.013	0.012	0.011	0.013	0.020	0.021	0.012	0.021	0.213	0.018	0.063
CL	0.041	0.026	0.042	0.041	0.016	0.015	0.017	0.016	0.041	0.024	0.015	0.024	0.318	0.027	0.094
ESC	0.184	0.208	0.333	0.184	0.329	0.278	0.237	0.323	0.184	0.431	0.278	0.431	3.399	0.283	1.000
FL	0.020	0.013	0.037	0.020	0.013	0.012	0.011	0.013	0.020	0.021	0.012	0.021	0.213	0.018	0.063
MV	0.102	0.104	0.067	0.102	0.066	0.093	0.102	0.065	0.102	0.048	0.093	0.048	0.990	0.082	0.291
HHP	0.082	0.078	0.056	0.082	0.033	0.046	0.068	0.032	0.082	0.036	0.046	0.036	0.676	0.056	0.199
LHP	0.061	0.052	0.048	0.061	0.022	0.023	0.034	0.022	0.061	0.029	0.023	0.029	0.464	0.039	0.137
QR	0.102	0.104	0.067	0.102	0.066	0.093	0.102	0.065	0.102	0.048	0.093	0.048	0.990	0.082	0.291
S	0.020	0.013	0.037	0.020	0.013	0.012	0.011	0.032	0.020	0.021	0.012	0.021	0.232	0.019	0.068
SM	0.143	0.156	0.111	0.143	0.198	0.185	0.169	0.194	0.143	0.144	0.185	0.144	1.914	0.160	0.563
TV	0.082	0.078	0.056	0.082	0.033	0.046	0.068	0.032	0.082	0.036	0.046	0.036	0.676	0.056	0.199
SV	0.143	0.156	0.111	0.143	0.198	0.185	0.169	0.194	0.143	0.144	0.185	0.144	1.914	0.160	0.563
														Max	0.283

Table 5: Table Showing Fraction rate and LOFS values.

LULC	B	CL	ESC	FL	MV	HHP	LHP	QR	S	SM	TV	SV	Sum rows	CV
B	0.018	0.013	0.031	0.018	0.016	0.014	0.013	0.016	0.019	0.023	0.014	0.023	0.2191981	12.36
CL	0.035	0.027	0.035	0.035	0.021	0.019	0.019	0.021	0.039	0.027	0.019	0.027	0.3229031	12.17
ESC	0.16	0.212	0.283	0.16	0.412	0.338	0.271	0.412	0.174	0.479	0.338	0.479	3.7177267	13.12
FL	0.018	0.013	0.031	0.018	0.016	0.014	0.013	0.016	0.019	0.023	0.014	0.023	0.2191981	12.36
MV	0.089	0.106	0.057	0.089	0.082	0.113	0.116	0.082	0.097	0.053	0.113	0.053	1.0496105	12.72
HHP	0.071	0.08	0.047	0.071	0.041	0.056	0.077	0.041	0.077	0.04	0.056	0.04	0.698393	12.4
LHP	0.053	0.053	0.04	0.053	0.027	0.028	0.039	0.027	0.058	0.032	0.028	0.032	0.4718235	12.19
QR	0.089	0.106	0.057	0.089	0.082	0.113	0.116	0.082	0.097	0.053	0.113	0.053	1.0496105	12.72
S	0.018	0.013	0.031	0.018	0.016	0.014	0.013	0.041	0.019	0.023	0.014	0.023	0.2439453	12.61
SM	0.124	0.159	0.094	0.124	0.247	0.225	0.193	0.247	0.135	0.16	0.225	0.16	2.0954329	13.14
TV	0.071	0.08	0.047	0.071	0.041	0.056	0.077	0.041	0.077	0.04	0.056	0.04	0.698393	12.4
SV	0.124	0.159	0.094	0.124	0.247	0.225	0.193	0.247	0.135	0.16	0.225	0.16	2.0954329	13.14
													Sum CV	151.3

Table 6: Table showing estimation of consistency vector (CV).

n	1	2	3	4	5	6	7	8	9	10
RI	0	0	0.58	0.9	1.12	1.24	1.32	1.41	1.45	1.49

Mean CV	**12.6**	
Consistency Index (CI) =		**(Mean CV-number of themes)/(No of themes -1)**
CI	0.06	
Consistency Ratio (CR) =		**CI/RI**
CR	0	
CR should never be more than 0.1		

Table 7: Table showing calculation of consistency index (CI) and consistency ratio (CR).

In the same manner for all the 6 factor maps calculation of LOFS and consistency ratio (CR) was done. After calculation of LOFS values for all the factor classes of all the factor maps, LOFS maps were prepared using Arc GIS by joining the LOFS tables to the individual maps respectively.

Factor Classes	
Slope	9
Curvature	2
SFM	6
LULC	8
Geomorphology	4
Regolith Thickness	4

Factor	Slope	Curvature	SFM	LULC	Geom	RT
Slope	1.00	8.00	4.00	2.00	6.00	6.00
Curvature	0.13	1.00	0.20	0.14	0.33	0.33
SFM	0.25	5.00	1.00	0.33	3.00	3.00
LULC	0.50	7.00	3.00	1.00	5.00	5.00
Geom	0.17	3.00	0.33	0.20	1.00	1.00
RT	0.17	3.00	0.33	0.20	1.00	1.00
Sum Clmn	2.21	27.00	8.87	3.88	16.33	16.33

Factor	Slope	Curvature	SFM	LULC	Geom	RT	Sum rows	Frac rate	Weight	Weight W N
Slope	0.45283	0.296296	0.451128	0.515971	0.367347	0.367347	2.450919	0.408486	12.64217	13
Curvature	0.056604	0.037037	0.022556	0.036855	0.020408	0.020408	0.193869	0.032311	1	1
SFM	0.113208	0.185185	0.112782	0.085995	0.183673	0.183673	0.864517	0.144086	4.459293	4
LULC	0.226415	0.259259	0.338346	0.257985	0.306122	0.306122	1.69425	0.282375	8.73917	9
Geom	0.075472	0.111111	0.037594	0.051597	0.061224	0.061224	0.398223	0.06637	2.054087	2
RT	0.075472	0.111111	0.037594	0.051597	0.061224	0.061224	0.398223	0.06637	2.054087	2

Table 8: Table showing mutual comparison of individual factor maps and weights.

The integer weight or rating and weights derived from AHP were used to obtain landslide susceptibility score map. The output map is then regrouped into three susceptibility class (high, moderate and low).

V. LANDSLIDE SUSCEPTIBILITY MAP

The Landslide susceptibility map (Plate 11) of Toposheet 48 J/5 and J/9 was obtained using AHP method. This map was generated after creating LOFS maps for all the factor classes and generating raw susceptibility score map which is classified into low, moderate and high susceptible areas so that vital information could be gained from the map by all decision makers immidiately. Approximately 5% (about 74 sq. Km's) area is falling in high susceptibility zones while about 12% (178 sq. Km's) area is falling in moderate susceptibility zone. Rest of the area is indicated as low susceptibility zone. Most of the high susceptible zones fall in 48 J/5. Some areas in the North – West part of toposheet No. 48 J/5 are falling in high susceptibility zones, Goyar, Tirval, Kheri, Kote and Digali. Besides these some parts in the south-east of 48 J/9 viz, Banagiri, Mamntipal, Saulakhu and Dhulalli are marked as high susceptibility zones. The zone in the centre of the study (Kodasalli, Solgar, Bare) area exhibits the most susceptible zone as many slides (originating from cut slope failures) were recognized in the same zone. Besides these some high susceptible zones are noticed south-west of 48 J/5 like, Bargal, Macholi, Gule Matogea and south-west of Malloni.

VI. CONCLUSIONS AND RECOMMENDATIONS

The susceptibility map is only valid under the given set of geo-environmental conditions taken as input in the susceptibility modelling. Any changes in the spatial distribution of the geo-environmental factors can affect the susceptibility of the area.

About 17% (252 sq. Km's) area is grouped under moderate to high susceptibility zone in toposheet no.'s 48 J/5 & J/9. Most of this area lies around transportation corridors (especially those leading to tourist spots) and extensive slope cut areas in addition to areas with steep slopes which too fall in the realm of moderate to high susceptible zones.

