



उत्तर पश्चिम हिमालय का भूस्खलन संग्रह

Landslide Compendium of Northwestern Himalayas

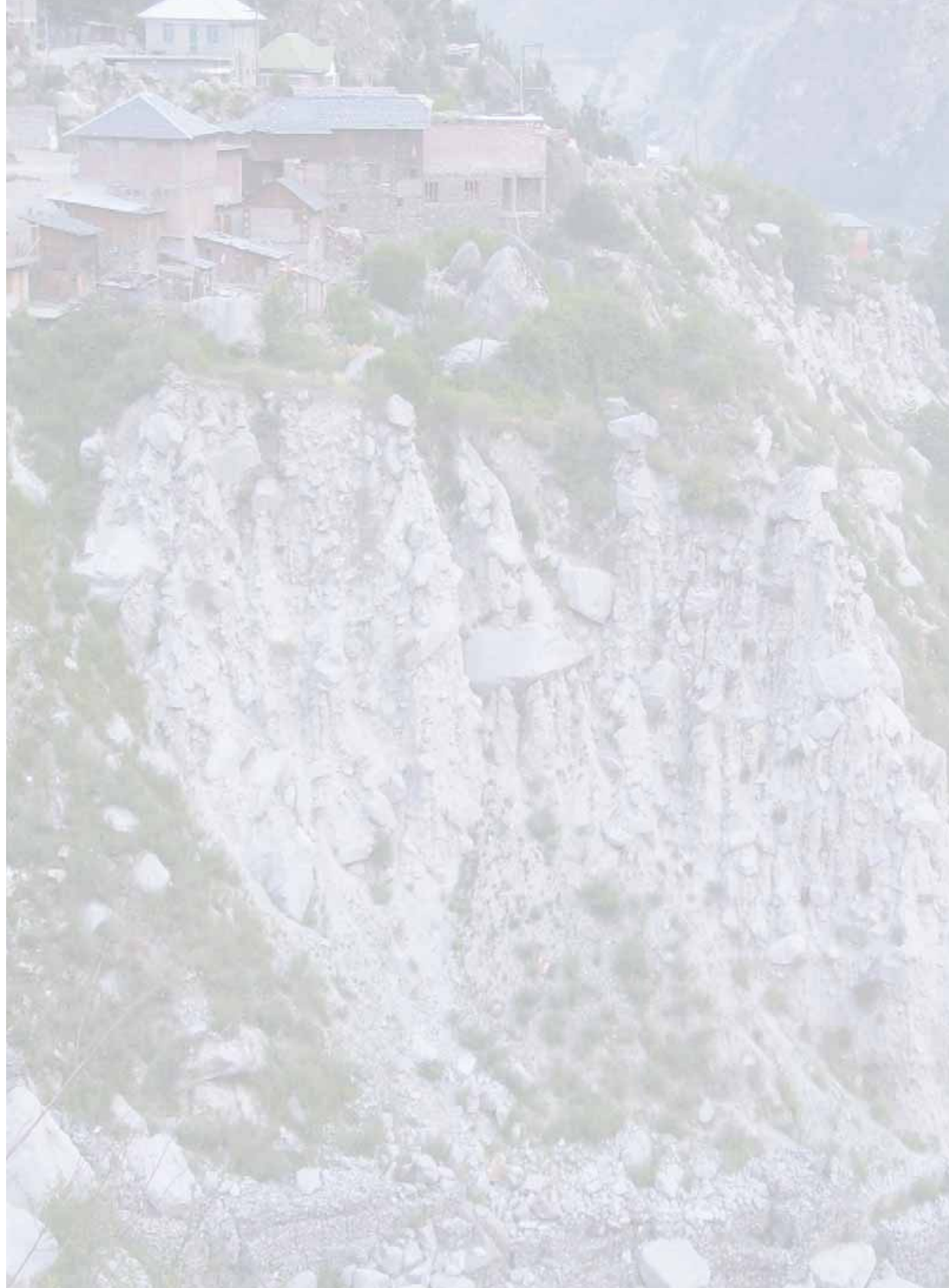


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GEOLOGICAL SURVEY OF INDIA

भारत सरकार के आदेश से प्रकाशित
PUBLISHED BY ORDER OF THE GOVERNMENT OF INDIA

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Compiled, prepared and presented by

Pankaj Jaiswal, Director, Geohazards Research & Management Cell, CHQ
Tamoghno Ghosh, Sr. Geologist, Geohazards Research & Management Cell, CHQ
Harish Kumar, Sr. Geologist, North Eastern Region, Shillong
Swagatam Bhowmik, Sr. Geologist, Geohazards Research & Management Cell, CHQ
Pankaj Kumar, Sr. Geologist, Mission-IV, CHQ
Saibal Ghosh, Director, Geohazards Research & Management Cell, CHQ

Editing

P. V. S. Rawat, Director (Retd.), GSI

Manuscript editing and processing for printing

Arpita Pankaj, Sr. Geologist
Publication and Information Division
Central Headquarters

Supervision

Nirmal Dhar, Director, Publication and Information Division, CHQ

Overall Supervision

Tribhuwan Singh Pangtey, Additional Director General & Head Mission-IV
Prabir Kumar Mondal, Additional Director General & Head Mission-III
G. P. Gupta, Deputy Director General, Mission-III B

Published by

Director General,
Geological Survey of India,
27 Jawaharlal Nehru Road,
Kolkata-700016

प्राककथन

भारतीय भूवैज्ञानिक सर्वेक्षण (जीएसआई) का संबंध भारत में भूस्खलन अध्ययन के साथ पुराने समय 1880 से है। विगत 130 वर्षों में जीएसआई ने भूस्खलन आपदा प्रबंधन में काफी योगदान दिया है। इन सभी वर्षों में जीएसआई द्वारा भूस्खलन अध्ययन के सभी क्षेत्रों में कई प्रगति की है ;चाहे वह भूस्खलन संवेदनशीलता मानचित्रण हो, साइट स्पेसिफिक विस्तृत भूस्खलन अनुसंधान, भूस्खलन आपदा और जोखिम का आकलन हो या हाल में ही विकसित हुआ भूस्खलन की पूर्व चेतावनी प्रणालीहो। खासकर, उत्तर-पश्चिम हिमालय में, उत्तराखंड, हिमाचल प्रदेश, और जम्मू एवं कश्मीर राज्यों में, जीएसआई ने फील्ड आधारित भूस्खलन अनुसंधानों में अधिकतम योगदान दिया है और सूचनाओं का भंडार उत्पादित किया है, जो देश के इस हिस्से में भावी अध्ययन हेतु बहुत ही महत्वपूर्ण हो सकता है। वर्तमान समय में विकास, संप्रेषण और बसने की क्रिया हेतु अपेक्षाकृत ज्यादा सुरक्षित पहाड़ी क्षेत्रों की बढ़ती मांग के साथ यह आवश्यकता महसूस की गई कि बेहतर प्रस्तुति और आसान पुनःप्रापन के लिए जीएसआई के समस्त उपलब्ध भूस्खलन कार्यों को एक जीआईएस समर्थ प्लेटफार्म के अधीन लाया जाए। 'उत्तर-पश्चिम हिमालय का भूस्खलन संग्रह (Landslide compendium of NW Himalaya) जीएसआई का एक ऐसा ही प्रयास है। जिसमें जीआईएस द्वारा उत्तराखंड, हिमाचल प्रदेश, और जम्मू एवं कश्मीर के राज्यों में सम्पन्न समस्त भूस्खलन अध्ययनों का मिलान, संकलन और प्रलेखीकरण किया गया है। इस संग्रह में समस्त पुराने एनालॉग भूस्खलन मानचित्रों को जीआईएस समर्थ प्लेटफार्म में बदला गया है, जो न सिर्फ इन अमूल्य मानचित्रों की सुस्पष्टता और पठनीयता को बढ़ाता है बल्कि भूस्खलन आपदा के सतत परिवर्तनीय स्थानिक अस्थायी परिवर्तनों की जरूरतों को पूरा करने के लिए यथावांछित अद्यतनीकरण एवं आशोधन हेतु भी गुंजाइश छोड़ता है। जिस प्रकार की सूचनाएं इस संग्रह में उपलब्ध है वो योजनाकारों, विद्यार्थियों, शोधार्थियों और अन्य स्टेक होल्डर्स के लिए अत्यंत महत्वपूर्ण होंगी जो उनके लिए भूस्खलन की स्थिति और विद्यमान ज्ञान-आधार की रिक्तियों को समझने में सहायक होगा और देश में भूस्खलन आपदा के प्रबंधन हेतु नवीन साधनों एवं प्रविधियों हेतु क्षेत्रों की खोज करने में मदद करेगा। मैं इस संग्रह को आकार देने संलग्न रहे सभी रचनाकारों और हमारे पदाधिकारियों को तहे दिल से धन्यवाद देता हूँ और कामना करता हूँ कि भारतीय भूवैज्ञानिक सर्वेक्षण का यह प्रयास सही अर्थों में सभी स्टेक होल्डर्स, प्रयोक्ताओं और समुदाय के लिए उपयोगी हो।

एम राजू
17/10/2016

एम. राजू
महानिदेशक
भारतीय भूवैज्ञानिक सर्वेक्षण

Foreword

Geological Survey of India (GSI)'s association with landslide study in India dates back to 1880. In last 130 years GSI has made significant contribution to landslide disaster management. In all these years, several advancements have been made by GSI in different domains of landslide studies which include landslide susceptibility mapping, site-specific detailed landslide investigations, landslide hazard and risk estimation or lately development of early warning for landslides. Particularly, in the NW Himalayas, in the states of Uttarakhand, Himachal Pradesh and Jammu & Kashmir, GSI has made maximum contribution to field-based landslide investigation and generated plethora of information, which can be of immense value to promote the study on landslides in this part of the country. In the recent times, with the growing demands of safer hill area for development, communication and settlement, it has been felt necessary to bring all the available landslide works of GSI under one GIS-enabled platform for better presentation and easy retrieval. 'Landslide compendium of NW Himalayas' is one such endeavour of GSI, wherein all landslide studies carried out by GSI in the states of Uttarakhand, Himachal Pradesh and Jammu & Kashmir are collated, compiled and documented. In this compendium all the old analog landslide maps have been transferred into GIS enabled platform, which not only enhances clarity and readability of these invaluable maps but also leaves the scope of updation and modification as and when required to cater the need for ever-changing spatio-temporal evolution of landslide hazard. The type of information available in this compendium will be of immense value to planners, students and researchers and other stakeholders and it will facilitate to understand the landslide situation, gaps in the existing knowledge-base, and to explore the scope for devising new tools and methodologies required for managing landslide hazards in the country. I convey my sincere thanks to all the authors and all our officials who have been involved in giving shape to this compendium and wish that this endeavor of GSI would really be useful to all stakeholders, end users and community.



17/10/2016.

Shri M. Raju
Director General
Geological Survey of India

भूमिका

भूस्खलन, हिमालय के पहाड़ी इलाकों में अधिकतर होने वाली प्राकृतिक आपदा, मानसून के अंतर्गत जुलाई से सितंबर तक और बर्फ गिरने के बाद जनवरी से मार्च तक सबसे अधिक होती है। तीव्र भूकंप भी भूस्खलन, विशेष रूप से अस्थिर चिह्नित ढलान क्षेत्रों में सक्रिय करता है। देश के 4.2 लाख वर्ग किमी या भूमि का 12.6% क्षेत्र को, बर्फ कवर क्षेत्र को छोड़कर, भूस्खलन के लिए संवेदनशील है। इसमें से 1.4 लाख वर्ग किमी उत्तर पश्चिम हिमालय का है, जो की उत्तराखंड, हिमाचल प्रदेश और जम्मू-कश्मीर के राज्यों में फैल हुआ है।

भारतीय भूवैज्ञानिक सर्वेक्षण (जी.एस.आई.) का उत्तर पश्चिम हिमालय में भूस्खलन के अध्ययन में योगदान पूर्व में 1880 से सर आर.डी. ओल्डम के द्वारा नैनीताल, उत्तराखंड में ढलान स्थिरता की समस्या के अध्ययन से किया गया। 1945 में, विशेष इंजीनियरिंग भूविज्ञान और भू-जल डिवीजन की स्थापना के साथ, जी.एस.आई. भूस्खलन के अन्वेषण सरकार के हितधारकों से अनुरोध पर और विभागीय अनुसंधान एवं विकास परियोजनाओं के रूप में शुरू किया। 1980 के बाद से, भूस्खलन संवेदनशीलता मानचित्रण का काम एक व्यवस्थित दृष्टिकोण से शुरू किया गया। जी.एस.आई. द्वारा किए गए भूस्खलन अध्ययन को दो व्यापक श्रेणियों में विभाजित किया जा सकता है: पूर्व आपदा अध्ययन, जो भूस्खलन संवेदनशीलता (जोखिम) जोनैशन के माध्यम से कमजोर ढलानों की पहचान विभिन्न पैमानों (मैक्रो, मेसो और माइक्रो) पर करना या संकट पूर्ण ढलानों: का अध्ययन उनके स्थिरता की स्थिति और गतिविधि का निर्धारण करने के लिए शामिल है; और आपदा उपरांत अध्ययन, जो घटित भूस्खलन कि विस्तृत जांच, विफलताओं के लिए जिम्मेदार कारणों को निर्धारित करने के लिए और ढलानों को स्थिर करने के लिए आवश्यक उपाय सुझाने के लिए सम्मिलित हैं।

पिछले कुछ दशकों में, जी.एस.आई. ने उत्तराखंड, हिमाचल प्रदेश और जम्मू-कश्मीर राज्यों में भूस्खलन के अध्ययन के लिए महत्वपूर्ण योगदान दिया है। राज्य सरकारों को प्रस्तुत किए गए प्रतिवेदन भूमि उपयोग की योजना बनाने के लिए और उचित शमन उपायों को अपनाने के लिए एक महत्वपूर्ण दस्तावेज के रूप में काम आता है। सबसे अच्छा उदाहरण नैनीताल शहर है जहाँ जी.एस.आई. के भूस्खलन जोनैशन मानचित्र का उपयोग, कानून के माध्यम से, भूमि के उपयोग के प्रबंधन के तरीकों में किया जा रहा है। अब तक भूस्खलन अध्ययन में जी.एस.आई. की उल्लेखनीय उपलब्धियों में निम्न कार्य शामिल हैं: प्रमुख नदी घाटियों की संवेदनशीलता मानचित्रण (24,000 वर्ग किमी क्षेत्र), शहर / जिला क्षेत्र की संवेदनशीलता मानचित्रण (लगभग 2000 वर्ग किमी क्षेत्र), सड़क गलियारा की संवेदनशीलता मानचित्रण (2100 किलोमीटर) और प्रमुख भूस्खलन की विस्तृत स्थल विशेष जांच के अध्ययन। इन सूचनाओं के भंडार के साथ जो जी.एस.आई. के पास है यद्यपि अनुरूप रूप में उपलब्ध है, यह अधिकतर महसूस किया गया कि उन्हें संकलन और बेहतर प्रस्तुति तथा आसान पुनर्प्राप्ति के लिए जी.आई.एस. मंच पर लाया जाय।

इस प्रयास में, “उत्तर पश्चिम हिमालय में भूस्खलन के अध्ययन” के इस संग्रह को तैयार किया गया है, ताकि देश में और विशेष रूप से उत्तराखंड, हिमाचल प्रदेश और जम्मू एवं कश्मीर राज्य के हितधारकों को लाभान्वित किया जा सके। इस संग्रह में उपलब्ध जानकारी से योजनाकारों, छात्रों और शोधकर्ताओं को सहायता मिलेगी। उन्हें भूस्खलन की स्थिति को समझने के लिए, वर्तमान ज्ञान के आधार में अंतराल और नए उपकरणों और प्रणालियों की खोज/ जांच से देश में भूस्खलन आपदा प्रबंधन के लिए आवश्यक रूप से तैयार करने में मदद मिलेगी।

Prelude

Landslide, a frequently occurring natural hazard in the hilly terrains of Himalayas, shows preponderance of activity during the monsoon from July to September and after the snow fall from January to March. The strong earthquakes also trigger landslides, particularly in regions marked by critically disposed and unstable slopes. About 0.42 million KM^2 or 12.6% of land area, excluding snow covered area, of the country is prone to landslide hazard. Out of this, 0.14 million KM^2 falls in North-West Himalayas, spread over the States of Uttarakhand, Himachal Pradesh and Jammu & Kashmir.