The susceptibility map thus obtained using Analytical hierarchy process (AHP) gives a qualitative indication in the study area about particular mapping units being susceptible to landslide occurrence under the cumulative effect of geo factors under consideration. This does not have any time connotation and also it is assumed that the same geo-environmental conditions will prevail in the future that augmented the present slope failures. The entire susceptibility and demarcation of the weak zones from landslide point of view is discussed in following points:

1. Some areas in the North – Western part of toposheet No. 48 J/5 are falling in high susceptibility zones, Goyar, Tirval, Kheri, Kote and Digali. All these are habitation hubs which although are covered by densely vegetated forests but the steep slopes and patchy rock exposures due to anthropogenic activities makes a possibility of slope failure in near future especially during rainy season. This has to be conveyed to the concerned authorities and preventive measures like slope terracing, retaining walls etc. should be taken up.
2. The road from Yellapur towards Ankola also has several locations where the landslide susceptibility is high. At many places the loose material lying on the road side slides even due to a slight rain. Although the area is covered by thick forest cover but running streams that cut across the roads during rainy season pose a considerable risk to the road during rainy season. Proper drainage along the road and diversion of drainage on the top of the slope should be done. Slope stability measures are also required to minimise the risk.
3. Similarly road sections on the Yellapur-Kaigha road have been observed to have weathered rock and also steep slope gradients. This area also has possibility of slope failures as indicated by susceptibility map. Heavy rainfall and deforestation may lead to loosening of the overburden which may slide. Preventive measures like slope stabilisation and conservation of forests need to be taken up so that the highway is kept safe from any damage.
4. Some areas exhibit slope failures of very recent origin due to road and house construction. This is quite evident in some parts in the south-east of 48 J/9 viz, Banagiri, Mamntipal, Saulakhu and Dhulalli. The zone in the centre of the study (Kodasalli, Solgar, Bare) area exhibits the most susceptible zone as many slides (originating from cut slope failures) were recognized in the same zone. Moreover some high susceptible zones are noticed south-west of 48 J/5 like, Bargal, Macholi, Gule-Matogea and south-west of Malloni also exhibit the same phenomenon.
5. The preparatory factors (e.g., slope, aspect, curvature, geomorphology and drainage) are not expected to change significantly in a short time period, local morphological changes

may occur due to land sliding, but this will not substantially affect the susceptibility model. However, some local changes in the land use pattern can take place, such as terracing of slope for cultivation or excavation for construction of new buildings. Such changes can induce instability "locally" and may increase or decrease the susceptibility of that slope.

6. The susceptibility map is generally meant for regional application because the information is shown on scale 1:50,000; however they are still of considerable significance from the point of specific land use and urban planning. Nevertheless, it is recommended that a detailed site-specific study may be duly conducted before planning and execution of the civil construction works. Areas with high susceptibility falling under high hazard should be given due attention while executing civil constructions.

7. Spatio-temporal prediction of a landslide is still difficult on macro-scale; hence questions can be raised about the predictive capability of a susceptibility map given the uncertainty in the occurrence of a landslide. In the event if a disaster strikes, then loss would be immense if buildings are not safely and properly located. Awareness among people is of utmost importance to reduce the loss of lives and property. The awareness should include information about the potential danger, its identification and its communication; the physical significance of hazard and inherent uncertainties; ways to reduce landslide risk and the available local mitigation options.

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Locality Index

Sl/No.	Village	Latitude (N)	Longitude (E)
1	Anashi	14.99	74.37
2	Baligadde	14.98	74.67
3	Devasa	14.94	74.61
4	Goyar	14.97	74.28
5	Gule Metagi	14.78	74.31
6	Heggumbali	14.88	74.72
7	Machcholi	14.77	7426
8	Ramnagar	14.82	74.62
9	Sarangadde	14.77	74.72
10	Sulageri	14.93	74.50
11	Sullani	14.90	74.43
12	Yellapur	14.97	74.71

Annexure – I: Tabular 41-Point geo-parametric sheet for landslide inventory data of major landslides.									
Location No.	**Distribution**	**Style**	**Failure mechanism**	**History**	**Triggering factor**	**Geo scientific causes**	**Remedial measures**	**Remarks**	Loc Coordinate
S1	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, Reduction of strength on saturation,	Benching		X=74.5903 Y=14.9854
S2	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Dip Slope seems to be the main cause of failure	Retaining wall		X=74.5761 Y=14.9740
S3	Retrogressive	Single	Shallow translational failure	Initiation	Anthropogenic	Overburden failure	Retaining wall		X=74:5696 Y=14.9708
S4	Retrogressive	complex	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, anthropogenic activity	Retaining wall		X=74.6538 Y=14.8935
S5	Retrogressive	complex	Shallow translational failure	Reactivation 1	Rainfall	Increase in pore pressure, Reduction of strength on saturation,	Retaining wall	Subsidence and cutting of road due to slide	X=74.6549 Y=14.8908
S6	Advancing	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, Reduction of strength on saturation,	Benching		X=74.5624 Y=14.8879
S7	Advancing	Single	Shallow translational failure	Reactivation 1	Anthropogenic	Toe cutting for road widening	Benching		X=74.5612 Y=14.8890
S8	Retrogressive	Composite	Shallow translational failure	Reactivation	Rainfall	Increase in pore pressure, Road cutting along Highway	Retaining wall		X=74.6543 Y=14.8755
S9	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, anthropogenic activity	Retaining wall		X=74.6613 Y=14.7782
S10	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, anthropogenic activity	Retaining wall		X=74.6537 Y=14.8361

S11	Retrogressive	Composite	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, Reduction of strength on saturation,	Slope gradation, proper drainage at toe	Boulders are lying at the crown of the slide.Evidence of Creep also seen	X=74.5611 Y=14.9021
S12	Retrogressive	complex	Shallow translational failure	Recent	Anthropogenic	undercutting,bed rock is weathered granite & is highly saturated	Terraced slopes	Area seems to be susceptible for sliding in future,creep movement is seen,underctting prominent	X=74.6548 Y=14.9972
S13	Retrogressive	Composite	Shallow translational failure	Reactivation 1	Rainfall	Reduction of strength on saturation, anthropogenic activity	Retaining wall		X=74.4395 Y=14.8376
S14	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, Reduction of strength on saturation	Retaining wall	Precariously hanging tree should be removed	X=74.3575 Y=14.9304
S15	Retrogressive	Single	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, toe removal	Retaining wall		X=74.3602 Y=14.9354
S16	Retrogressive	Composite	Shallow translational failure	Initiation	Rainfall	Increase in pore pressure, Reduction of strength on saturation,	Slope gradation, proper drainage at toe	Boulders are lying at the crown of the slide.Evidence of Creep also seen	X=74.3613 Y=14.9449
S17	Retrogressive	complex	Shallow translational failure	Recent	Anthropogenic	undercutting,bed rock is weathered granite & is highly saturated	Terraced slopes	Area seems to be susceptible for sliding in future,creep movement is seen,underctting prominent	X=74.3611 Y=14.9413

PLATE 1

Geological map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

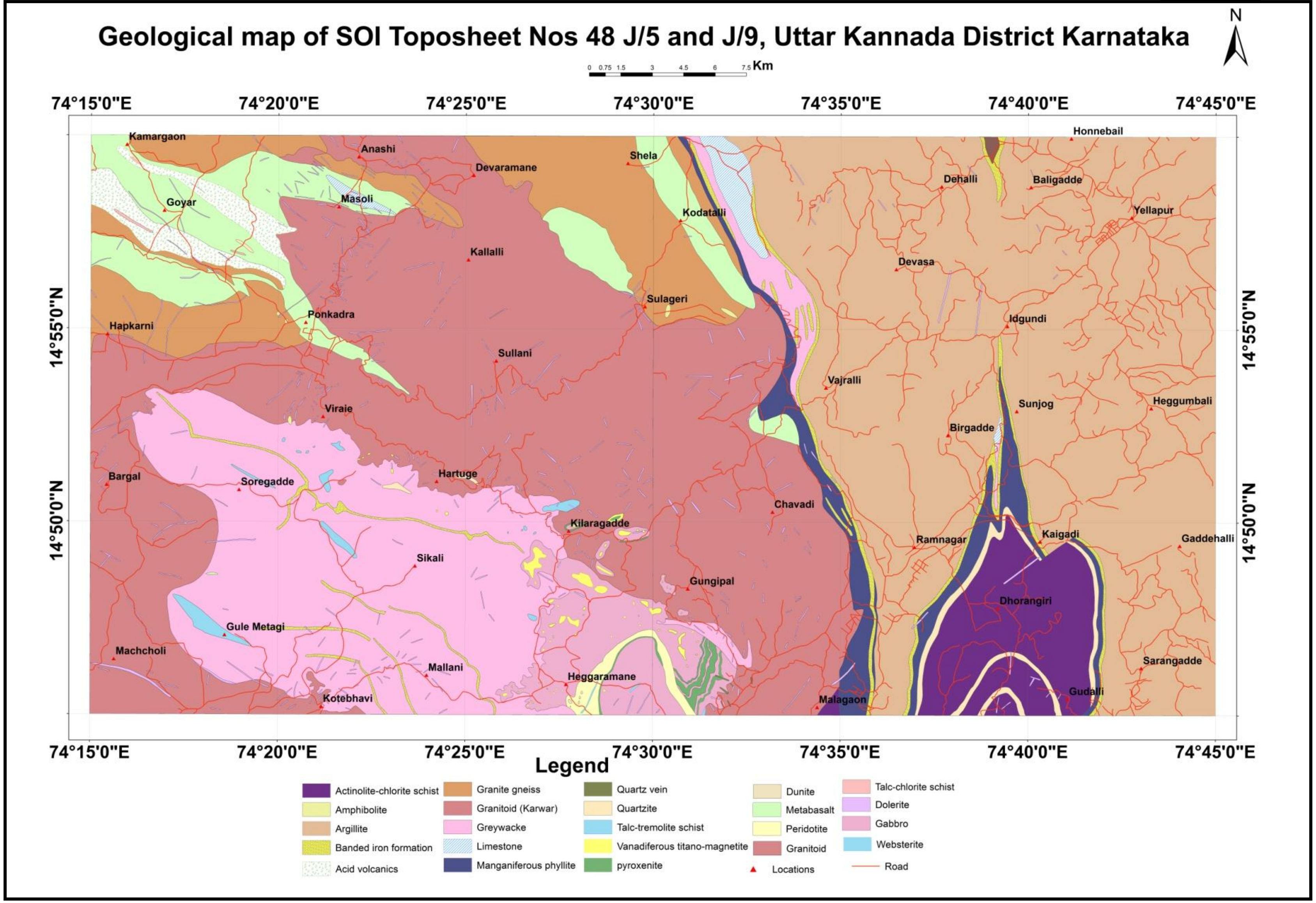


Plate 2

Slope Gradient map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

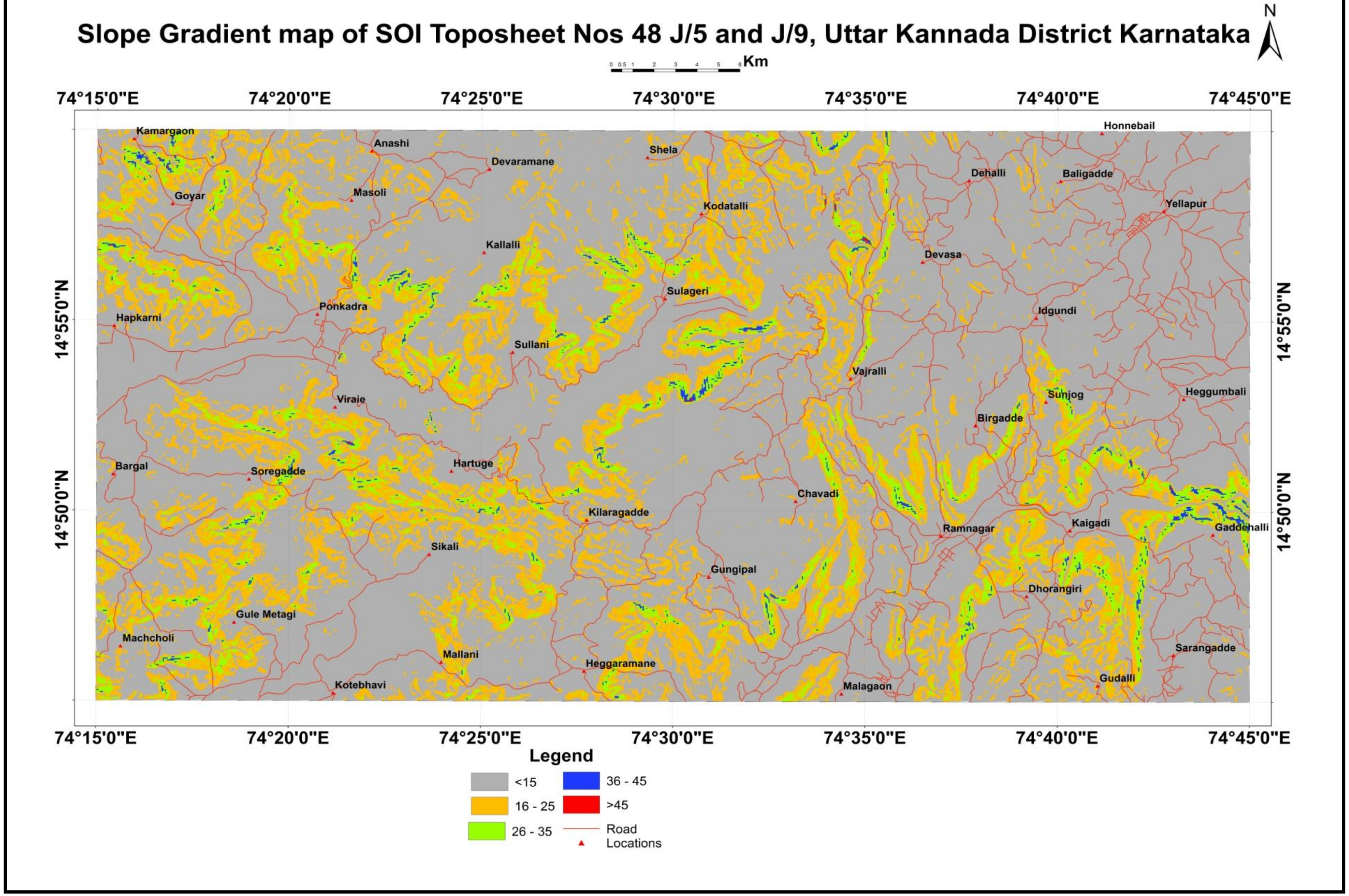
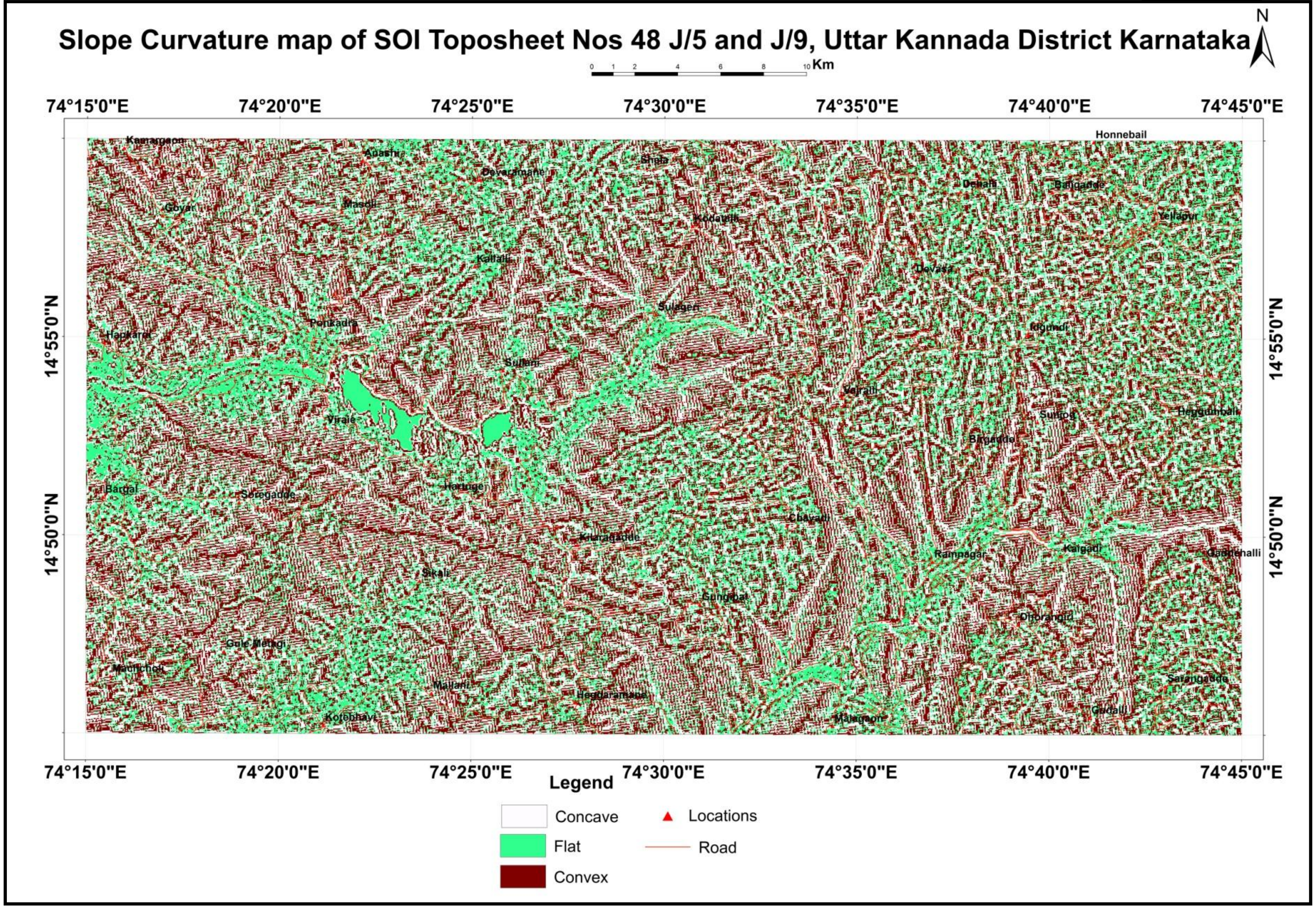
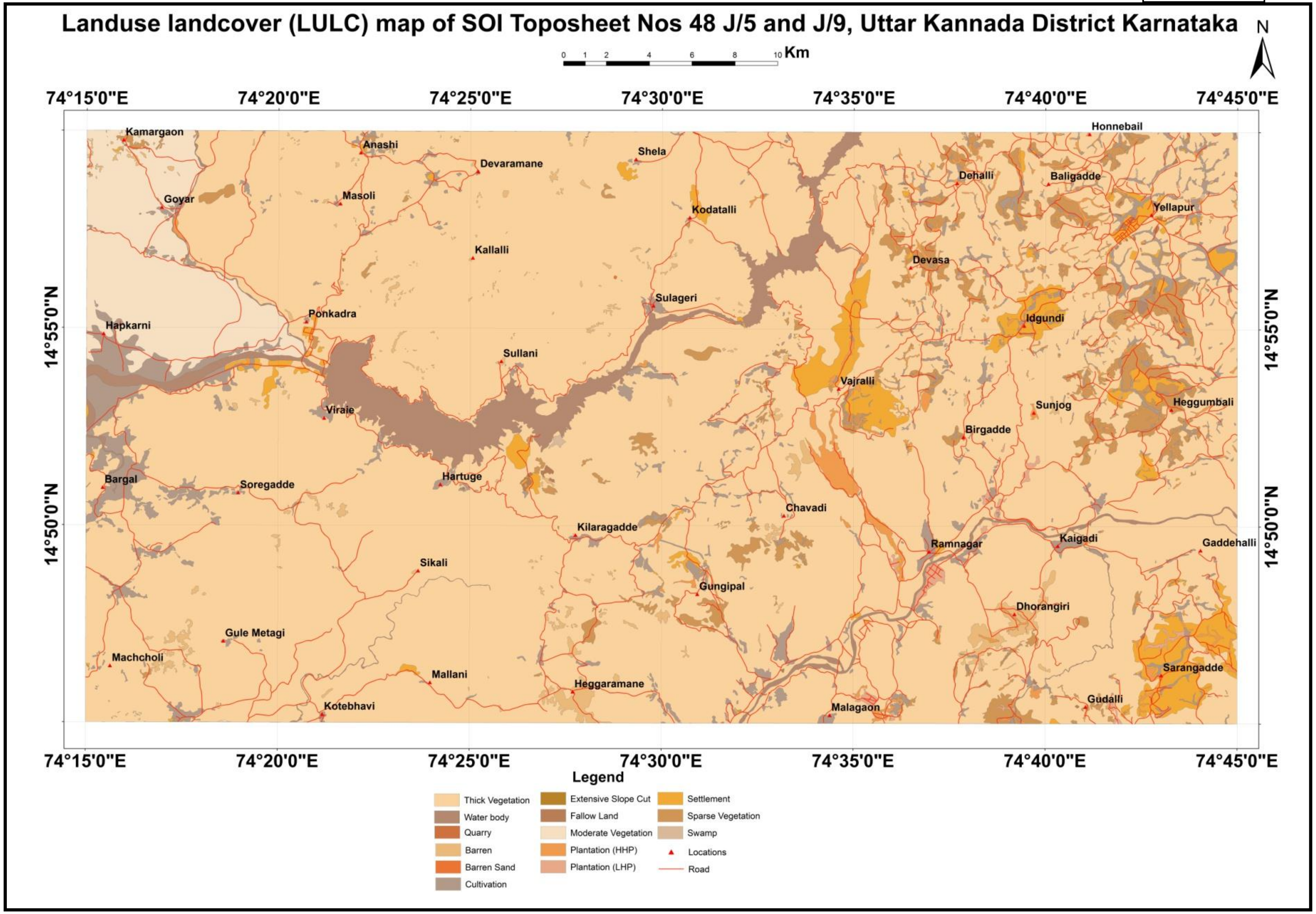


Plate 3



Slope Curvature map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka
N
0 1 2 4 6 8 10 Km
74°15'0"E
74°20'0"E
74°25'0"E
74°30'0"E
74°35'0"E
74°40'0"E
74°45'0"E
14°55'0"N
14°50'0"N
Honnebail
Legend
Concave
Flat
Convex
Locations
Road

Plate 4



Landuse landcover (LULC) map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka
N
0 1 2 4 6 8 10 Km
74°15'0"E
74°20'0"E
74°25'0"E
74°30'0"E
74°35'0"E
74°40'0"E
74°45'0"E
14°55'0"N
14°50'0"N
Kamargaon
Anashi
Devaramane
Shela
Honnebail
Dehalli
Baligadde
Yellapur
Goyar
Masoli
Kodatalli
Kallalli
Devasa
Sulageri
Idgundi
Ponkadra
Hapkarni
Sullani
Vajralli
Viraie
Sunjog
Heggumbali
Birgadde
Hartuge
Bargal
Soregadde
Chavadi
Kilaragadde
Ramnagar
Kaigadi
Gaddehalli
Sikali
Gungipal
Dhorangiri
Gule Metagi
Machcholi
Mallani
Sarangadde
Heggaramane
Kotebhavi
Malagaon
Gudalli
Legend
Thick Vegetation
Water body
Quarry
Barren
Barren Sand
Cultivation
Extensive Slope Cut
Fallow Land
Moderate Vegetation
Plantation (HHP)
Plantation (LHP)
Settlement
Sparse Vegetation
Swamp
Locations
Road