Geological Survey of India (GSI)'s contribution to landslide studies in NW Himalayas dates back to 1880 with the study of problem of slope stability in Nainital, Uttarakhand by Sir R.D. Oldham. In 1945, with the establishment of specialised Engineering Geology and Ground Water Division, GSI started undertaking landslide investigations both based on requests from Government stakeholders and as departmental R&D projects. Since 1980, a more systematic approach for landslide susceptibility mapping was initiated. The study of landslides carried out by GSI since then can be divided into two broad categories: Pre-disaster studies, which include identification of vulnerable slopes through landslide susceptibility (hazard) zonation on various scales (macro, meso and micro) or studying the critical slopes individually to determine their stability status and activity; and Post-disaster studies, which include detailed investigations of landslides that have occurred, to determine the causes responsible for such failures and to suggest effective treatment measures required to stabilize the slopes.

In the last few decades, GSI has made significant contribution to landslide studies in States of Uttarakhand, Himachal Pradesh and Jammu & Kashmir. The reports submitted to State Governments form a vital document for land use planning and adopting appropriate mitigation measures. The best example is the Nainital town where GSI's landslide susceptibility zonation map is being used, through legislation, in land use management practices. Till date notable achievements of GSI in landslide studies include susceptibility mapping of major river basins (covering about 24,000 KM^2 area), town/district area (covering about 2,000 KM^2 area), road corridor (covering about 2,100 km) and detailed site-specific investigation of major landslides. With this volume of information already available with GSI, though mostly in analog form, it has always been felt to compile and bring it on GIS platform for better presentation and easy retrieval. In this endeavour, this compendium of 'Landslide studies in NW Himalayas' is prepared so that stakeholders in the country and particularly of the States of Uttarakhand, Himachal Pradesh and Jammu & Kashmir can be benefitted. The information available in this compendium will also be of immense value to planners, students and researchers and will help them to understand the landslide situation, gaps in the existing knowledge-base, and to explore the scope for devising new tools and methodologies required for managing landslide hazards in the country.

Landslide Compendium of Northwestern Himalayas

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Chapter 1: Introduction

In Northwest Himalayas, landslide is one of the common natural phenomena particularly during monsoon between July and September and after the snow fall between January and March. In this region, particularly areas marked by structurally adverse and unstable slopes, landslides are also triggered by strong earthquakes. About 0.42 million km² or 12.6% of land area, excluding snow covered area, of the country is prone to landslide hazard. Out of this, 0.14 million km² falls in North-West Himalayas (Uttarakhand, Himachal Pradesh and Jammu & Kashmir). The landslide prone area of the country is spread over 1,034 toposheets (1:50,000 scale of the Survey of India) (Fig. 1.1). Out of these, the NW Himalayas i.e., the states of Uttarakhand, Himachal Pradesh and Jammu & Kashmir covers 365 toposheets, having about 75,300 km² of accessible areas with settlements and roads and 74,500 km² of highly inaccessible and high altitude remote areas.

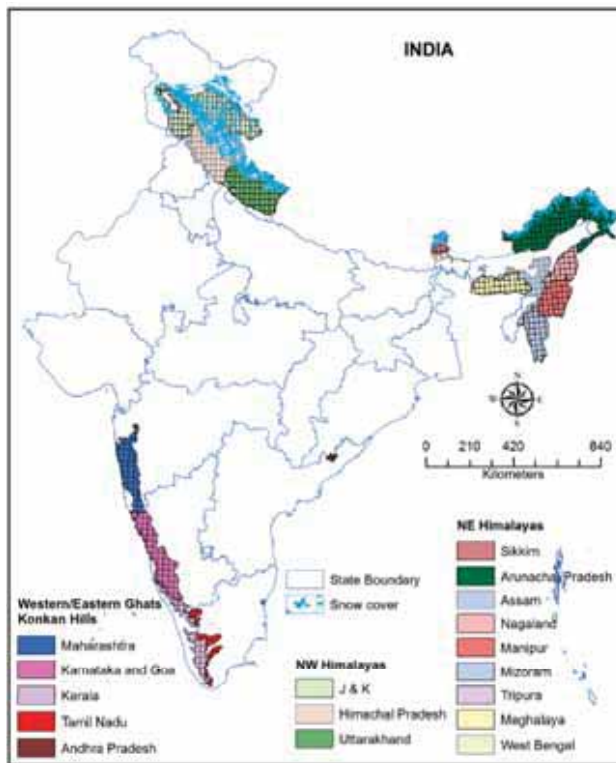


Fig. 1.1. Distribution of toposheets and hill areas prone to landslides in India.

1.1 Objectives

Landslide is a persistent problem in the NW Himalayas. Academic institutions and Government Agencies

engaged in landslide research in the interest of the nation to bring out ways to mitigate landslide hazard. GSI, as a nodal agency for landslide studies in India, has been involved in landslide studies since 1880s. The data available in GSI's repository such as landslide susceptibility maps on different scales, landslide inventory data, detailed maps of major landslides, etc., provide a base data for researchers to further their research work. To make such plethora of data available to the users' agencies, in a friendlier interphase and under one platform, a project on the preparation of a compendium of landslides in NW Himalayas was taken up. This landslide compendium thus aims to achieve the following main objectives:

- 1) to collate and present landslide susceptibility maps at various scales available in the GSI repository in a GIS-enabled platform,
- 2) to document and present a brief account of the site-specific information on some major and prominent landslides, causes of their failure and suggested remedial measures,
- 3) to present brief details of landslide events investigated by GSI as a post-disaster reconnaissance survey,
- 4) to present inventory of major landslides.

It is to understand that landslide being a dynamic geomorphic process, its spatial geodatabase needs dynamic update at certain intervals. For this compendium, the available notes, reports on various landslide studies of GSI since 1940s till 2014 have been compiled and presented so far. The available analog spatial databases (e.g., maps) are transferred into GIS platform so that future update becomes easier.

1.2 GSI's contribution to landslide studies

GSI's contribution to landslide studies in NW Himalaya dates back to 1880 with the study of the problem of slope stability in Nainital, Uttarakhand by Sir R. D. Oldham. In 1890, C. S. Middlemiss re-studied the Nainital area. In 1893, T. H. Holland investigated Gohna landslide, a massive rockfall that blocked the river Birahi Ganga at Gohna in Garhwal Himalaya. Between 1939 and 1945, the Second World War Period, the strategic branch of GSI was entrusted with the work for safer road alignments. In 1945, with the

establishment of specialised Engineering Geology and Ground Water Division, GSI started undertaking landslide investigations both demand based and R&D related. s dates back to 1880 with the study of the problem of slope stability in Nainital, Uttarakhand by Sir R. D. Oldham. In 1890, C. S. Middlemiss re-studied the Nainital area. In 1893, T. H. Holland investigated Gohana landslide, a massive rockfall that blocked the river Birahi Ganga at Gohna in Garhwal Himalaya. Between 1939 and 1945, the Second World War Period, the strategic branch of GSI was entrusted with the work for safer road alignments. In 1945, with the establishment of specialised Engineering Geology and Ground Water Division, GSI started undertaking landslide investigations both demand based and R&D related.

Since 1980, GSI is involved in a more systematic approach for landslide mapping. Its significant contribution is mainly towards: (I) macroscale/mesoscale (1:50,000-1:5,000) landslide susceptibility zonation mapping (which is referred earlier as hazard mapping) of river basins, road corridors, including pilgrimage yatra routes, towns and district-wise coverage; (ii) site-specific detailed mapping of landslides on micro-scale (<5,000); and (iii) post-disaster rapid geotechnical assessment of landslides.

The basic purpose of macroscale/mesoscale landslide susceptibility zonation is to divide the area into discrete zones of different degree of susceptibility to slope failures. Generally, it is grouped into three (high, moderate and low) or five landslide susceptibility classes (very high, high, moderate, low and very low), depending on the methodology. Between 1980 and 2004, landslide susceptibility analyses were carried out, under regular fieldseason programmes, using probabilistic methods (e.g., Sharma, 1996; Sanwal and Jaiswal, 2005). The work components include preparation of slope facets and calculation of slope angle and direction for each facet, classification of rock slopes into different slope type based on relation of bedding/foliation dip and slope direction by using data from detailed field work, landslide inventory mapping and estimation of failure probability for each slope facet. The synthesis and integration of data required for the susceptibility analysis were done 'manually'. Since 2005, a heuristic method based on BIS guidelines (BIS, 1998) and its subsequent modified susceptibility mapping (e.g., Chandra, 2003; Kumar *et al.*, 2010). The work components in BIS method include preparation of slope facets, which

forms the basic mapping unit and preparation of six to ten thematic maps such as lithology, structure, relative relief, land use, etc. for assigning specified numerical ratings in each facet based on occurrence of the thematic class. The BIS based susceptibility mapping was completely based on detailed field work wherein attempts are made to physically verify each facet in the field, particularly for assigning structural attributes. In BIS method, the synthesis and integration of data required for the susceptibility analysis were done 'manually'. From 2014 onwards, with the launch of National Landslide Susceptibility Mapping (NLSM) Programme, the susceptibility mapping is now being carried out in GIS using Weighted Multi-class index overlay method. At present, the synthesis and integration of data required for the susceptibility analysis are being carried out in GIS.

GSI also made significant contribution towards post disaster landslide studies, particularly in detailed geological mapping of landslides on 1:1000/2000 scale. Earlier GSI used Theodolite/ Telescopic Alidade for surveying, but with the advancement of technology, now high precision 'Total Station' is being used. The studies include topographical survey (contour map of 2-5 m interval), geological mapping, geophysical survey (resistivity, thermal and natural gamma logging, etc. as carried out in Surbee landslide by Singh and Verma (2009)), drilling for estimation of slip surface, collection of soil/rock samples for determination of shear parameters, etc.

Besides, the macro, meso and micro-scale systematic landslide investigations, one of the most valuable contributions of GSI in NW Himalayas is the post-disaster rapid geotechnical assessment of landslides and preparation of a detailed inventory of landslides. Often GSI undertakes such assignments as a part of 'service item', either on the request of the State Government aftermath of any major landslide event or own departmental items. The work includes, geological assessment of the disaster prone areas, immediately after the disaster, and renders suggestion of appropriate remedial options to contain the risk.

1.3 Understanding landslide susceptibility maps: Authors' perspective

The susceptibility maps presented in this compendium give the qualitative estimation that an area or a slope unit will be

affected by a future landslide source, but the “future” here is not connected to a time period, such as the next day or the next 5 years or 50,000 years. It only indicates the susceptibility status of a slope to slope failure irrespective of a time of an event to occur. When time component is included, the resulted map is termed as a 'landslide hazard' map. Such maps provide information on where, when and how big a landslide might happen in an area (Varnes, 1984). Because of lack of data on the frequency of events such hazard maps are yet difficult to generate for a macro-scale study (van Westen *et al.*, 2006).

The susceptibility model used to predict the spatial location of potential landslides is based on certain assumptions. It is assumed that landslides will occur in future under the same conditions and triggering factors that produced them in past. One has to take into account that geo-environmental conditions of an area such as land use or hydrological conditions may change due to human action. Conditions may also change when the source of a landslide is exhausted by earlier landslide or the morphology of the slope is changed and becomes stable. The local changes in the land use pattern, such as terracing of slope for cultivation or excavation for construction of new buildings can induce instability 'locally' and may increase or decrease the susceptibility of that slope. It is to understand that the susceptibility map is only valid under the geo-environmental conditions taken as input in the susceptibility modeling. Any changes in the spatial distribution of the geo-environmental factors can affect the susceptibility of the area. Therefore, it is always suggested that susceptibility analysis in a given area needs updating after a certain time period such as 10-15 years or after a large landslide event and/or massive change in land use patterns. Particularly after the landslide event of 2013 in Uttarakhand, GSI is revisiting the area already covered under macro-scale landslide susceptibility mapping in NW Himalayas through its National Landslide Susceptibility Mapping (NLSM) Programme.

The assessment of the landslide susceptibility is extremely important for high landslide vulnerable areas because it gives basic construction standards for new roads or buildings, helps to assess the impact of future landslides and can also be used to locate key facilities like hospitals, fire stations, emergency operation centers, safe shelters, etc.

As a general recommendation given in the reports that if end users intend to use only the susceptibility map for land use planning, then no public or personal utility projects should be allowed in highly susceptible areas, strict building safety regulations should be followed in moderate susceptible areas and constructions with simple slope stability measures be allowed in low susceptible areas. This is a general recommendation related to the landslide susceptibility based on the given land use condition; however it is to understand that the susceptibility values can be lowered if proper mitigation/remedial measures are adopted beforehand such that a high susceptible area can be made less vulnerable to landslide. Therefore, the authors suggest that the susceptibility map should be interpreted accordingly and the degree of susceptibility in response to mitigation measures should be worked out judiciously. In this regard, cost-benefit analysis should be carried out for better and sustainable planning.

Furthermore, it is suggested here that the susceptibility map showing the potential landslide initiation areas should not be used alone for planning; rather limits of potential debris flows should also be marked for the specific planning site. The susceptibility map on scale 1:50,000/25,000 is actually meant for regional application; however they are still of considerable significance from the point of specific land use and urban planning. Nevertheless, a detailed site-specific study may be duly conducted before planning and execution of the civil construction works. Areas with very high and high susceptibility falling under high hazard should be given due attention while executing any civil constructions. One should understand that spatiotemporal prediction of a landslide is still a difficult task 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 the loss would be immense if buildings are not safely designed and properly located. The only economical way of reducing “at least” the loss of life is by making people aware of the inherent risk. Therefore, more priority should be given in increasing awareness amongst people through Community Based Disaster Management Programme (CBDMP).

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It is indeed a moment of great pleasure and immense satisfaction for us to express our profound gratitude towards to all the geoscientists of GSI whose works have been cited or discussed in this Compendium. Without their relentless and painstaking efforts under difficult and hostile Himalayan conditions and without mentioning their excellent contribution in landslide studies in reports and notes, such a huge work undertaken by the present authors would not have been successfully completed. The authors, through this small effort pay their revered tributes to all those great geoscientists of GSI who contributed their seminal inputs to this great societal cause by serving this premier organisation.