Plate 5

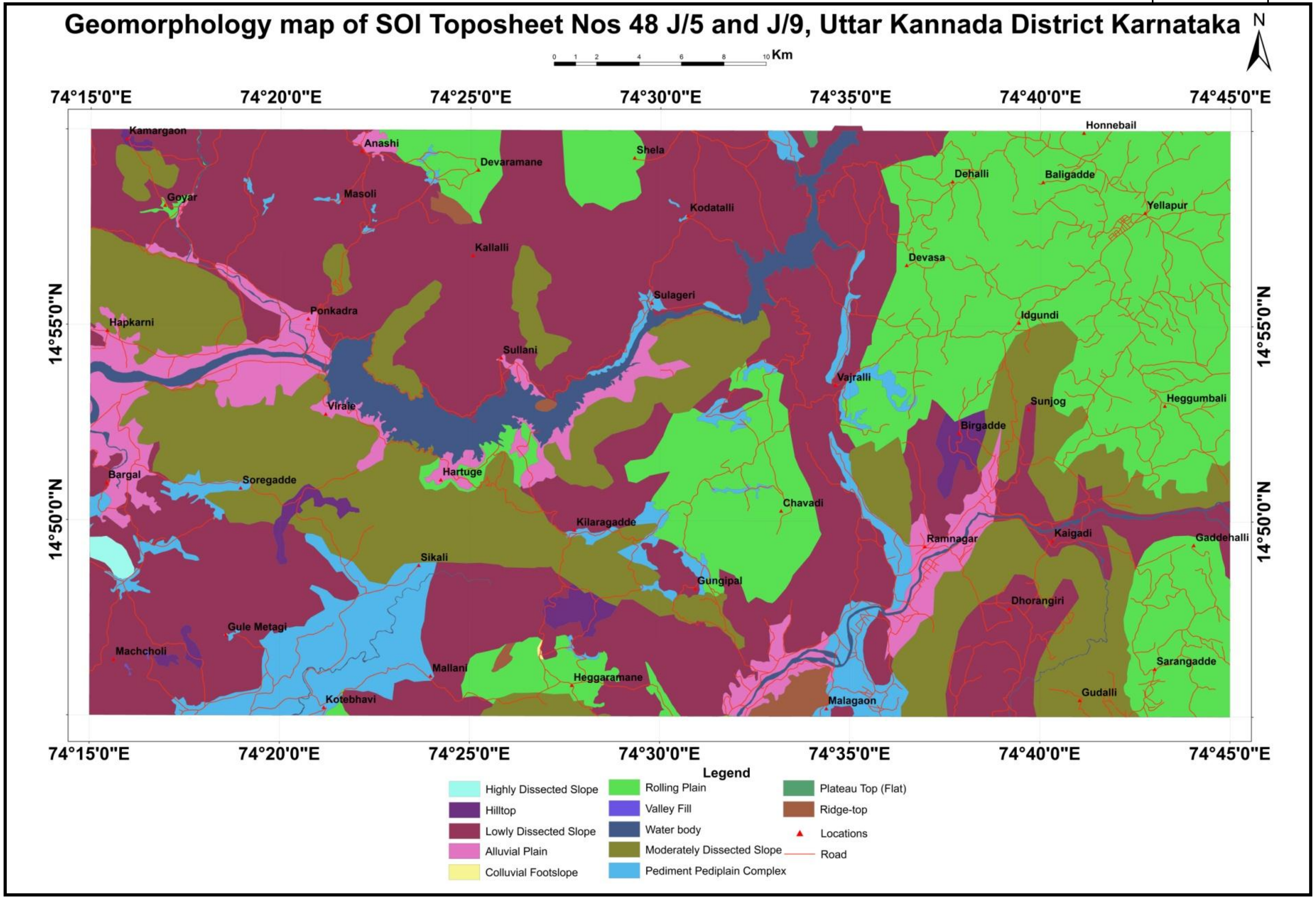

Geomorphology map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka
N
0 1 2 4 6 8 10 Km
74°15'0"E
74°20'0"E
74°25'0"E
74°30'0"E
74°35'0"E
74°40'0"E
74°45'0"E
14°55'0"N
14°50'0"N
Kamargaon
Anashi
Devaramane
Shela
Honnebail
Goyar
Masoli
Kodatalli
Dehalli
Baligadde
Yellapur
Kallalli
Devasa
Sulageri
Ponkadra
Hapkarni
Idgundi
Sullani
Vajralli
Heggumbali
Virale
Sunjog
Birgadde
Hartuge
Bargal
Soregadde
Chavadi
Kilaragadde
Ramnagar
Kaigadi
Gaddenalli
Sikali
Gungipal
Dhorangiri
Gule Metagi
Machcholi
Mallani
Heggaramane
Sarangadde
Kotebhavi
Malagaon
Gudalli
Legend
Highly Dissected Slope
Hilltop
Lowly Dissected Slope
Alluvial Plain
Colluvial Footslope
Rolling Plain
Valley Fill
Water body
Moderately Dissected Slope
Pediment Pediplain Complex
Plateau Top (Flat)
Ridge-top
Locations
Road

Plate 6

Slope Forming Material (SFM) map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

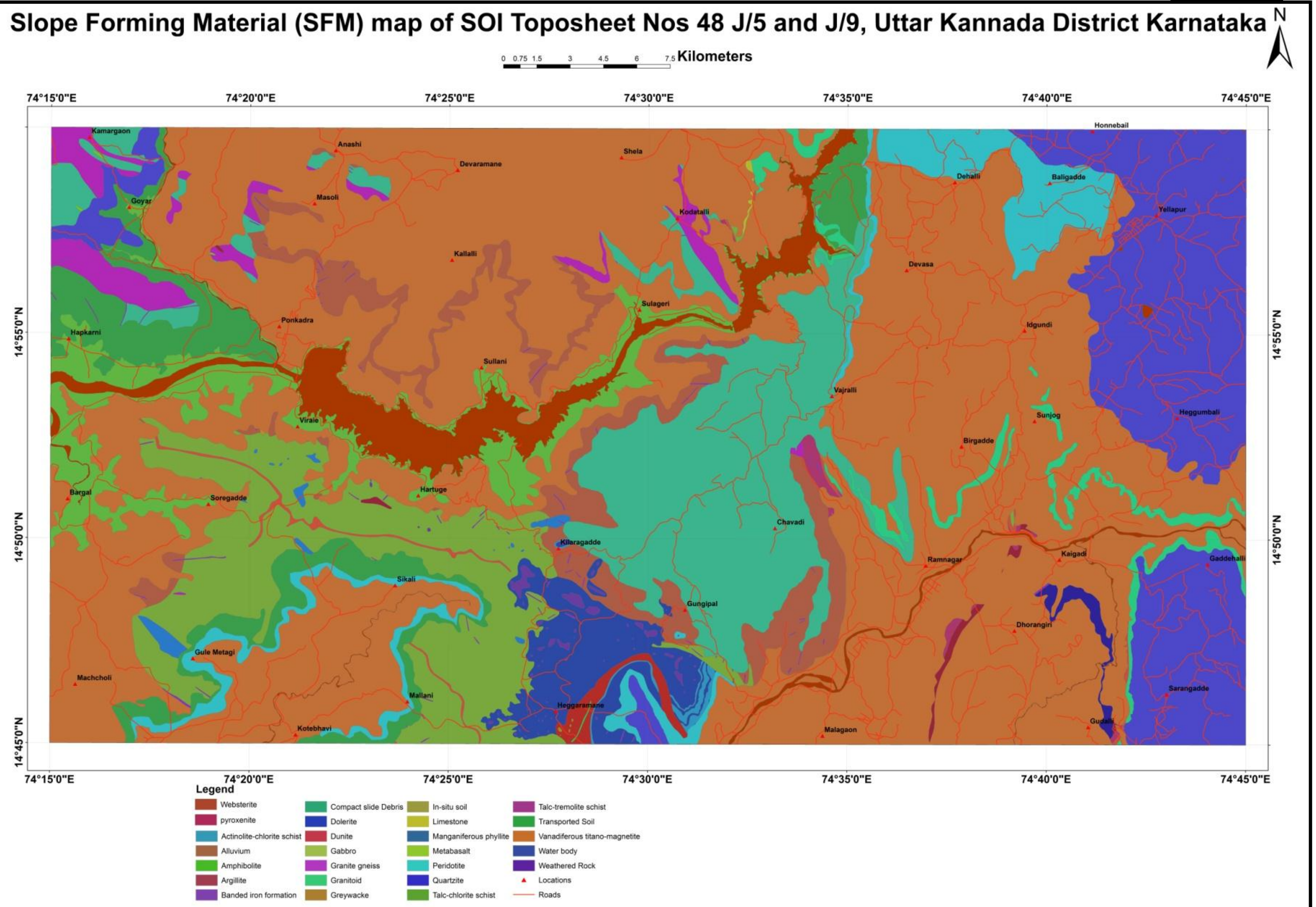


Plate 7

Slope Aspect map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

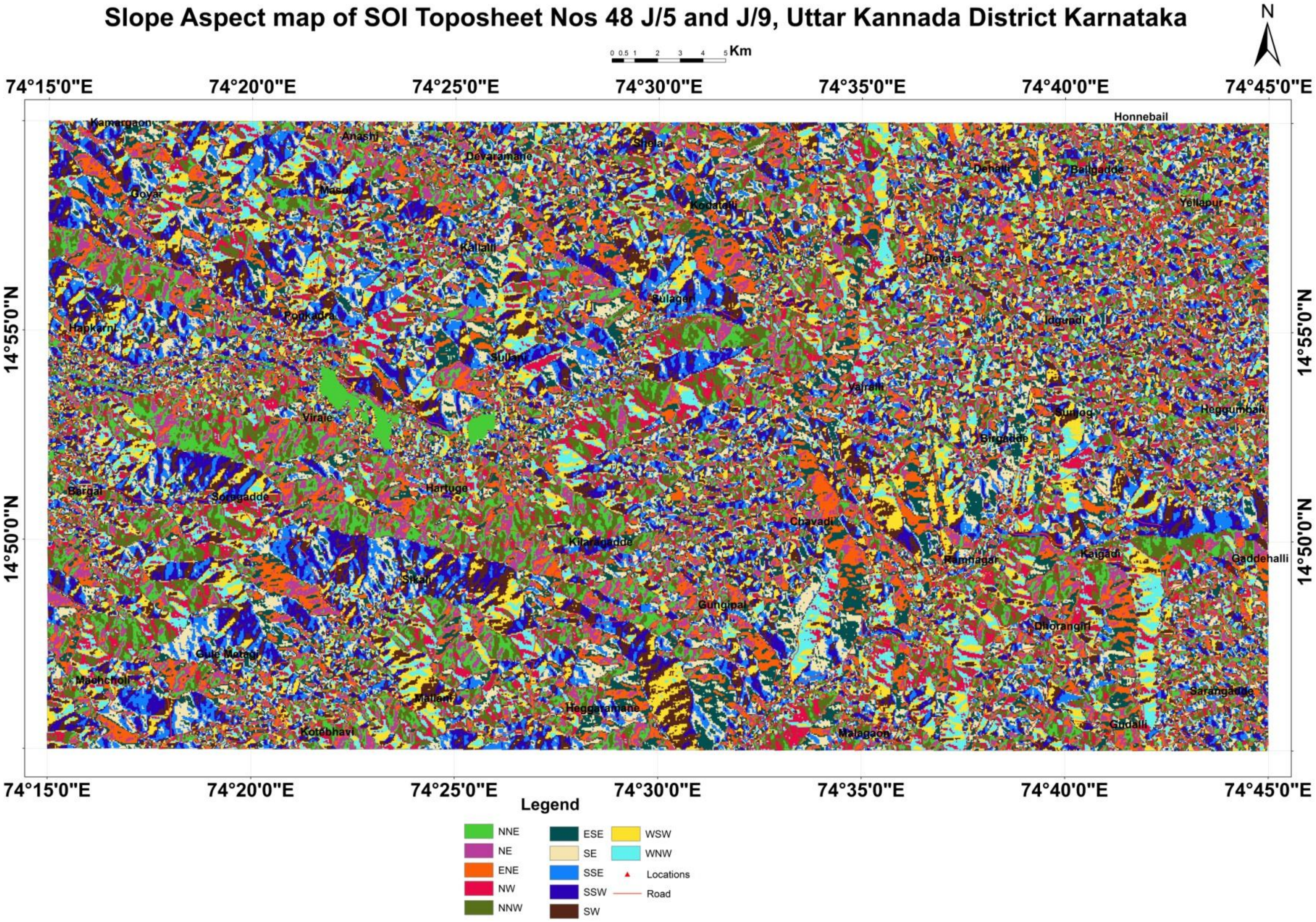


Plate 8

Regolith Thickness map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

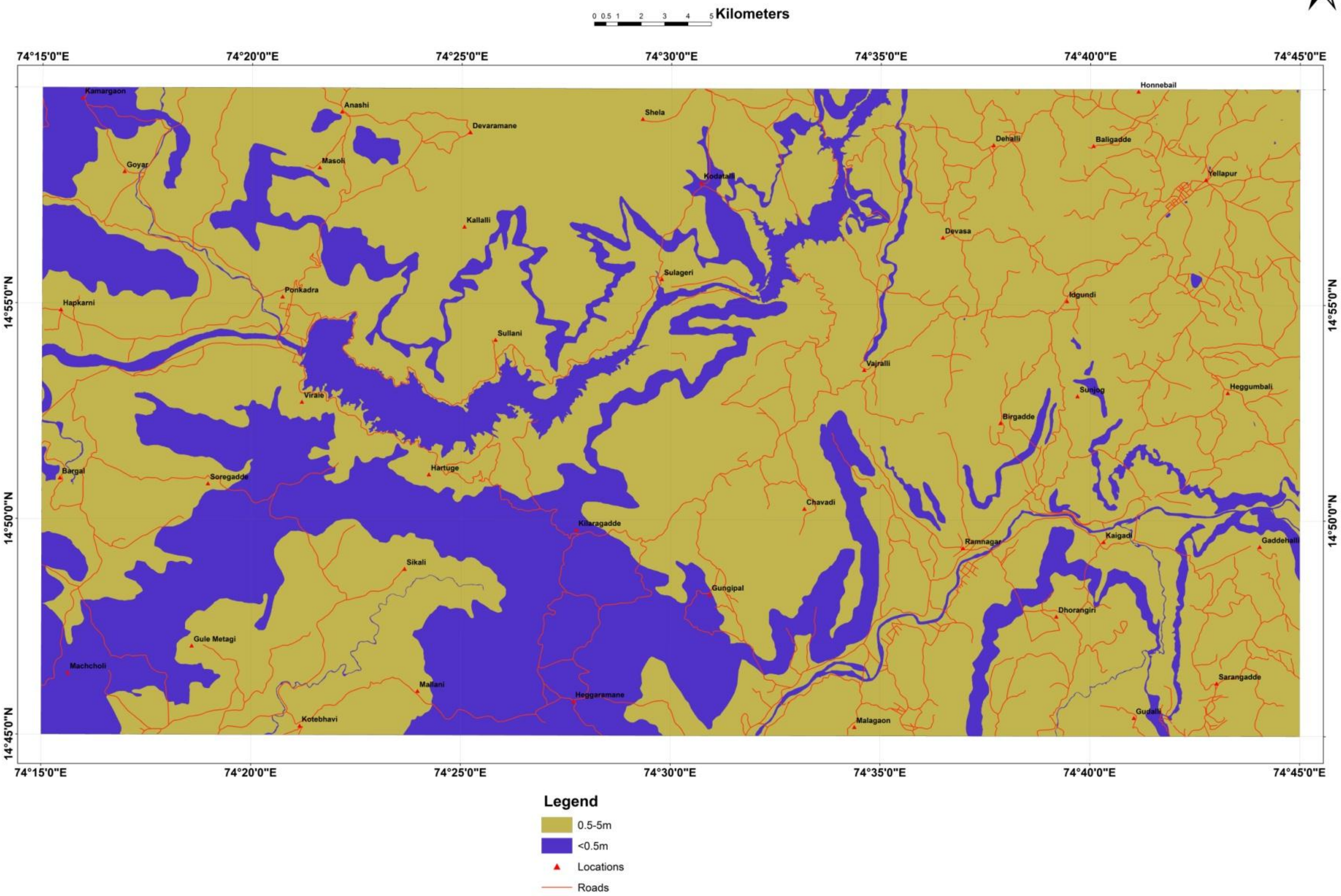


PLATE 9

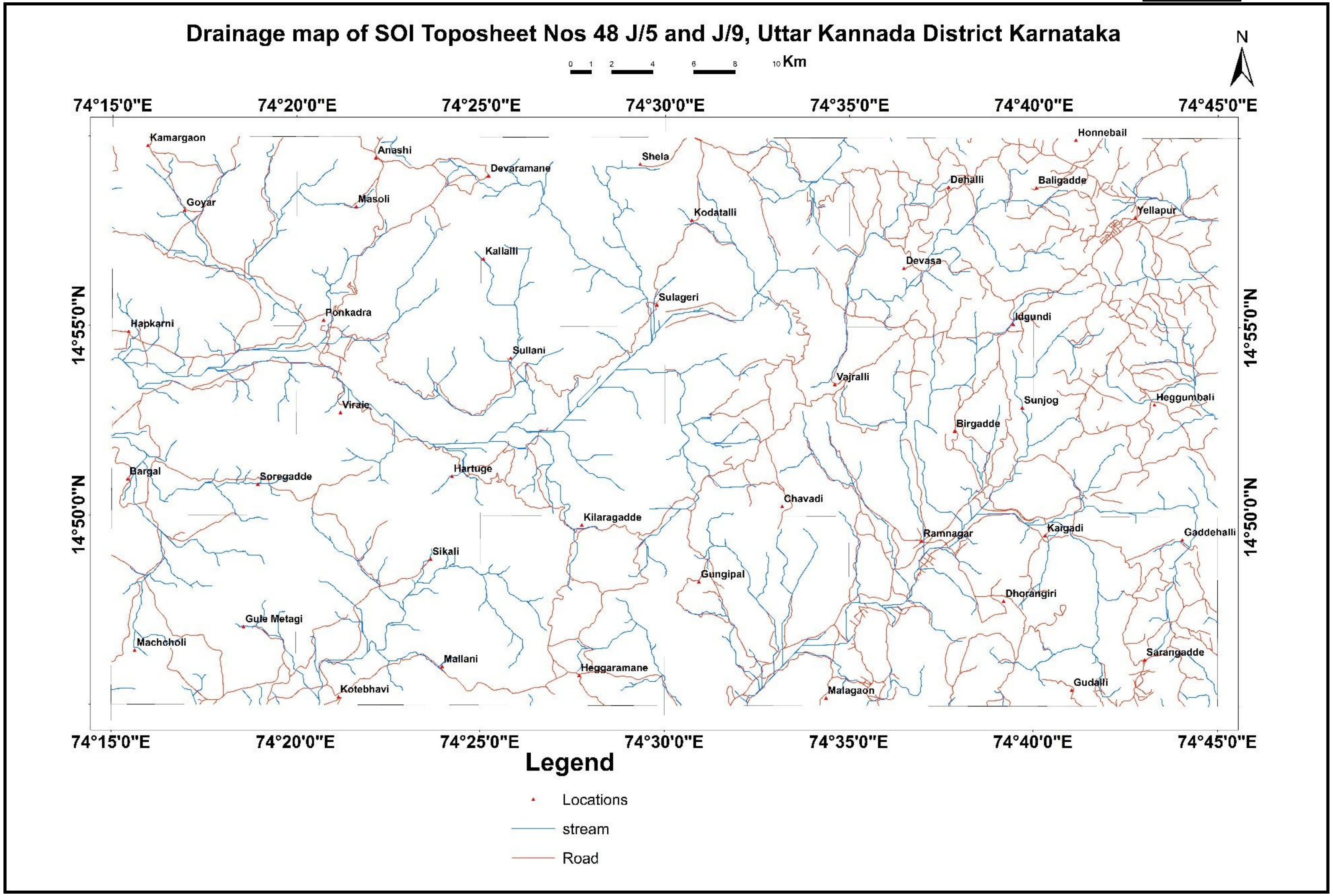

Drainage map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka
N
0 1 2 4 6 8 10 Km
74°15'0"E
74°20'0"E
74°25'0"E
74°30'0"E
74°35'0"E
74°40'0"E
74°45'0"E
14°55'0"N
14°50'0"N
Kamargaon
Anashi
Devaramane
Shela
Honnebail
Goyar
Masoli
Kodatalli
Dehalli
Baligadde
Yellapur
Kallalli
Devasa
Sulageri
Ponkadra
Hapkarni
Idgundi
Sullani
Vajralli
Viraje
Sunjog
Heggumbali
Birgadde
Bargal
Soregadde
Hartuge
Chavadi
Kilaragadde
Ramnagar
Kalgadi
Gaddehalli