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Chapter 2: Methodology

In Northwest Himalayas, different methods and approaches have been used from time-to-time to map landslide susceptible zones on macro-scale (1:50,000/25,000) and mesoscale (1:10,000). Prior to 2014, the susceptibility mapping has been carried out 'manually' with a base map taken as Survey of India toposheet. From 2014 onwards, with the availability of high-resolution remote sensing data and Geographical Information System (GIS), the thematic map generation and data integration for landslide susceptibility mapping is being carried out in GIS under the ongoing National Landslide Susceptibility Mapping (NLSM) Programme.

In this chapter, the different methodology used for landslide susceptibility mapping in NW Himalayas is presented. This is primarily based on collation and compilation of old studies carried out by GSI. It may be noted that in the reports the 'susceptibility' maps so generated are, in many cases, termed as 'hazard' maps, depending on the methodology used in the analysis.

2.1 Landslide susceptibility mapping on a macro-scale

2.1.1 Unique condition unit method

In the early stage of landslide susceptibility mapping, Gupta (1982) used 'unique condition unit approach' for the preparation of 1:50,000 scale landslide susceptibility map in Sutlej River basin. This method demarcates slopes with more or less identical sets of contributing/controlling factors such as lithological and mineralogical characteristics, structural features, slope geometry and groundwater fluctuations. The mappable units in bedrock have been demarcated on the basis of lithology, structural features such as bedding, foliation, nature, intensity and orientation of joints/fractures, overall slope geometry, and general groundwater condition. In the overburden areas the demarcation has been done on the basis of lithological characteristics of the material, angle of repose and overall groundwater condition. The slopes have been further categorized on the basis of incidence of natural slides including old and presently inactive ones and corresponding susceptibility to sliding. In the final analysis, zones showing different degrees of instability of slopes on the basis of incidence of susceptibility to sliding have been demarcated.

For evolving the parameters required for zonation, the following thematic maps were prepared manually on scale 1:50,000 with the help of toposheets:

1. Slope Forming Material (SFM) map - depicting distribution of rock/overburden, with relevant structural details,
2. Slope map (SM) - showing slope inclination,
3. Vegetation cover and land use map - showing different land use and land covers,
4. Drainage slope and landslide incidence map.

The landslide susceptibility map was prepared after analysis and integration of all the data collected from the above thematic maps. If the incidence of both active and old inactive landslides forms more than 10% of the area of a particular slope which has been susceptible to sliding then it has been classified under zone of high instability; whereas if a particular slope has 2%-10% of its area covered by landslides, it has been classified under zone of medium instability. The slope having less than 2.0% area covered by landslides has been identified as zone of low instability.

2.1.2 Probabilistic method

During 1990s, the landslide susceptibility mapping on 1:50,000 scale was carried out by adopting 'Probabilistic approach' (Sharma and Kandpal, 1994; Sharma, 1996). In NW Himalayas, this method has been used to study many river basins and road corridors, for examples Yamuna River basin, Bhagirathi River basin, Ganga River basin, Ravi River basin, Beas River basin, Gangotri, Badrinath, Kedarnath, Kailash-Mansarovar yatra route corridors, etc. The method takes into cognizance the incidences of landslides recorded in the field and the analysis of the angle of failure of slope facets. A manually prepared slope facet is used as the basic mapping unit. For evolving the parameters required for zonation, the following thematic maps were prepared on scale 1:50,000.

1. Slope Forming Material (SFM) map-cum-Landslide Incidence map— depicting distribution of landslides and rock/overburden, with relevant structural details,
2. Slope Morphometry map (SMM) – showing slope direction and inclination (V/H ratio) for individual facets.

The landslide susceptibility map was prepared after analysis and integration of all the data collected from the above thematic maps. The critical V/H ranges (inclination of failed slopes), in different slope categories, in each geological formation, have been used as a guide for assessing susceptibility categories to all slopes identified in the area. The probability of failure for a given set of conditions is statistically calculated in percentage. These values are then extrapolated to slope facets showing similar geological and slope conditions presuming that under similar conditions they would behave similarly. In order to demarcate landslide susceptible zones, the obtained probability values are grouped as:

Probability > 50%	- High susceptible zone
Probability > 20–50%	- Moderate susceptible zone
Probability = 20%	- Low susceptible zone

2.1.3 BIS method

During early 2000, the 1:50,000 scale landslide susceptibility mapping has been carried out according to the methodology prescribed by Bureau of India Standards IS 14496 (Part 2): 1998 (BIS, 1998). The BIS method is based on the rating system. Major causative factors responsible for the slope instability used in the analysis are: i. lithology, ii. structure, iii. slope morphometry, iv. relative relief, v. land use and vi. hydrogeological conditions. Landslide Hazard Evaluation Factor (LHEF) rating being a numerical system, each factor is assigned to a maximum rating on the basis of its estimated significance causing instability. The Landslide Hazard Evaluation Factor (LHEF) rating of each factor was added in order to get Total Estimated Hazard (TEHD) of a slope facet. A manually prepared slope facet is used as the basic mapping unit. TEHD has been divided into five zones in ascending order, as enumerated below:

TEHD value < 3.5 is Zone I -Very low hazard (VLH) zone
 TEHD value 3.5–5 is Zone II -Low hazard zone (LH)
 TEHD value 5.1–6 is Zone III -Moderate hazard zone (MH)
 TEHD value 6.1–7.5 is Zone IV -High hazard zone (HH)
 TEHD value > 7.5 is Zone V -Very high hazard zone (VHH)

Some of the studies where BIS method has been used include Yamunotri yatra road corridor, Kalka-Shimla railroad corridor, etc. In these studies landslide 'hazard' terminology is used to describe the susceptibility status of the slopes.

2.1.4 Modified BIS method

During early and late 2000, a modified version of BIS method has also been used for 1:50,000 scale landslide susceptibility mapping. Some of the examples include landslide susceptibility mapping of Ramganga River basin, Pithoragarh district, Bageshwar district, Tiuni-Harkidun road corridor, Narkanda-Rampur road corridor, etc.

The modification in BIS (1998) method was proposed by Geological Survey of India. The modified BIS method is also based on the rating system. Major causative factors responsible for the slope instability used in the analysis are: i. lithology, ii. structure, iii. slope morphometry, iv. relative relief, v. land use, vi. land cover, vii. hydrogeological conditions, viii. rainfall, ix. landslide incidences and x. slope erosion. Landslide Hazard Evaluation Factor (LHEF) rating being a numerical system each factor is assigned to a maximum rating on the basis of its estimated significance causing instability. The Landslide Hazard Evaluation Factor (LHEF) rating of each factor was added in order to get Total Estimated Hazard (TEHD) of a slope facet. A manually prepared slope facet is used as the basic mapping unit. TEHD has been divided into five zones in ascending order, as enumerated below:

TEHD value < 4.9 is Zone I -Very low hazard zone (VLH)

TEHD value 4.9–7.0 is Zone II -Low hazard zone (LH)

TEHD value 7.1–8.4 is Zone III -Moderate hazard zone (MH)

TEHD value 8.41–10.5 is Zone IV -High hazard zone (HH)

TEHD value > 10.5 is Zone V -Very high hazard zone (VHH)

Similar to BIS method, in these works also landslide hazard' terminology is used to describe the susceptibility status of the slopes.

2.2 Landslide susceptibility mapping on a mesoscale

2.2.1 SMR based method

In GSI, the mesoscale landslide susceptibility mapping on 1:10,000 was carried out according to the methodology prescribed by Bureau of India Standards IS 144 96 (Part 2): 1998, modified by Geological Survey of India with the inclusion of additional parameter on SMR classification of

Romana (1988). An example of the use of this method is the landslide zonation of Joshimath area in Uttarakhand. Till date, no standard methodology is available with known validation for mesoscale landslide susceptibility analysis.

The SMR based method is based on rating system. Major causative factors responsible for the slope instability used in the analysis are: i. lithology, ii. structure, iii. slope morphometry, iv. relative relief, v. land use, vi. land cover, vii. hydrogeological conditions, viii. rainfall, ix. landslide incidences, x. slope erosion, xi. seismicity and xii. intact strength of slope material (shear parameter). Landslide Hazard Evaluation Factor (LHEF) rating being a numerical system each factor is assigned to a maximum rating on the basis of its estimated significance causing instability. The Landslide Hazard Evaluation Factor (LHEF) rating of each factor was added in order to get Total Estimated Hazard (TEHD) of a slope facet. A manually prepared slope facet is used as the basic mapping unit. TEHD has been divided into five zones in ascending order, as enumerated below:

TEHD value <5.60 is Zone I-Very low hazard zone (VLH)

TEHD value 5.60 – 8.0 is Zone II- Low hazard zone (LH)

TEHD value 8.01 – 9.60 is Zone III - Moderate hazard zone (MH)

TEHD value 9.61 – 12.0 is Zone IV - High hazard zone (HH)

TEHD value >12.0 is Zone V - Very high hazard zone (VHH)

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Chapter 3: Landslide studies in Uttarakhand

3.1 Introduction

Uttarakhand, often referred as “Devbhumi” as it houses a number of ancient Hindu temples, is a mountainous state located within the Northwest Himalayas. The state covers about 53,000 km² area, of which about 46,000 km², excluding the permafrost region, forms part of mountainous terrain of the Himalayas. Out of its 13 districts, 12 fall under mountainous region (Fig. 3.1), where landslides are one of the most common and perennial natural hazards.

Every year this picturesque state attracts millions of tourists and pilgrims, not only for leisure and pleasant stay in natural and serene environment but also for a visit to the “Char Dhams” i.e., Yamunotri, Gangotri, Kedarnath and Badrinath. The yatra routes leading to “Char Dhams” and Lipu Lekh (a gateway to Kailash Parvat and Mansarovar Tal in China) are located within landslide vulnerable zones of Uttarakhand. Being negotiated through the geologically most complex, structurally fragile and geotechnically unstable slopes, these yatra routes, at numerous stretches, are

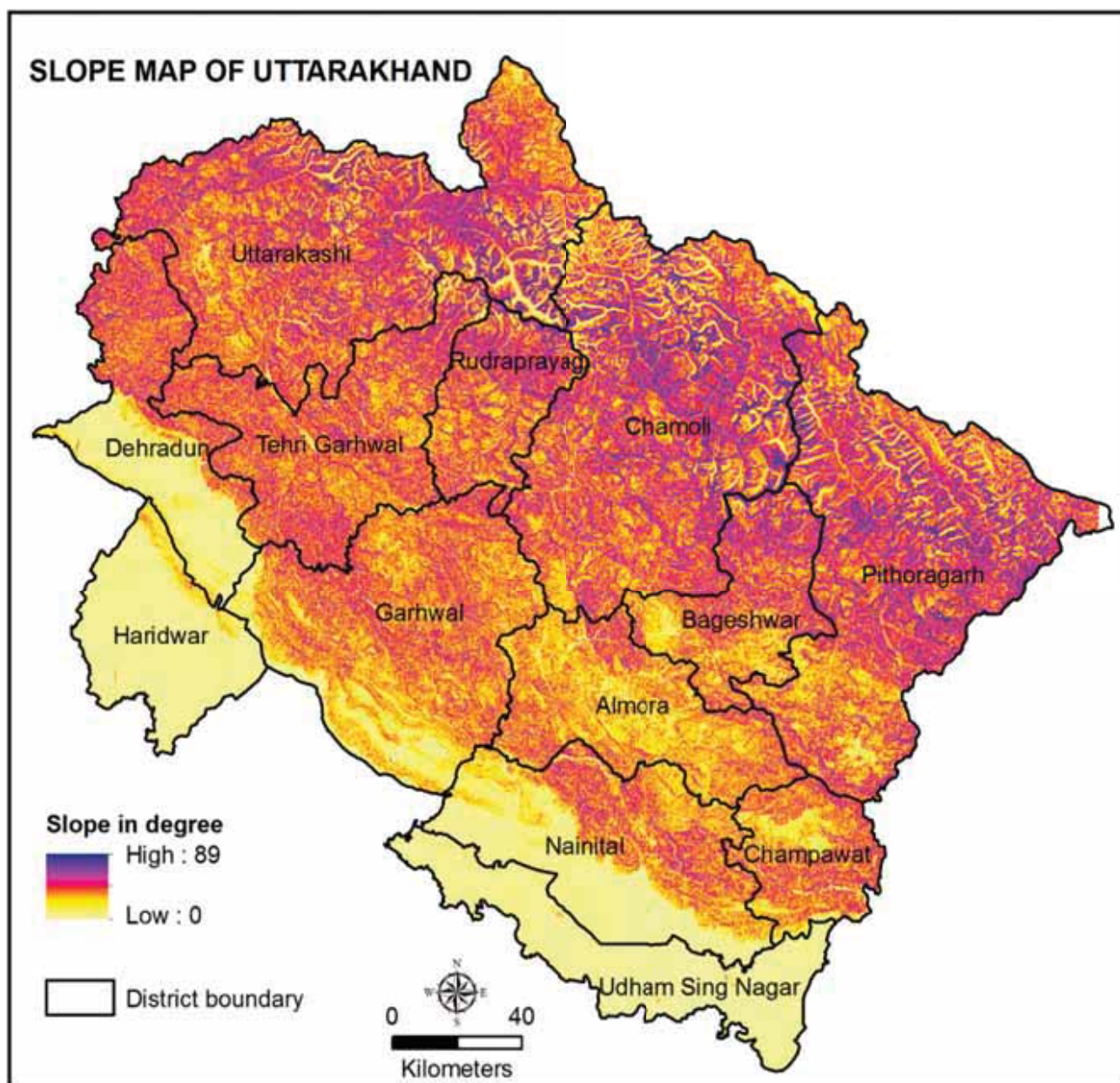


Fig. 3.1. District boundary of Uttarakhand shown over the slope map prepared from Aster DEM.

highly susceptible to landslides, particularly during monsoon (June-October).

3.1.1 Geology and Geomorphology

Geologically, Uttarakhand exposes rocks of the Himalayan tectogene of age ranging from Late Proterozoic to Phanerozoic. From south to north, the state can be subdivided into four major morphotectonic belts, viz.; the Sub or Outer Himalaya, the Lesser Himalaya, the Higher Himalaya and the Tethys Himalaya (GSI, 2012). The Sub-Himalaya belt exposes sedimentary rocks (molasse) of the Neogene period. Its northern boundary is marked by the Main Boundary Fault (MBF) and southern boundary by the Himalayan Frontal Fault (HFF). The rock sequences exposed between MBF and Main Central Thrust (MCT) towards further north constitute the Lesser Himalaya belt. The rock types are mostly of Mesoproterozoic and Neoproterozoic time. The regionally metamorphosed rocks, along with the granitoids of Lesser Himalaya occurring as klippe, overlie the sedimentary sequence. The Higher Himalaya exposes metamorphosed rocks of greenschist to amphibolite facies of Proterozoic age. Granites of various ages are emplaced in the metamorphosed rocks. The Tethys Himalaya is composed of sedimentary sequences ranging in age from Neoproterozoic to Late Mesozoic. The contact of the Tethyan sedimentaries with the underlying crystalline sequence of the Higher Himalaya is tectonic.

Geomorphologically, the Extra-Peninsular Region of the Himalayan orogenic belt within Uttarakhand is bounded between Yamuna River in the west and Kali River in the east. Three east-west trending parallel ranges represent the Higher, Lesser and Outer Himalayas. Antecedent rivers such as Kali, Ganga and Yamuna have cut deep gorges through these ranges to enter into the Ganga Plain. The glaciers and lofty snow covered peaks are typical geomorphic expression of the Higher Himalaya. These peaks are clustered in four groups, viz.; (i) Banderpunch (ii) Kedarnath-Chaukhamba, (iii) Kamet and (iv) Nandadevi, and are separated by transverse gorges of Bhagirathi, Alaknanda and Dhauliganga rivers. The Outer Himalaya is the southernmost range and is composed of fluvial deposits. The Lesser and Outer Himalaya have a steep sloping southern face and gentle sloping northern face. A structural valley or Dun (Dehradun) valley is located in the Outer Himalaya

(www.wihg.res.in).

3.1.2 Landslide hazard

Landslide is a common natural as well as a man-made hazard in Uttarakhand, particularly during monsoon. It not only causes direct loss of life and property, but also indirect loss by blocking the transportation routes. In the recent past, due to extensive road construction and other developmental activities, the frequency of landslides has increased manifold in Uttarakhand. The main loci of landslides are along the two zones lying in close proximity to MBF and MCT.

In the recent past, Uttarakhand has witnessed several landslide events. In 2010, during the monsoon, landslides and floods disrupted the communication road and resulted in 220 casualties and immense loss to properties. During 2012 monsoon, Bageshwar, Chamoli, Pithoragarh, Rudraprayag and Uttarkashi districts were hit by flash floods, debris flow and landslides, thereby leading to 164 casualties. The disaster of 16-17 June, 2013 in the state surpassed all other records of the recent past in terms of magnitude of the event. It resulted in many casualties and affected more than 4000 villages, completely destroying more than 2500 houses and about 11,000 livestock. The districts of Rudraprayag, Uttarkashi and Chamoli got ravaged by innumerable flash floods, debris flow and landslides. The disaster accounted colossal loss of life and properties. Apart from the three events, several more events had been recorded in the last two decades as given in table 3.1.

3.1.3 Landslide studies by Geological Survey of India

GSI contributed immensely in the landslide studies of Uttarakhand. As early as in the year of 1880, Sir R. D. Oldham worked on the slope stability of Nainital in Uttarakhand. In 1890, C. S. Middlemiss re-visited the Nainital area again in the year 1890 with the same objective. Another work in the year 1893, has been carried out by T. H. Holland on Gohana landslide in Garhwal Himalaya.

Till date, GSI has accomplished landslide susceptibility zonation mapping and detailed study of a number of complex landslides in different scales in the state of landslide susceptibility mapping of river basins such as Yamuna,

Table 3.1. Major landslide events in Uttarakhand (source: www.nidm.gov.in).

Date/Year	Location	Remarks
1867, 1880	Nainital	The 1880 landslide took place on the Sher-ka-Danda slope in Nainital due to rainfall and an earth tremor. The debris filled a portion of the Naini lake.
1893	Alaknanda	Landslides occurred in the Birehi Ganga River near its confluence with the Alaknanda River. A landslide dam was formed with a 10-13 m afflux.
1968	Rishi-Ganga	The Rishi Ganga River in Garhwal was blocked due to landslide at Reni village.
July 1970	Patal Ganga,	Landslide dam formed at Patal Ganga, which resulted in flash floods in the Alaknanda River and triggered many landslides.
1971	Kanauldia <i>gad</i>	A 30 m high landslide dam formed on Kanauldia <i>gad</i> , a tributary of the Bhagirathi River.
Aug. 1978	Uttarkashi	The breaching of landslide dam on Kanauldia <i>gad</i> caused flash floods downstream at Uttarkashi.
1920, 1952, 1963, 1964, 1965, 1968, 1969, 1970, 1971, 1972, 1985, 2010	Kaliasaur	Kaliasaur or Sherobagar is a recurring landslide located on the Rishikesh-Badrinath road.
Aug. 1998	Okhimath	69 people were killed due to several landslides in Madhyamaheshwar valley.
18 th Aug. 1998	Malpa, Kali River	A rock slide at Malpa killed more than 210 people.
24 th Sept. 2003	Varunavat Parvat, Uttarkashi	Three landslides triggered due to rainfall and resulted in complete destruction of numerous buildings, hotels and government offices located at the foot of the hill slopes.
5 th July 2004	Badrinath, Chamoli	16 persons killed as cloudburst triggered massive landslides on the Joshimath-Badrinath road.
29 th -30 th June 2005	Govindghat, Chamoli	11 people were killed in a debris flow.
6 th Sept. 2007	Dharchula, Pithoragarh	A landslide triggered due to excessive rainfall resulted in 15 fatalities and loss of livestock.
2008	Amru Band	17 people killed and caused huge damages to roads and houses.
8 th Aug. 2009	Berinag- Munsiyari road, Pithoragarh	Forty three people died due to landslide triggered by cloudburst
18 th -21 th Sept. 2010	Ganga- Alaknanda valley	About 220 people died and many sectors of major and minor roads severely damaged.
14 th Sept. 2012	Okhimath, Rudraprayag	68 people killed in the landslides, which caused extensive damages to the buildings, agricultural lands and roads at several places.
16 th -17 th June 2013	Uttarakhand	Flash flood-induced landslide. 680 people died, and 4,117 missing. Huge devastation to infrastructures and other properties mainly in 5 districts of Uttarakhand i.e., Bageshwar, Chamoli, Pithoragarh, Rudraprayag and Uttarkashi.

Bhagirathi, Ganga and Ramganga rivers; susceptibility mapping along important roads such as route leading to Yamunotri, Gangotri, Kedarnath, Badrinath, etc.; susceptibility mapping of important towns and districts such as Nainital, Joshimath, Tehri reservoir rim, Ranikhet, Bageshwar, Pithoragarh, etc. (Fig. 3.2).

In this compendium, GSI work on landslides in Uttarakhand is dealt according to the following sequence:

1. Macro-scale landslide susceptibility mapping of river basins, district/town, road corridor
2. Meso-scale landslide susceptibility mapping of town
3. Micro-scale (site specific) landslide studies
4. Post-disaster study of landslides

3.2 Macro-scale landslide susceptibility mapping

3.2.1 Landslide susceptibility mapping of Yamuna River basin

Yamuna River basin, occupying nearly 2,400 km² area along the western border of Uttarakhand, has attained enormous importance as it accommodates several small and big hydroelectric projects under various stages of development. Communication routes leading to famous Yamunotri shrine, Banderpunch glacier and Harkidun National park also cut across the valley. This part of Uttarakhand is relatively less developed and scantily populated; however the rugged mountainous terrain, abound in natural beauty, has been frequently marred by landslide activities, especially along valley slopes harbouring the settlements and communication routes. The entire Yamuna River basin falls in the Survey of India toposheets: 53F/13, 53F/14, 53F/15, 53J/1, 53J/2, 53J/3, 53J/5, 53J/9, 53I/4, 53I/8, and 53I/12, and is flanked in the east by the Bhagirathi valley and in the west by Tons valley.

Recognising the importance of the area and the growing concern about damaging effects and devastations caused by the landslides, which disrupt normal life, GSI has carried out landslide susceptibility mapping for 1,800 km² area of the valley, covering parts of toposheets: 53F/13, 53F/14, 53J/1, 53J/2, 53J/5, 53J/9, 53I/4, 53I/8, and 53I/12. The work was carried out on scale 1:50,000 between 2002 and 2005 under three field season programmes (Sanwal and Jaiswal, 2005; Sanwal and Jaiswal, 2006; Jaiswal and Baruah, 2009).

Geologically, the area forms part of the Lesser and Higher

Himalayan Proterozoic sequence of rocks which are invariably capped by Quaternary sediments. The rocks exposed in the area mainly belong to Central and Puroila Crystalline, Deoban Group, Jaunsar Group (Morar-Chakrata, Mandhali, Chandpur and Nagthat Formation) with Main Central Thrust (MCT), Puroila Thrust (PT) and North Almora Thrust (NAT) being the major tectonic elements. Recent to Sub-Recent unconsolidated loose deposits, comprising river-borne material, fan alluvium, slope wash material and scree are widespread along the river valleys and on the valley slopes. Widespread occurrences of these deposits are recorded around Naugaon, Barkot, Rajgarhi and Puroila.

River Yamuna, a glacial fed stream, emerging from the shadows of the 6315 m high Banderpunch summit to the north, is the principal drainage. Along its course, the river is flanked by a number of multi-levelled unpaired river terraces; the prominent terraces are observed at Nayangaon, Nandgaon, Yamuna Chatti, Nainbagh, Damta, Lakhamandal and Kharsali area. The area, in most parts, is marked by moderate to steep slope condition and hills having fairly high relief. The area comprises structural and denudational hills and intermontane valleys which are the result of orogenic movement coupled with weathering and erosion. In addition, fluvial and fluvio-glacial geomorphic units find expression in the form of active flood plain, terraces, fans, peri-glacial solifluction flows/deposits, morainic heaps/ridges, erratic, perched blocks, etc. The Upper Yamuna basin is bounded by the high rising hills of the Pustar Dhar, Yoni Dhar, Pandrasu Dhar, Thadol Danda, Hardi Dhar, Phalachu Danda and Rari Pass, which increase in height northward until it reaches the maximum elevation at Banderpunch glacier.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer Section 2.1.2, Chapter 2). Based on field traverses and study of satellite imagery, a total 568 landslide incidences have been recorded, out of which a detailed inventory of 109 prominent landslides has been prepared. Annexure-I provides an inventory of some of the major landslides. Table 3.2 gives brief details of 16 major landslides. The inventory gives information on the location, type and dimension of the landslide, nature of the material involved, causative factors and its remedial measures.

Plate 3.1 shows the landslide susceptibility map of Yamuna River basin, covering 1800 km² area. The high susceptible

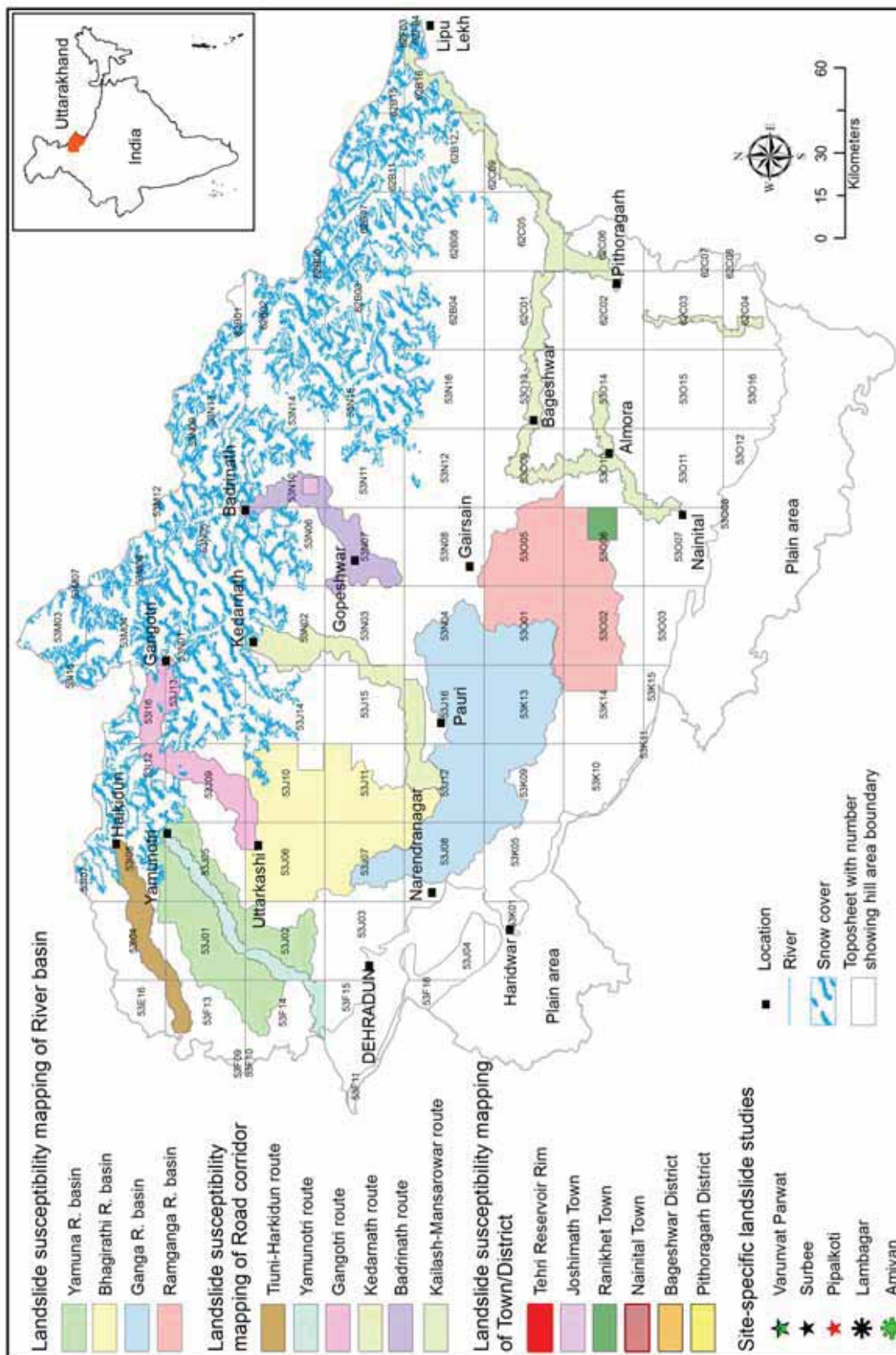
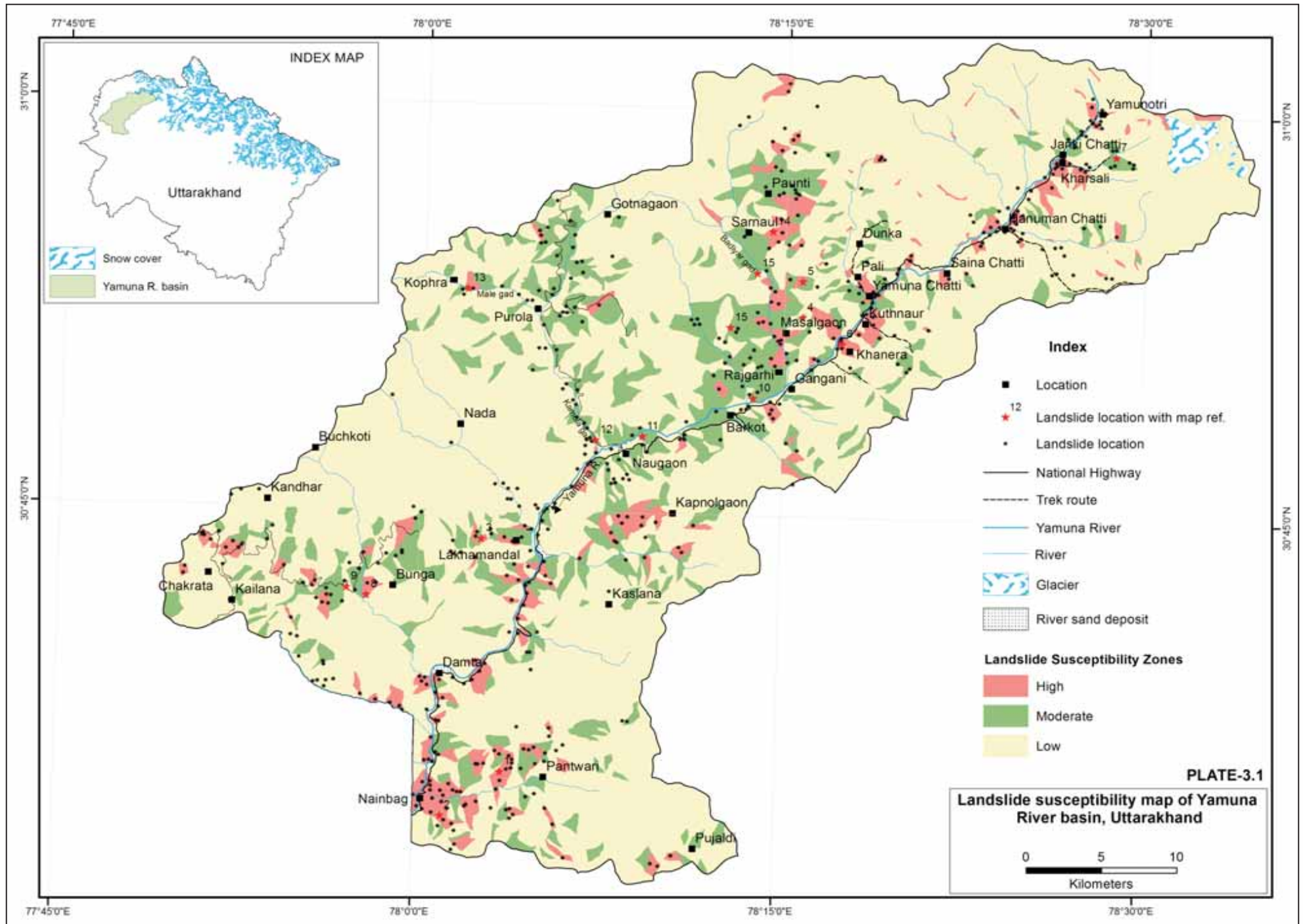