Sikali
Gungipal
Dhorangiri
Gule Metagi
Machcholi
Mallani
Heggaramane
Sarangadde
Kotebhavi
Malagaon
Gudalli
Legend
Locations
stream
Road

PLATE 10

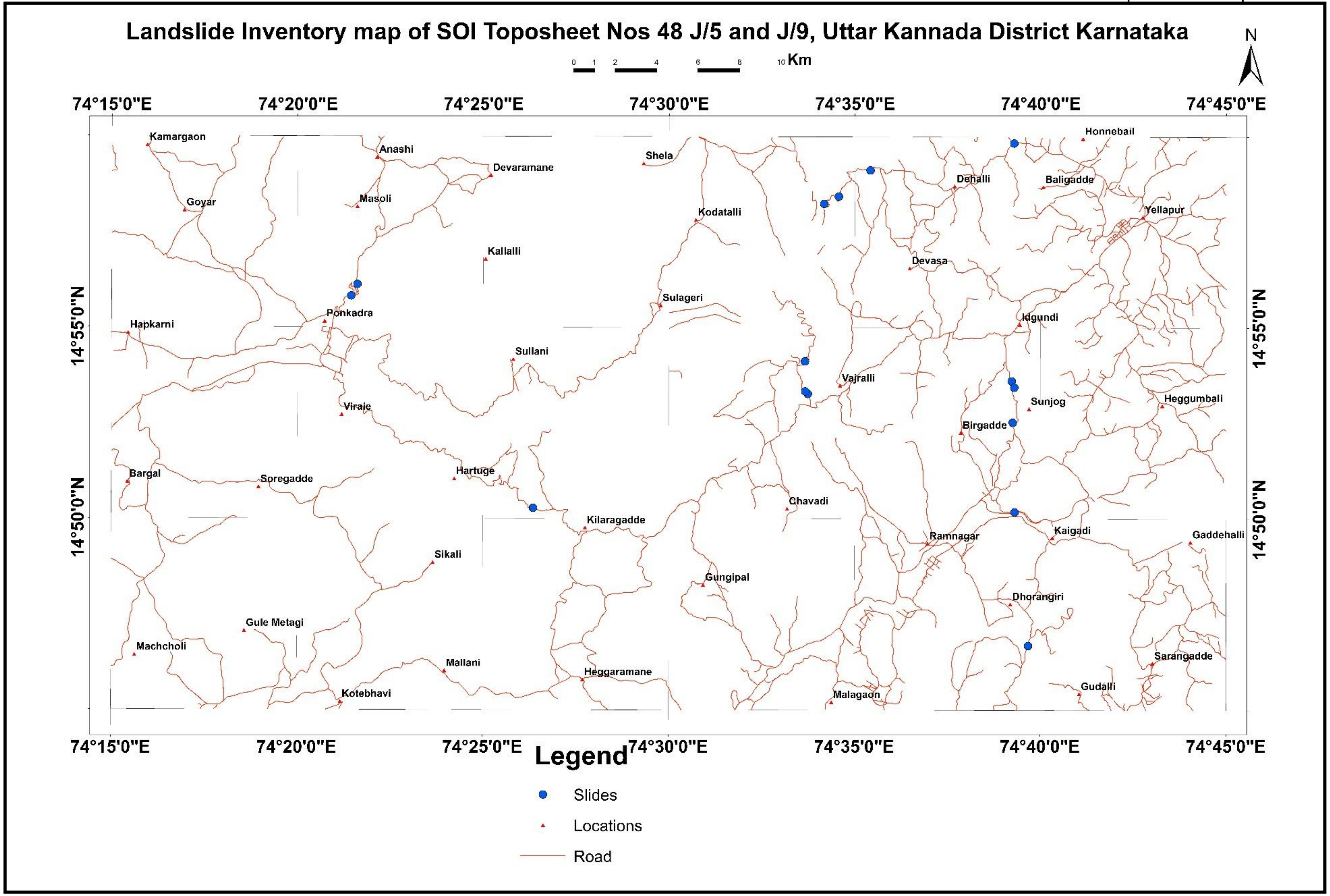

Landslide Inventory map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka
N
0 1 2 4 6 8 10 Km
74°15'0"E
74°20'0"E
74°25'0"E
74°30'0"E
74°35'0"E
74°40'0"E
74°45'0"E
14°55'0"N
14°50'0"N
Kamargaon
Anashi
Devaramane
Shela
Honnebail
Goyar
Masoli
Kodatalli
Dehalli
Baligadde
Yellapur
Kallalli
Devasa
Sulageri
Ponkadra
Hapkarni
Idgundi
Sullani
Vajralli
Sunjog
Heggumbali
Viraje
Birgadde
Bargal
Soregadde
Hartuge
Chavadi
Kilaragadde
Ramnagar
Kaigadi
Gaddehalli
Sikali
Gungipal
Dhorangiri
Gule Metagi
Machcholi
Mallani
Heggaramane
Sarangadde
Kotebhavi
Malagaon
Gudalli
Legend
Slides
Locations
Road