Fig. 3.2. Landslide studies carried out by GSI in Uttarakhand till 2013.



Landslide susceptibility map of Yamuna River basin, Uttarakhand

zones, representing critically unstable slopes, scattered along the communication routes, river banks and high relief slopes coupled with escarpments. The slopes of moderate susceptible zones manifest slope movements in isolated pockets. These are mostly the rock fall zones, on the left bank of Kamola *gad*, near its confluence with the Yamuna, where steep, open-jointed rocks, recurrently cause disruption to traffic, on the busy Purola highway. A prominent moderate zone is also present north of Rajgarhi. The low susceptible zones are spread over vast stretches of dense forests or the areas which are not subjected to the intensity of instability contributing factors such as weathering, denudation and human interference.

Based on the field observations and the analysis of data, the following recommendations were made: (i) the landslide susceptibility map should be taken as a base map for future developmental works such as town and road network planning. However, the landslide susceptible zones represent only a generalized picture of slope stability conditions in their present state. Under the influence of natural or man-made changes, further alterations or modifications in the zonal boundaries, dimension and the vulnerability cannot be ruled out, (ii) in the high susceptible zones, restrictions in developmental works are to be seriously considered. For erecting any civil structure in high or moderate susceptible zones, a site-specific landslide studies are recommended, (iii) suitable slope stabilization measures, as per site condition, must be planned and initiated in the active slide zones, prioritizing the areas of societal concerns. Special attention is drawn for immediate rehabilitation of Durbil village and stabilization of slopes at Paunti village and Yamunotri temple area and immediate restoration of the swept away portions of the road at Kophra in Male *gad* and the right bank slopes of Badiyar *gad*, opposite Bachangaon.

3.2.2 Landslide susceptibility mapping of Bhagirathi River basin

Bhagirathi River basin, occupying nearly 6,900 km² area along the western part of Uttarakhand, has attained enormous importance as it accommodates several small and big hydroelectric projects, including the Tehri dam. Communication routes leading to famous Gangotri shrine cut across the valley. The headwaters of the Bhagirathi are formed at Gaumukh (3,892 m), at the foot of the Gangotri

glacier and Khatling glaciers in the Garhwal Himalaya. It is then joined by its tributaries, such as Kedar Ganga, Jadh Ganga, Asi Ganga and Bhilangna River. The basin is flanked in the east by the Ganga valley and in the west by Yamuna valley.

This part of Uttarakhand is known for its rugged mountainous terrain and has been frequently marred by landslide activities. Notable landslides in this region include Varunavat Parvat landslide, Sukhi landslide, Bhatwari subsidence zone, etc. GSI has carried out landslide susceptibility mapping for 2,270 km² area of the valley, covering parts of toposheets: 53J/6, 53J/7, 53J/8, 53J/10, 53J/11 and 53J/12. The work was carried out on scale 1:50,000 between 1992 and 1995 under three field season programmes (Chandra et al., 1999; Kandpal, 1997; Sharma and Kandpal, 1994).

Geologically, the area forms part of the Lesser and Higher Himalayan Proterozoic sequence of rocks which are invariably capped by Quaternary sediments. The rocks exposed in the area mainly belong to Central Crystalline, Garhwal Group and Jaunsar Group with Main Central Thrust (MCT) and North Almora/Srinagar Thrust (NAT) being the major tectonic elements. Recent to Sub-Recent unconsolidated loose deposits, comprising river-borne material, fan alluvium, slope wash material and scree are widespread along the river valleys and on the valley slopes. These occur along the courses of major drainages and in the NW parts of the area on the right bank of Bhagirathi River at very gentle slopes.

The area of Bhagirathi river catchment falls in the Lesser and Central Himalayas of Garhwal region where high rugged peaks and 'V' and 'U' shaped valleys are the dominating landforms. The maximum elevation occurs in the northern part at 4,077 m near Kyakikhal, while the minimum is at Devprayag (424 m), at the confluence of Bhagirathi with Alaknanda River. Majority of the ridges are structurally controlled longitudinal strike ridges with the ir spurs forming transverse ridges and intermittent deep dissected valleys. The trend of these ridges varies from NW-SE to N-S and E-W and some, at places, develop knife-edge ridges, isolated hillocks on major water divide lines and very steeply inclined to sub-vertical scarps. Bhagirathi River forms the major drainage of the area having structurally controlled river courses along major lineaments.

Table 3.2. Inventory of major landslides in Yamuna River basin.

Map Ref.	Dimension		Type of slide	Causative factors and temporary remedial measures
	Length (m)	Width (m)		
1.	80	400	Debris slide	Extensive bank erosion induced instability to sheared rock mass. Slope flattening and benching, boulder pitched wall with wire-crate at the road level, planting vegetal cover all along the slide surface were suggested.
2.	500	90	Rock fall	Isolated rock fall along steep slopes $>60^\circ$, rocks are highly shattered. Slope scaling and removal of detached rock mass/blocks, retaining wall with wide bench over it to facilitate debris accumulation were suggested.
3.	100	+80	Rock slide	Detachment of massive rocks along open, valley dipping $J = 60^\circ/145^\circ$, along NNE-SSW strike extension of a fault. Slope scaling and removal of detached rock mass, shotcrete and toe wall and ditch to facilitate debris accumulation were suggested.
4.	1000	200	Rock fall	Dislodgement due to structural discontinuity. Increase the density of forest to check the movement of rolling blocks was suggested.
5.	2500	500	Rock fall	Dislodgement due to structural discontinuity. Increase the density of forest to check the movement of rolling blocks was suggested.
6.	250 -300	200	Rock cum debris slide	Toe cutting by Yamuna, shattered basic and quartzitic rocks acting as loose debris failing under saturated condition during rains. Concrete toe support, removal of overhangs and destressed mass, back dressing and erection of retaining walls at suitable bench level were suggested.
7.	500	250	Rock cum debris slide	Toe erosion by Unata <i>gad</i> . Retaining wall at toe was suggested.
8.	100	200	Rock slide	Erosive action of river causing failure of highly sheared phyllite, in a prominent fault zone. Spot bolting and high strength toe wall were suggested.
9.	70	150	Debris slide	Slide caused by toe erosion along Khutno <i>gad</i> . Further erosion could endanger Tungrali village. Slope flattening and benching, toe wall to arrest erosion and to provide adequate drainage were suggested.
10.	100	60	Debris slide	Toe erosion by Yamuna during floods.
11.	80	100	Debris slide	Toe erosion by Yamuna; gully erosion and further head ward erosion is seen.
12.	150	50	Rock fall and Wedge failure	Wedge failure along $65^\circ/230^\circ$ of highly shattered rock occurring as dead mass.
13.	200	130	Debris Slide	Toe erosion by Male <i>gad</i> has resulted in slide, subsidence, ground fissures and complete damage to road.
14.	1000	450	Rock slide (wedge failure)	Slide material causing extensive defacing of hill. The material is brought down by <i>nala</i> causing accumulation and resulting into a huge rock debris fan, partially damming the river course.
15.	250	80	Debris slide	Toe cutting by Badiyar <i>gad</i> , inducing slope movement resulting in complete damage to road.
16.	150	60	Rock slump	Slumping of rock mass along the dip slopes.



Fig. 3.3. Rock cum debris slide downstream of Khanera village (slide no. 6, Table 3.2).



Fig. 3.4. Major rock slide and resulted debris fan on left bank of Badiyar gad (slide no. 14, Table 3.2).

The drainage pattern in its initial stages is dendritic to trellis but in lower reaches it shows mainly parallel to sub-parallel drainage pattern controlled by structural elements. The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer section 2.1.2, Chapter 2). Based on field traverses, a total 526 landslide incidences have been recorded, out of which a detail inventory of 333 prominent landslides has been prepared. The maximum number of landslides (206 landslides) occurs within rocks of Chandpur Formation, followed by 188 in Garhwal Group, 92 in Central Crystallines, 34 in Nagthat Formation and six in overburden sediments. The inventory gives information on the location, type and dimension of landslide, nature of material involved and its causative factors.

Plate 3.2 shows the landslide susceptible map of Bhagirathi River basin, covering 2,270 km² area. The entire area has been differentiated into 4,547 slope facets. Out of these, 564 slopes occur in Central Crystallines, 2,226 in Garhwal Group, 1360 in Chandpur Formation, 387 in Nagthat Formation, and 37 slopes in overburden mass. About 174 km² (7.6%) area occurs in high, 263 km² (11.6%) in moderate and 1,833 km² (80.8%) in low landslide prone zones. Major concentrations of high susceptible slopes are located north of Chinyalisaur and along Bhagirathi River around Dobara and Tehri. Some sporadic patches of high zones also occur around Ghansyali. The slopes north of Uttarkashi town including Varunavat Parvat are categorised as high susceptible.

3.2.3 Landslide susceptibility mapping of Ganga River basin

The Ganga basin covers over 12,500 km² in Northern India and ranks among the largest in the world in drainage basin area and length. Flowing across the great alluvial Indo-Gangetic plains, the Ganga is bordered by the Himalayas to the north and the Vindhya-Satpura ranges to the south. The river has two main headwaters in the Himalayas- the Bhagirathi and the Alaknanda. River Ganga takes her name from downstream of Devprayag, where both Bhagirathi and Alaknanda meet.

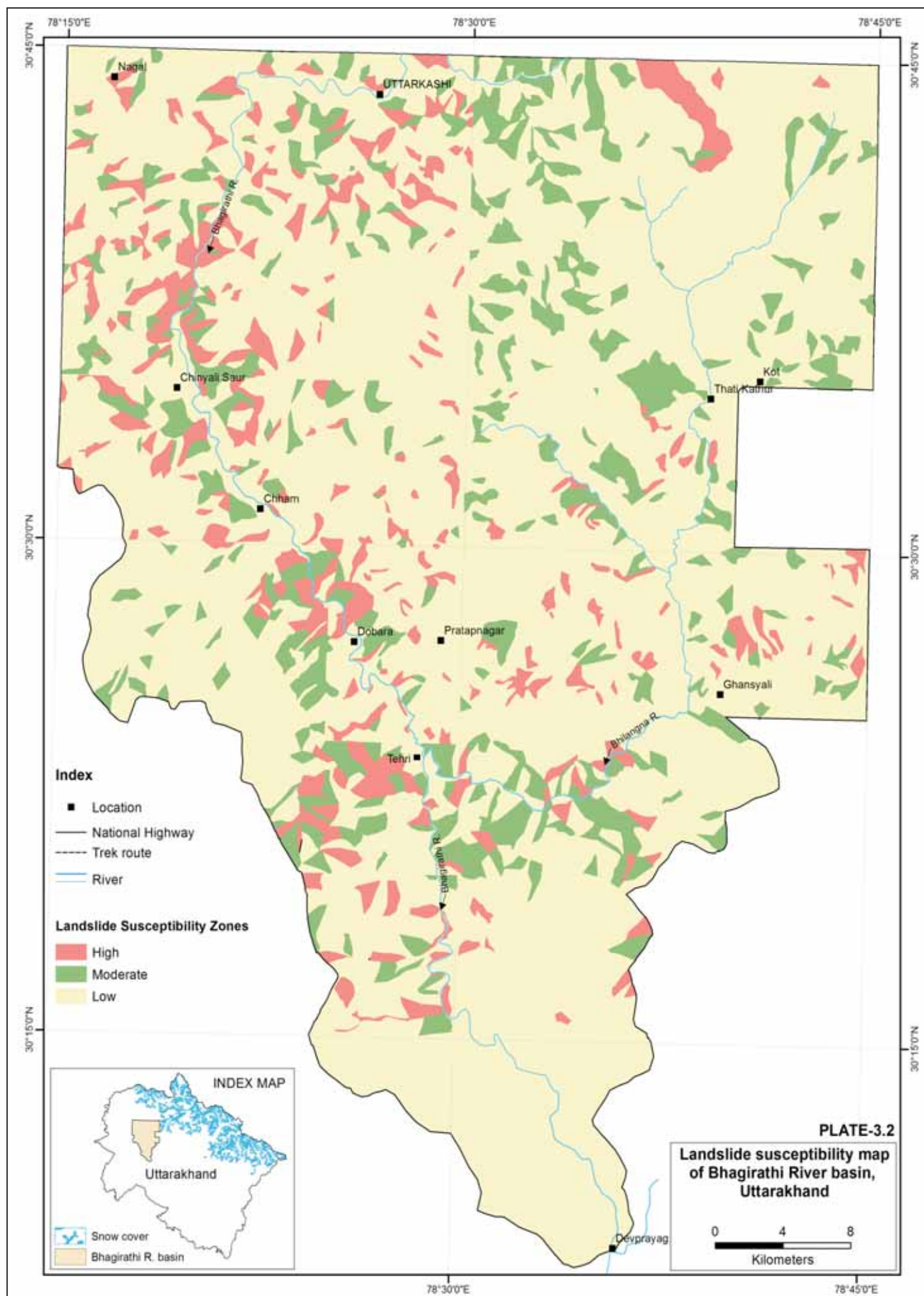
GSI has carried out landslide susceptibility mapping for 3,050 km² area of the Ganga valley, covering parts of toposheets: 53J/7, 53J/8, 53J/12, 53J/11, 53J/16, 53K/5,

53K/9, 53K/13, 53N/4 and 53O/1. It extends from Chamba, Devprayag, Pauri and Paithani in the north to Kandabal, Lansdowne, Chaukhatiakhal, Diba Danda in south, and Rishikesh in the west to Baijro, Thallisain in east. The work was carried out on scale 1:50,000 between 1995 and 1999 under four field season programmes (Bhatnagar *et al.*, 2009).

Geologically, the area forms part of Garhwal syncline with general trend of NNW-SSE having moderate to steep dips in either direction due to folding. The area is occupied by the rocks belonging to Dudhatoli Crystalline, Saknidhar Formation, Chandpur Formation, Nagthat Formation/Deventok Quartzite, Manila Phyllite Formation, Lansdowne Granite, Blaini/Infra Krol Formation, Krol Group and Tal Group. The main rock types are quartzite, phyllite, slate, shale, limestone, granite, gneiss, garnetiferous schists, etc. Quaternary to Recent sediments observed in the area occur as localised terraces along major drainage channels, slope wash debris deposits, etc. Few large terraces are seen near Banghat along Nayar River, at Chametakhal along Medi Gad, at Paithani in Paschimi Nayar Valley and at Bigha on the bank of Purvi Nayar River. Toe erosion causes localised slips in these terraces resulting as bank failures.

Ganga valley covers parts of Central Himalaya and Lesser Himalaya of Garhwal Region and exhibits rugged topography having a relief difference of about 2,755 m. The maximum spot elevation is 3,098 m at the water divide in Dudhatoli Forest, east of Thallisain. The minimum elevation of 343 m occurs at Muni-ki-Reti on banks of River Ganga, near Rishikesh. The area is represented by strike ridges and other structurally controlled ridges having a regional trend of NW-SE reflecting a strong control of regional strike of geological formations and master joints over them. The majority of inter-montane valleys are narrow having 'V' shaped transverse sections with deep dissected relief. At places, the valleys are open to facilitate development of small and isolated river terraces. River Ganga is the trunk channel of the area. The drainage pattern is generally subparallel to trellis, having medium drainage density. The fluvial terraces are generally small, isolated and unpaired occurring on either of the banks.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer section 2.1.2, Chapter 2)



Landslide susceptibility map of Bhagirathi River basin, Uttarakhand

Based on field traverses, a total 330 landslide incidences have been recorded, out of which a detailed inventory of 22 prominent landslides has been prepared. The inventory gives information on the location, type and dimension of landslide, nature of material involved and its causative factors. The maximum landslides (69%) occur mainly within Saknidhar, Chandpur and Nagthat formations. Lansdowne granite records minimum landslides (0.3%). Out of 330 landslides, 125 slides are rock slide, 180 are debris slide and 25 are mixed slide, where rock and debris are mixed.

Plate 3.3 shows the landslide susceptibility map of Ganga basin, covering 3,050 km² area. The entire area has been differentiated into 4,861 slope facets. Out of these, 440 slope facets (9.05%) occur in Dudhatoli Crystalline; 1,478 facets (30.40%) in Saknidhar Formation; 922 facets (18.96%) in Chandpur Formation (these include 15 slope facets of intrusive Lansdowne granite also); 1,016 facets (20.90%) in Nagthat Formation; 130 facets (2.67%) in Manila Phyllite Formation; 173 facets (3.56%) in Infra-Krol Formation; 351 facets (7.22%) in Krol Group, and 351 facets (7.22%) in Tal Group. Physically, 706 slope facets are in bedrock and 1,155 slopes in overburden. In toposheet 53J/7, 53J/8 and 53J/12, the high and moderate landslide susceptible zones occur all along the Ganga River valley, and in Nilkanth- Gular Chatti, Luxmanjhula- Phulchatti and Vyasi-Kaurialia areas. In toposheet 53J/16, the high and moderate susceptible prone zones are particularly aligned along the course of Paschimi Nayar River, Nautha-Saklayana area, Maudakhal-Nisni area, along the course of Kher *nala* and sporadically along Kotdwar- Pauri road Section. In toposheet 53 N/4, the scattering of high and moderate susceptible zones indicate that Khand-Tila section, an area in the proximity of Baijkot, along Dhailyali *gad* and Kuth-Rikhali section are generally prone to mass wasting process.

3.2.4 Landslide susceptibility mapping of Ramganga River basin

The Ramganga catchment encompasses an area of approximately 3,100 km² and displays artistic heritage with places of tourist attraction. The main townships are Ranikhet, Bhikyasen, Chaukhutiya, Dwarahat, Dhumakot, Marchula, Nainidanda, Syalde, Manila, etc.; besides, a number of pockets of rural population, which are connected by road network of different status. The road network is

further connected with railway route from Kathgodam.

The basin experiences recurring landslide and slope instability events causing disruption of important communication routes, irrigation project, cultivated slope terrace, rural and urban settlements and loss of human life. GSI has carried out landslide susceptibility mapping for 2,100 km² area of the Ramganga valley, covering parts of Chamoli, Nainital and Almora districts of Uttarakhand. The area falls in toposheets: 53J/7, 53J/8, 53J/12, 53J/11, 53J/16, 53K/5, 53K/9, 53K/13, 53N/4 and 53O/1. The objective of the study was to assess/evaluate and demarcate the landslide prone and susceptible areas in the basin. The investigation has been carried out as per guidelines prescribed by BIS code IS 14496 (Part 2):1998 modified by GSI. The work was carried out on scale 1:50,000 between 2005 and 2009 under four field season programmes (Kumar *et al.*, 2010).

Regionally, the area exposes rocks of Jaunsar Group, Almora Crystalline Group, Bhowali volcanics, Garhwal Group, Baliana Group, Krol Group and Siwalik Group. At places, these are covered by Quaternary sediments. The area mainly lies in NW-SE trending synformal metamorphic belt commonly referred as 'Almora Crystalline'. In the north, it is separated from Garhwal Group of rocks by the North Almora Thrust (NAT). Major tectonic elements encountered are North Almora Thrust, South Almora Thrust (SAT) and Main Boundary Thrust (MBT). Main Boundary Thrust trends NW-SE direction and it separates Siwalik sediments with Pre-Siwalik litho-package.

The Ramganga basin characteristically exhibits rugged ridge and valley topography. The major ridges in the area act as water divide with other adjoining basins, e.g. the N-S trending Dharpani Dhar ridge forms water divide between Ramganga River and Kosi River systems. Physiographically, at places Lesser Himalayan range represents pronounced relief with high ridges and deep ravines to U-shaped valley; basically, these areas exhibit highly dissected and rugged topography controlled by long ridges and deep narrow valleys. Apart from these, various other types of geomorphic features, i.e., strike ridges, strike valleys, escarpments, dip slopes, alluvial terraces, meanders of river channels, wide valleys, gorges, steep slopes, etc., belonging to the Lower, Middle and Higher Himalaya, define the geomorphology of the area. The basin is drained by

Ramganga River and its tributaries such as Nayer *nadi*, Badangarh *nadi*, Kamand *nala*, Bairhat *nala*, Dev *gad*, Gabhini *gadhera* and Jhak *gadhera*. It flows from NE to SW following the general slope of the basin; at places, it has made deep and narrow gorge whereas at flatter stretches it shows meandering pattern.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer section 2.1.4, Chapter 2). Based on field traverses, a detail inventory of 145 landslide incidences has been prepared. The inventory gives information on the location, type and dimension of landslide, nature of material involved and its causative factors. Out of 145 landslides, 19 slides are rock slide, 88 are debris slide and 38 are composite slide, containing both rock and debris. Jaunsar Group of rocks have maximum landslide incidences (75 slides), followed by Almora Group (57 slides), Garhwal Group (3 slides), and two slides each in Bhowali, Mandhali and Krol formations and rest in Infra Krol and Siwalik rocks. Table 3.3 gives brief details of 14 major landslides. Annexure-I provides an inventory of some of the major landslides. The main triggering factor of the landslides is intense rainfall in the area. Subsequently, over saturation of highly weathered material and toe cutting by local drainage coming down the hills have led the different types of slides and subsidence. At places, the dipping strata parallel to sub-parallel with slope direction towards road/valley side are also a major contributing factor in sliding of the rock mass.

Plate 3.4 shows the landslide susceptibility map of Ramganga basin, covering 2,100 km² area. The entire area has been differentiated into 3,636 slope facets. Out of these, 642 slope facets (17.66%) occur in very low susceptible category; 2,025 facets (55.69%) in low susceptible; 775 facets (21.31%) in moderate susceptible; and 174 facets (4.79%) in high susceptible category. Due to the presence of active landslide and subsidence in the area, the 20 affected slope facets (0.55%) were put in very high susceptible category. The landslide loci at Chamara, Dhoba, Jardo and Utindagaon villages are categorised into very high to high susceptible zone.

3.2.5 Landslide susceptibility mapping of Pithoragarh district, Kumaon Himalaya

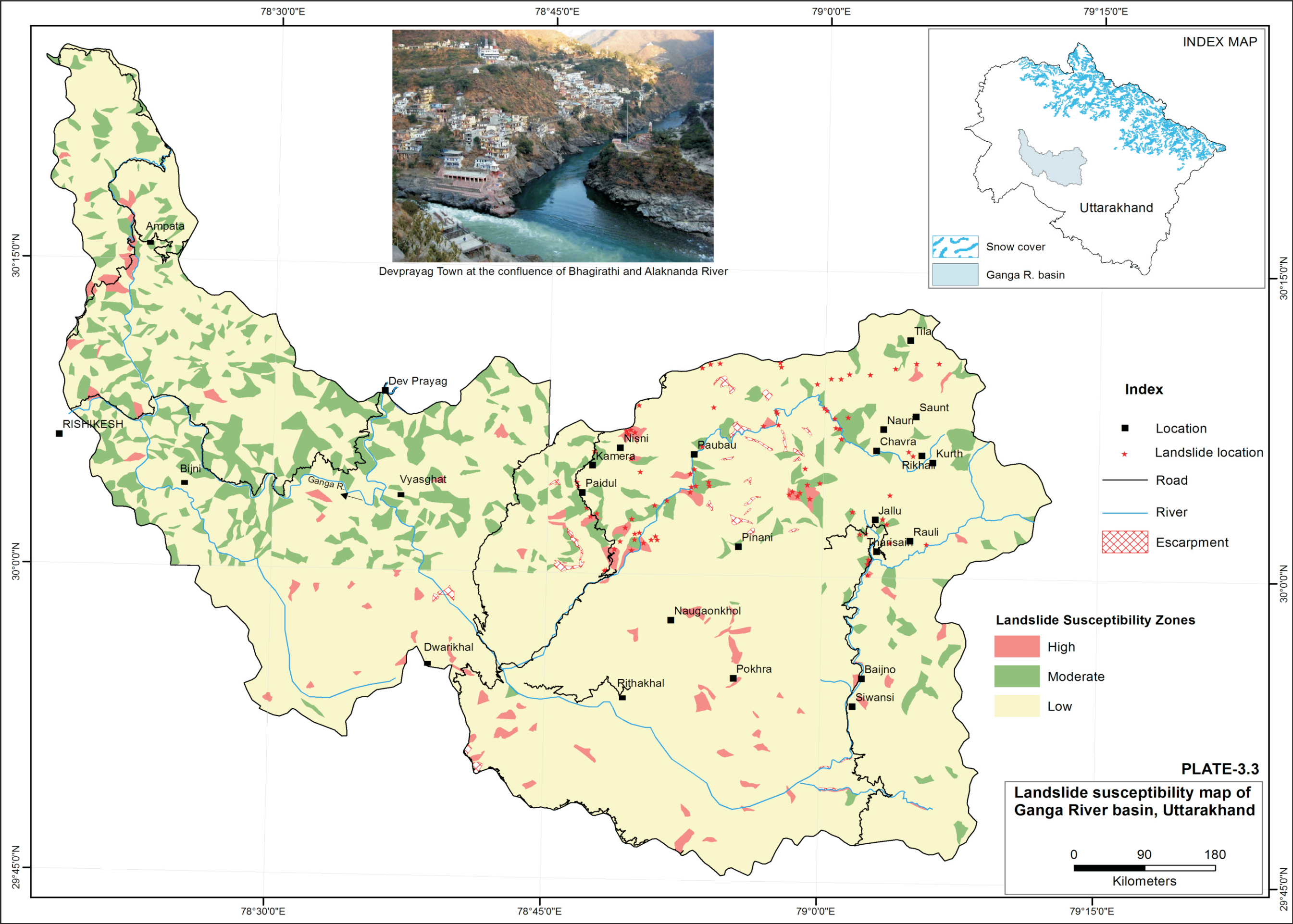
Pithoragarh district is the easternmost Himalayan district in

the state of Uttarakhand. It covers a total area of 7,110 km² and is bounded by two international borders: the Tibet plateau to the north and Nepal to the east. The Kali River originates from Kalapaani and flows south, forming the eastern border with Nepal. The Hindu pilgrimage route for Mount Kailash-Lake Manasarovar passes through this district via Lipulekh Pass in the greater Himalayas.