PLATE 11

Susceptability map of SOI Toposheet Nos 48 J/5 and J/9, Uttar Kannada District Karnataka

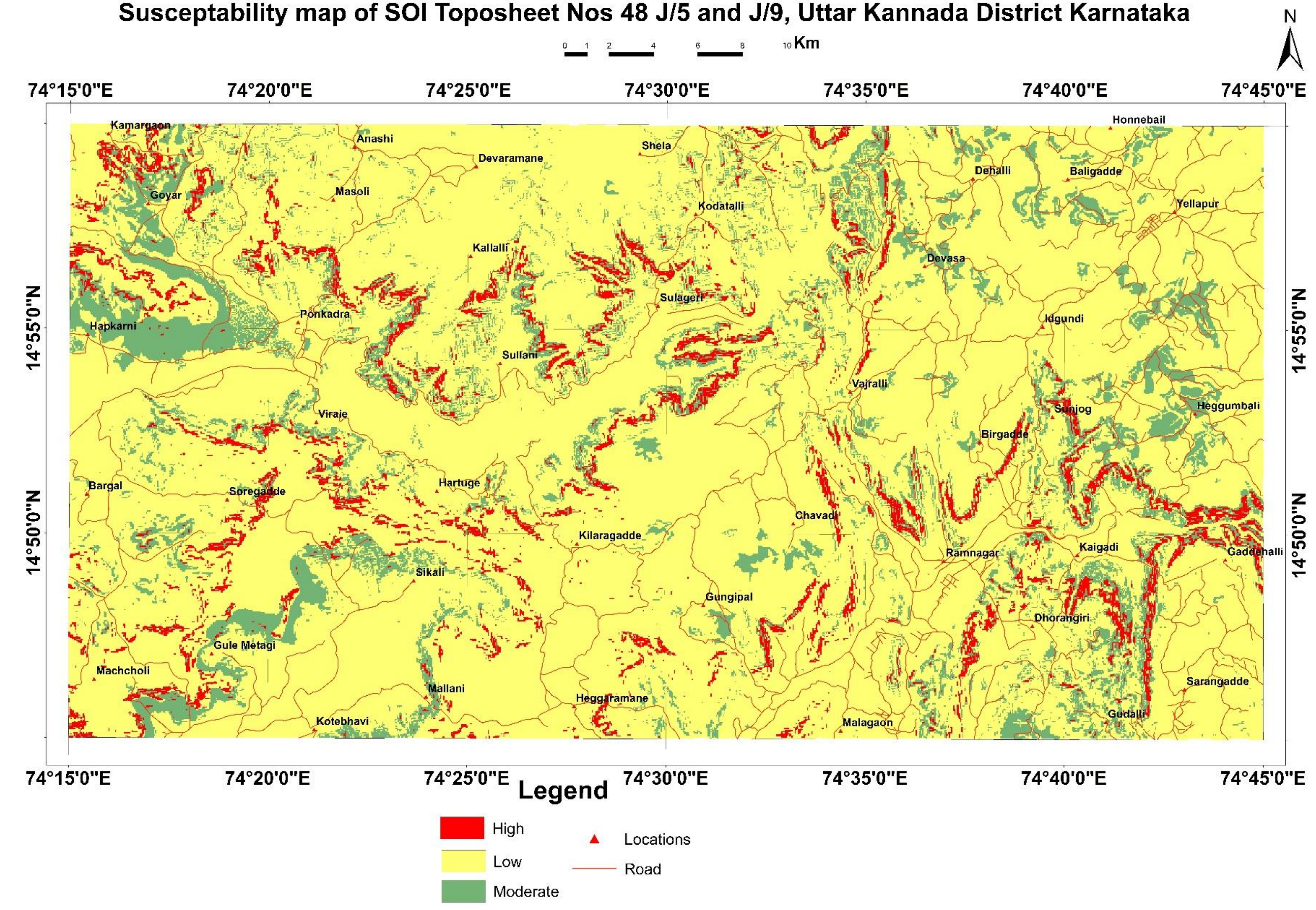


Photo 1

Photo 2

Photo 3

Photo 4

Photos (1 to 4) showing Slope failures along Kiagha-Yellapur road section.

Photo: 5 Extensive road cut – Yellapur-Kaigha road

Photo: 6 Old and Abandoned rock quarry Near Karda

Photo: 7 Thick Vegetation along Kali nadi near Hartuge

Photo: 8 Low dissected slope –West of Kaigha Nuclear Power Plant

Photo: 9 Pediment – pediplain Complex Near Anashi (NW of study area)

Photo: 10 Fresh exposed rock (In situ) North of Kaigha

Photo: 11 Granitic (In situ soil) West of Soregadde

Photo: 12 Alluvial plain used for paddy cultivation near Sullani

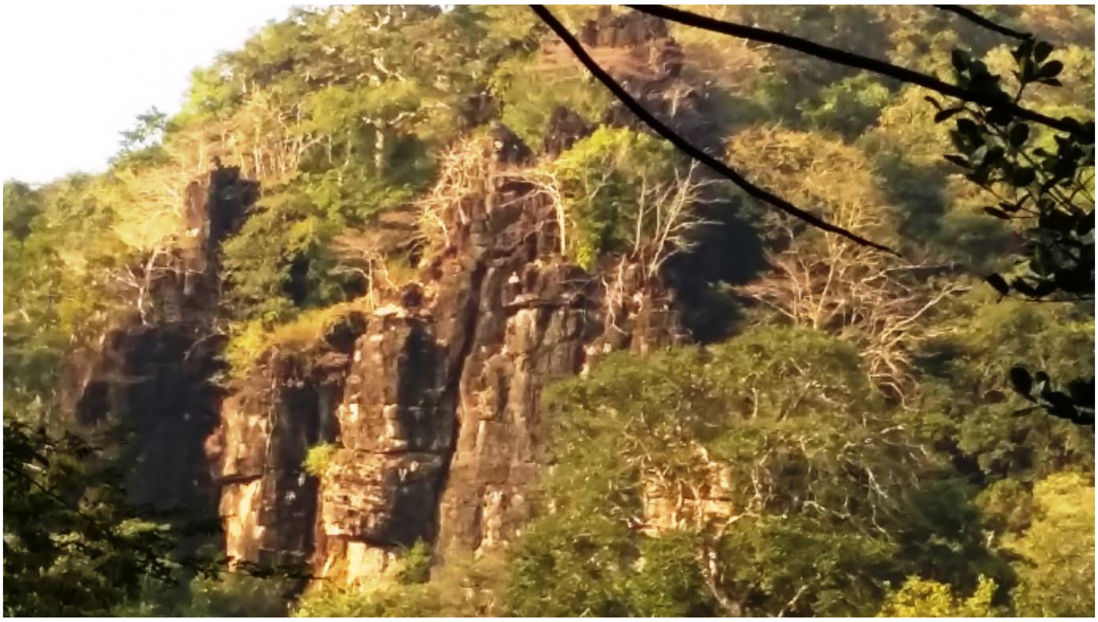


Photo: 13 Regolith thickness 0 to 0.5m – South of Devasa

Photo: 14 Regolith thickness 0.5m to 5m – Yellapur-Ankola road