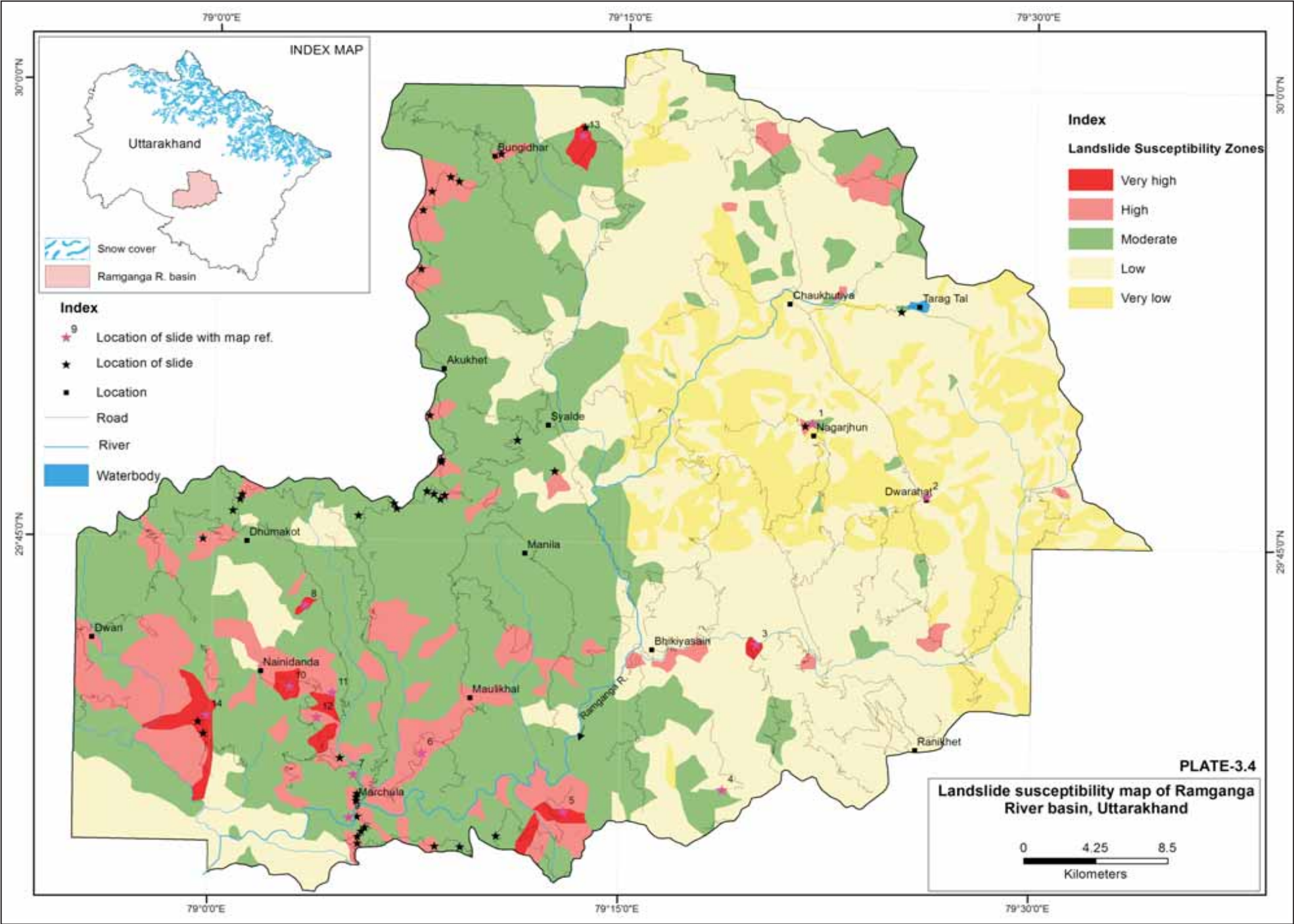
The landslide susceptibility mapping on macro-scale (1:50,000) was carried out in parts of Pithoragarh district covering 812 km² area, encompassing toposheets: 62C/1, 62C/2 and 53O/13. The important locations in the study area are Chaukori, Thal, Nachini, Dor, Muwani, Gangolihat, Dewalthal, Kwiti and Berinag. The work was carried out under field season programme of 2012 and 2014 (Tripathi *et al.*, 2014).

Geologically, the area exposes crystalline rocks of Almora Group, Jhartoli Formation and Askot Formation (=Dharamgarh=Lachim=Lekh=Adhauli=Bairagaon) of undifferentiated Proterozoic age; low-grade metamorphosed rocks belonging to Rautgara Formation, Pithoragarh Formation, Kanalchhina Formation and Berinag Formation (=Nagnithank Formation) of Garhwal Group of Mesoproterozoic age and Quaternary sediments belonging to Older Alluvium and Newer Alluvium Group of Holocene age. Structurally, the Proterozoic rocks are complexly folded and faulted. The general trend of the rocks is in NW-SE and WNW-ESE with moderate to high dips towards north. The trend of axial trace of synform and antiform is NW-SE. There are several transverse faults. The Almora Group is delimited from the Garhwal Group by North Almora Thrust (NAT) dipping due south. Askot and Jhartoli formations occur as synclinal klippe in the area.

Geomorphologically, the area exhibits rugged topography of Lesser Himalayan terrain with high peaks and deep gorges, with elevation ranging from 725 m to more than 4,000 m above msl. The ruggedness increases northwards, particularly north of MCT, where peaks/ridges mostly over 4,000 m found covered with a zone of perpetual snow. The area is drained by southerly flowing Ramganga River and Sarju River and their tributaries viz. Gurghatiya *Gad*, Dokarna *Nala*, Barar *Gad*, Mehar *Gad*, Bhojpatri *Gad* and Jakula *Nala* of Ramganga River and Paqnar River, Shilang



Landside susceptibility map of Ganga River basin, Uttarakhand



Landside susceptibility map of Ramganga River basin, Uttarakhand

Table 3.3. Inventory of major landslides in parts of Ramganga River basin.

Map Ref.	Dimension		Type of slide	Causative factors and temporary remedial measures
	Length (m)	Height (m)		
1.	50	60	Rock cum debris slide	Caused due to toe cutting made for road construction and <i>nala</i> erosion. Construction of retaining wall and accumulation ditch at toe were suggested.
2.	50	40	Rock cum debris slide	Caused due to toe cutting due to road construction. Construction of retaining wall at toe was suggested.
3.	60	150	Debris slide	Caused due to toe cutting by river.
4.	15	100	Debris flow	Caused due to toe cutting made for road construction.
5.	100	200	Debris slide	Caused due to toe cutting made for road construction.
6.	100	40	Debris slide	Caused due to toe cutting made for road construction. Flattening/back dressing of slope was suggested.
7.	100	20	Rock cum debris fall	Adverse alignment of discontinuities and percolation of water through joints triggered landslides. Breast wall along the toe of the slide was suggested.
8.	200	400	Subsidence	Subsidence due to deep toe/lateral cutting by <i>nala</i> . Cracks developed in houses; Breast wall along the toe of the slide was suggested.
9.	150	350	Rock cum debris slide	Adverse alignment of discontinuities; polyphase deformation. Breast wall along the toe of the slide was suggested.
10.	200	300	Subsidence	Subsidence due to deep toe/lateral cutting by <i>nala</i> . Breast wall along the toe of the slide was suggested.
11.	150	500	Subsidence	Subsidence due to deep toe/lateral cutting by <i>nala</i> . Breast wall along the toe of the slide was suggested.
12.	200	500	Subsidence	Subsidence due to deep toe/lateral cutting by <i>nala</i> . Breast wall along the toe of the slide was suggested.
13.	150	300	Debris slide	Highly weathered rock mass resting on steep slope. Removal of slide material, moderation of slope were suggested.
14.	100	150	Debris slide and subsidence	Highly deformed weathered rock. Removal of slide material, moderation of slope were suggested.

Gad, Gokarneshwar *Gad*, Kalapani *Gad*, Mangarh *Gad*, Syuti *Gad*, Kin *Gad*, Bhaneri *Gad*, Panar *Gad*, Ling *Gad*, Boel *Gad*, Thulli *Gad* and Rain *Gad* of Sarju River.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer section 2.1.4, Chapter 2). Based on field traverses, a detailed inventory of 76 landslide incidences has been prepared. Table 3.4 gives brief details of 20 major landslides. The inventory gives information on the location, type and dimension of landslide, nature of material involved, causative factors and its

remedial measures. It is observed that the concentration of slides is mainly confined to the North-Eastern segment where the Garhwal Group of rocks (quartzite, dolomite and slate/phyllite) have undergone intense fracturing, jointing and shearing, perhaps, due to structural disturbance and apparently to some extent owing to new road cutting /widening (anthropogenic activity). Most of the slide incidences fall in high relief areas marked by gully erosion and toe cutting. Annexure-I provides an inventory of some of the major landslides.

Plate 3.5 shows the landslide susceptibility map of Pithoragarh district, covering 812 km² area. Based on Modified BIS approach, the study area was grouped into five classes of varying landslide susceptibility condition. The area has been divided into 796 slope facets of which most of the facets, 510 facets lie in low susceptible zone whereas very low susceptible zone is represented by 260 facets followed by 20 facets of moderate susceptible zone. Only six facets represent high susceptible whereas very high susceptible zones are absent. Moderate susceptible zones are located either in slates or near landslide incidences. Land use and anthropogenic activities may also influence the landslide susceptible zones because many low to moderate susceptible zones are located along the major communication routes where slope cutting can induce instability. Around Chaukori, Udiyari and Berinag most of the area falls under very low to low susceptible category. Between Nachani and Bhainsiabagar, along Ramganga River, most of the area falls under low to moderate susceptible category with a few patches of high susceptible along Rati *gad* and Sim *gad*. A limited area north of Thal along Chandrabhaga, Ghati *gad* and Lakri *gad* falls under moderate susceptible category whereas most of the area comes under low susceptible category. Towards East and Northeast of Tejam; and around Bhainskot, Malla and Samkot Talla, most of the area comes under low susceptible category with few pockets of very low susceptible category.

Most of the areas falling under very low susceptible zones can be used for developmental works. Geologically, most of the area is occupied by quartzite, dolomite which has low ratings, followed by gneisses and migmatites having low to moderate ratings. Moderate susceptible zone are located near highly disturbed areas or where landslide incidences are noted. The very low susceptible zone and low susceptible zone are safer for development, though would require necessary slope protection measures. The medium susceptible zone may feature locally unstable slopes. Before taking developmental schemes in such areas, detailed geotechnical studies may be carried out to identify vulnerable slopes for adopting suitable remedial measures. Unscientific mining practices for talc in some pockets of the area are one of the contributing factors for slope instability. Dust from talc generated during blasting may also create health hazards. So it is recommended to observe necessary

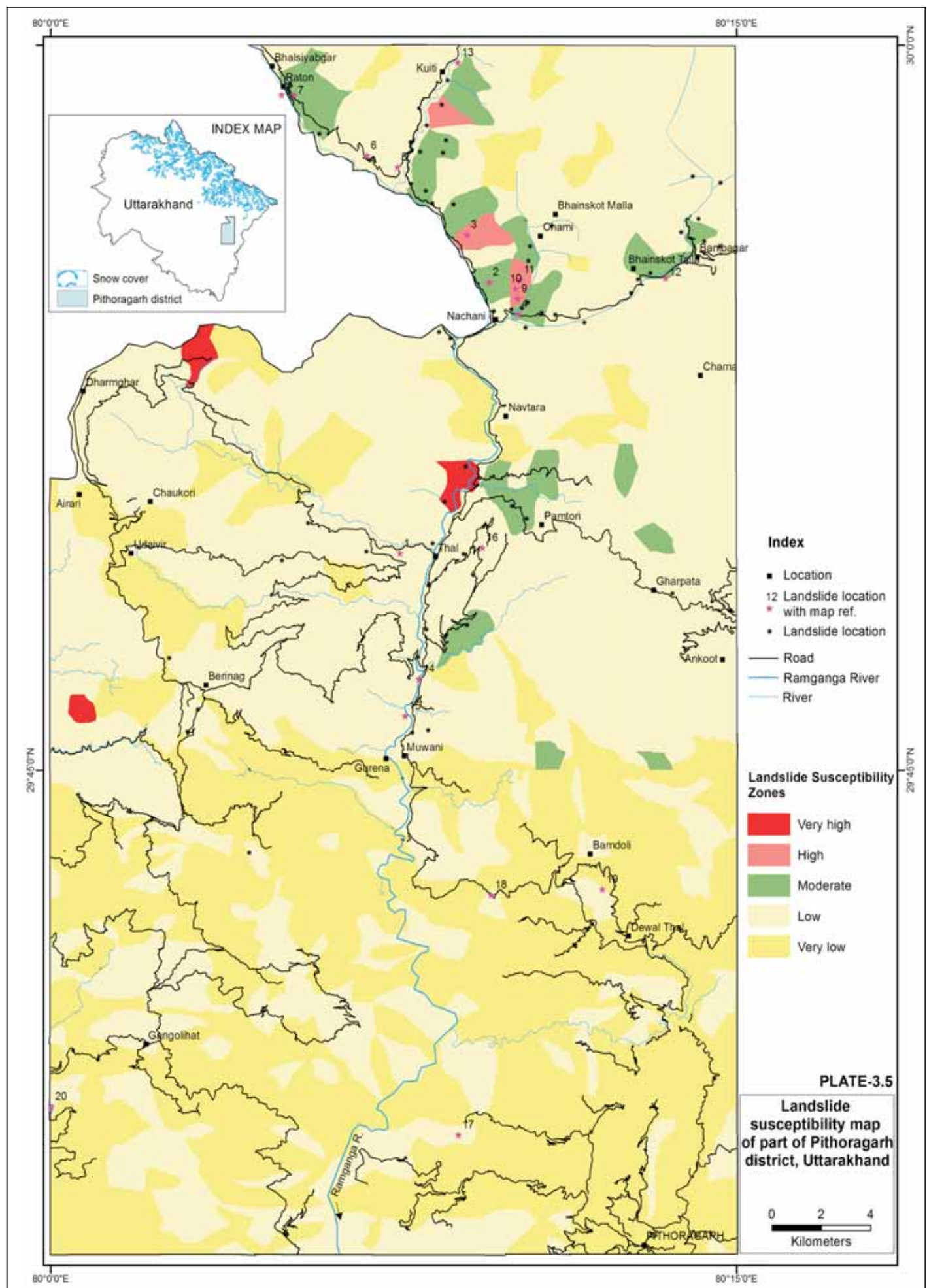
precautionary measures to prevent health problems. Landslides recorded along Nachani-Kulti section along Ramganga River; and along Nachani-Selmali section along Bhojpatri *gad* require detailed geotechnical assessment for the stability of the communication routes and habitations/villages.

3.2.6 Landslide susceptibility mapping of Bageshwar district, Kumaon Himalaya

Bageshwar district is in the eastern Kumaon region of Uttarakhand and is bounded on the west and northwest by Chamoli district, on the northeast and east by Pithoragarh district, and on the south by Almora district. It covers a total area of 2,302 km². The main townships in the district are Garur, Baijnath, Bageshwar Kapkot, Kanda and Dharamghar, besides a number of villages, which are connected by road network of different status. The area is also known for its trekking route to Pindari glacier.

Landslide is a perennial hazard in the Bageshwar district. It experiences recurring landslides and slope failures causing disruption of important communication routes, damages to irrigation projects, cultivated terraced slopes, rural and urban settlements and loss of human life. The landslide susceptibility mapping on macro-scale (1:50,000) was carried out in parts of Bageshwar district covering 1,200 km² area, encompassing toposheets: 53O/5, 53O/9, 53O/10, 53O/13, 53O/14, 53N/8, 53N/12, 53N/16, 62B/4 and 62C/1. The work was carried out during field season programmes of 2009 and 2013 (Kumar *et al.*, 2013).

Geologically, the area exposes rocks of Central Crystalline Group, Dharamgarh/Baijnath Formation of Unclassified Crystallines, Almora Crystalline, Rautgara Formation, Pithoragarh Formation and Berinag Formation of Garhwal Group and Quaternary Alluvium. The area mainly lies in NW-SE trending synformal metamorphic belt commonly referred to as Almora Crystalline. In the north, it is separated from the Garhwal Group of rocks by the North Almora Thrust (NAT). Apart from North Almora Thrust (NAT), Baijnath Thrust (BT) is also one of the major tectonic elements in the area which demarcated the boundary between Baijnath Formation and Almora Group. Parts of the area, located North of MCT (Main Central Thrust) exposes gneisses, schist and migmatite of Central Crystalline Group



Landslide susceptibility map of part of Pithoragarh district, Uttarakhand

of Archaean age. The crystalline rocks of undifferentiated Proterozoic age i.e., Dharamgarh and Baijnath formations are exposed as klippe and occupy the core of the synform. Biotite gneiss, chlorite schist, inter bands of schistose quartzite with metavolcanics of Dharamgarh Formation occur near Kameridevi and Dharamgarh whereas Quartzite and gneiss of Baijnath Formation are exposed near Thara Izar. The rocks of Garhwal Group of Mesoproterozoic age occupy the major part of the area and are classified into Pithoragarh and Berinag formations in ascending order. The Pithoragarh Formation is exposed in north-western part of toposheets 53O/13, south of MCT in 62B/4 and 53N/16 and the entire part of 62C/1. Quaternary deposits include alluvial, colluvial, glacial and fluvio-glacial sediments.

Geomorphologically, the area exhibits rugged topography controlled by narrow and sharp ridges, with elevation ranging from 950 m to more than 4,000 m above

msl. The ruggedness increases towards north, particularly north of MCT, with peaks/ridges attaining great heights (over 4,000 m), which are found covered with a zone of perpetual snow. In the area, the geomorphic features/landforms are represented by strike parallel ridges and valleys, steep slopes/escarpments, dip parallel slopes/consequent slopes, alluvial terraces, meanders of river channels, gorges, etc. The general slope is towards SE. The signature of Quaternary glacial activity is present in the northern part of the area. The glacial landforms, which are depositional in nature, include morainic dumps/ deposits, stony trails, and erratics covering the valley slopes. The erosional landforms of glacial origin are indicated by U-shaped valleys, hanging valleys, palaeo-cirque areas, escarpments, etc. The planation surfaces in upper reaches of the valley slopes are indicative of erosion caused by iceaction. The main drainage is represented by Ramganga

Table 3.4. Inventory of major landslides in Pithoragarh district.

Map Ref.	Morphometric characters of landslide	Nature of landslide	Remarks and temporary remedial measures
1.	60 m high and 150 m wide	Sinking/ Subsidence zone	At least 3– 4 levels of subsidence in the gabion walls are noticed in the area.
2.	500-600 m high as well as wide	Debris slide /subsidence zone	The sources debris are highly sheared rocks (slate, phyllite, limestone and dolomite) exposed near the crown (escarpment) and flanks of the slide. A <i>nala</i> passing within the slide is the main cause for the mobilization of the slide.
3.	250 m high as well as wide	Rock cum debris slide	The main cause of the slide is the toe erosion by river Ramganga River on the curve/meander of the stream.
4.	90-100 m high and $\pm$ 150 m wide	Rock slide	Exposed rock mass include phyllite and sheared deformed limestone. Toe- erosion by <i>Sim gad</i> is the cause of the slide.
5.	70 m high and $\pm$ 100 m wide	Debris cum rock slide	Road widening/cutting is the main cause of the slope instability.
6.	100 m high and 90 m wide	Debris cum rock slide	The rock mass consists of sheared dolomite.
7.	100 m high and 70 m wide	Rock cum debris slide	
8.	100 m high and 200 m wide	Debris cum rock slide	It is predominantly an old debris cone which has got reactivated due to toe- erosion (by local <i>nala</i>) and road cutting.
9.	75-80 m high and 250-300 m wide	Rock cum debris slide	Wedge failure and toppling has been observed due to interplay of following three joint sets: $J_1 = 80^\circ/N200^\circ$; $J_2 = 75^\circ-80^\circ/N300^\circ$ and $J_3 = 10^\circ-15^\circ/N125^\circ$. The slide zone has come into existence due to toe-erosion (<i>Sim gad</i>) and road cutting.
10.	200 m high and 150 m wide	Rock cum debris slide	
11.	100 m high and 80 m wide	Rock cum debris slide	The rock mass exposed in the slide area are fractured and sheared talcose phyllite/dolomite sequence.

Contd.

Map Ref.	Morphometric characters of landslide	Nature of landslide	Remarks and temporary remedial measures
12.	135 m high and 125 m wide	Rock cum debris slide	The road cutting and toe-erosion by Bhojpatri <i>gad</i> are the main causative factors.
13.	275 m high and 225 m wide	Rock cum debris slide	Toe-erosion by the <i>nala</i> is the main causative factor.
14.	250-300 m length and 80 m wide	Old rock slide	The causative factor is toe-erosion by Ramganga River.
15.	300 m long and 150 m wide	Rock cum debris slide	Gneisses/ gneisses exposed near the slide zone.
16.	150 m high 200 m wide and 300 m long	Sinking / subsidence zone	
17.	50 m high and 150 m wide	Debris slide	Induced by road cutting.
18.	100 m high and 30 m wide	Debris slide	Heavy rainfall accelerated sheared material to move along the slope.
19.	120 m high and 65 m wide	Rock fall	Highly and closely spaced jointed limestone slid rapidly along slope after heavy rainfall.
20.	80 m high and 30 m wide	Rock cum debris slide	Phyllite and slate are exposed in the slide zone. Disintegrated rock mass and debris slid along slope after heavy rainfall.

Map Ref. is the slide number given in Plate 3.5.

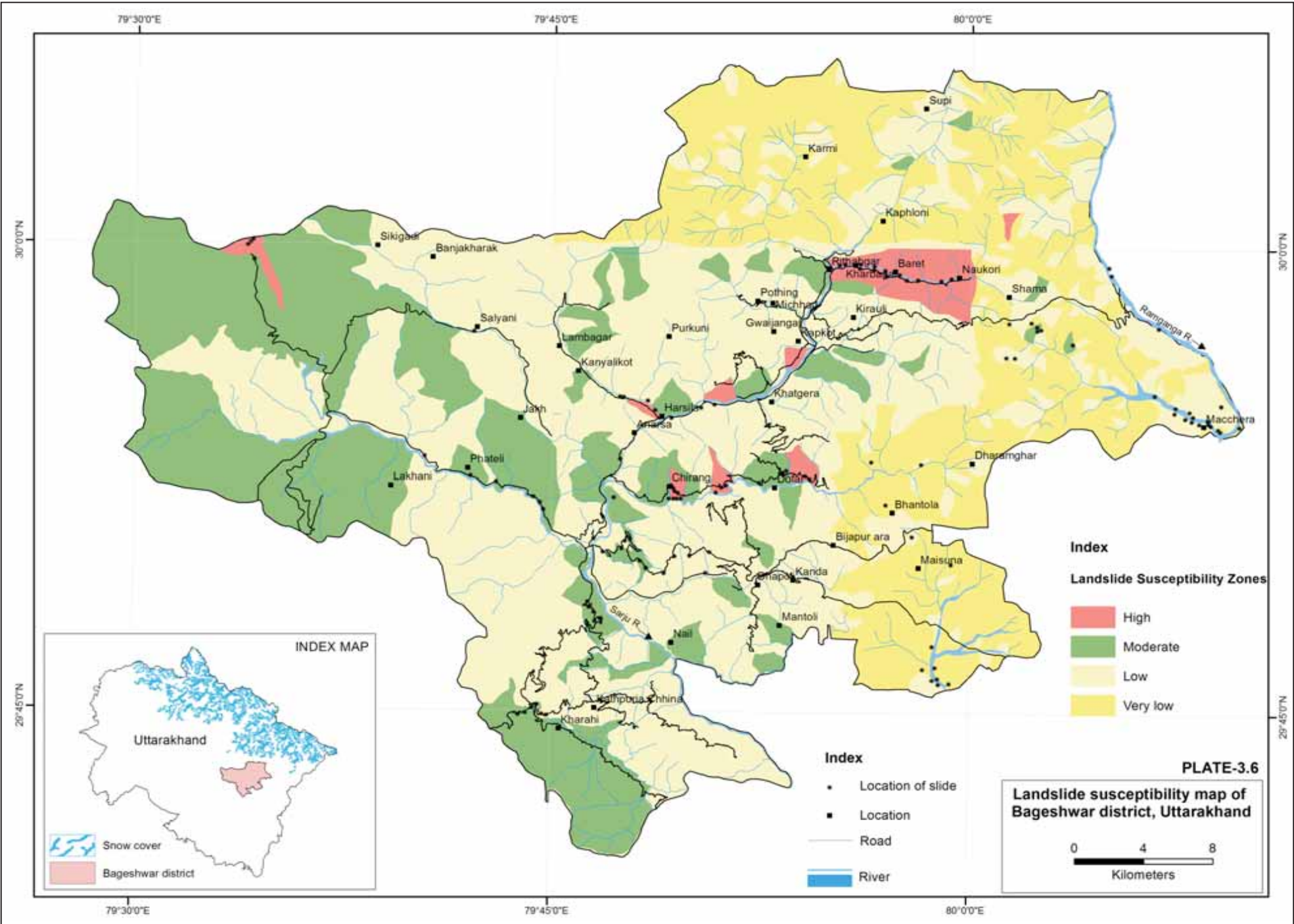
River and Gomti River and their tributaries (locally called *gad* or *gadhera* and *nadi*) viz., Garur Ganga River; Sarju River and other perennial streams as Lohar Nadi, Dhatoli *Nala*, Latoliya *Gadhera*, Saukala *Gadhera*, Ghanghali *Gadhera*, Ratagarh *Gadhera* and Chhira Raula of Gomti River. Gomti River flows at elevation about 2,591 m from NW to SE. The river forms shallow and shows meandering at number of places. Numerous small drainages cut through the mountainous terrain to join the various stream and tributaries in form of dendritic patterns. The high ridges in the area are represented by Dhars (long ridges). Ramganga River is another major stream with a southerly flow direction and marks the eastern limits in the northern part of the area. The other important drainage line, which falls in the eastern part of the study area and forms a tributary of Ramganga is Mehar *gad*. The Sarju River flowing with a south-westerly course and its major tributary-Pungar Nadi marks the drainage network in the northern and northwestern part of the area. The Sarju and its tributaries valleys exhibit sparsely developed fluvial terraces along their courses. These form gently sloping flat surfaces on either side of the river course. These terraces represent the old flood plains or former valley floors.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer section 2.1.4,

Chapter 2). Based on field traverses, a detailed inventory of 73 landslide incidences has been prepared, which includes debris slides (33 nos.), rock cum debris slide (29 nos.), rock slide (4 nos.), rock fall (3 nos.), mudflow (3 nos.) and one subsidence. Annexure-I provides an inventory of some of the major landslides.

Plate 3.6 shows the landslide susceptibility map of Bageshwar district, covering 1,200 km² area. Based on the Modified BIS approach, the study area was grouped into five classes of varying landslide susceptibility. The area has been divided into 1,462 slope facets of which 694 facets lie in very low susceptible zone, 534 in low susceptible zone, 214 in moderate susceptible zone and 20 facets in high susceptible zone. Due to gentle slopes, open valleys and low-intensity rainfall in the area no slope facet falls in very high susceptible zone. Some of the critical/ vulnerable areas identified during field work include:

- Takula- Kophalgair road section: The 7 km long road stretch between Takula and Kophalgair consists of highly weathered rock; this stretch been identified as highly vulnerable due to occurrence of debris fall during heavy rains.
- Kophalgair- Katpurichinna road section: The 8 km long road stretch between Katpurichinna-Kophalgair consist



Landside susceptibility map of Bageshwar district, Uttarakhand

of highly weathered rock of quartz arenite of Rautgara formation; this has been identified as highly vulnerable due to occurrence of debris fall during heavy rainfall.

iii. Kharbagar – Naukri road section (Revti Ganga valley):

The entire valley of Revti Ganga, a tributary of Sarju River has been affected by intense rainfall in September 2010 and subsequently Kharbagar and Breta villages were particularly affected by rock cum debris slides. The entire stretch of road between Kharbagar – Naukri was severely affected due to major landslides and bank erosion of Revti Ganga. A 100 m long stretch of road was badly affected near Kharbagar connecting the Bageshwar-Pindari highway. Mostly slope failures have occurred on the right bank of Revti Ganga severely affecting Kharbagar, Baret and Devibagar villages. The dominant slope forming material in the valley includes calcareous and sericitic quartzite and slate of Tejam (=Pithoragarh) Formation of Garhwal Group with a thick overburden of glacio-fluvial deposit. The trace of the shear zone/fault plane passes through this affected zone.

- iv. Landslide at Shumgarh village: A landslide, having 15 m width and 25 m height, has been identified on the Bageshwar-Pindari Glacier road, 45 km from Bageshwar on a hill slope at an elevation of nearly 1,400 m, at the right bank of Sarju river in Kapkot tehsil, Bageswar district, Uttarakhand. The slide occurred on the south-western slope of east-west trending ridge. The inclination of slope is 29° which falls in moderate to steep slope (25°-35° slope angle). Three minor local seasonal drainages are draining the slope. This slide is a major threat to the nearby village during monsoon.

3.2.7 Landslide susceptibility mapping of Uttarkashi district, Garhwal Himalaya

The magnitude 6.6 Uttarkashi earthquake of 20th October, 1991 caused great damages to life and property apart from bringing in conspicuous terrain changes in the form of rock and debris slides, slump related ground fissures, changes in the discharge of water spring as well as the chemistry of geothermal waters. In view of the widespread slope stability problems, a post-earthquake landslide susceptibility of Uttarkashi district was evaluated by assessing the effects of topography on the seismic intensity and the attenuation

pattern as reflected by the density of coseismic slope failures. The dynamic forces induced by the earthquake and the consequent failure of the critical slopes have served as a natural experiment in testing the efficacy of the landslide susceptibility zonation.

The landslide susceptibility mapping on macro-scale (1:50,000) was carried out in parts of Uttarkashi district covering 760 km² area, encompassing toposheets: 53J/5, 53J/6, 53J/9 and 53J/10. Geographically, the area is confined between downstream of Uttarkashi town in the south and upstream of Gangnani in the north. The work was carried out during two field season programmes of 1991 and 1993 (Joshi and Pande, 1994).

Geologically, the area exposes lithostratigraphic units of Central Crystallines, Garhwal Group and Dudatoli Group. The Central Crystallines made up of banded augen gneiss, migmatitic gneiss, granite gneiss, marble, calc silicate with minor amount of amphibolite, whereas the Garhwal Group comprises quartzite, slate and limestone of Uttarkashi Formation, grey to blackish limestone, dolomite and slate and quartzite of Shyalana Formation and massive white quartzite with parting of meta-argillite/thick bands of meta volcanics of Nagni Thank Formation. The Garhwal Group is overlain by Dudatoli Formation which comprises of limestone of Chandpur Formation and metavolcanics. Structurally, the Proterozoic rocks are complexly folded and faulted. Regional thrust planes demarcate the boundary of almost every lithostratigraphic unit of the area. Along Bhagirathi River, North Almora Thrust (NAT) separates the rocks of Dudatoli Group in the south from the Garhwal Group near Margaon village and these in turn are thrust over by Central Crystallines along the Main Central Thrust (MCT) in the vicinity of Kumalti. Further upstream Dhar Martoli Fault marks the boundary between the Central Crystallines and meta-sedimentaries of Martoli Group of rocks near Suki village.

Geomorphologically, the area is characterised by high rugged hills and deep cut V-shaped valleys. The high ruggedness of the area is due to large altitudinal differences of different order of hillocks; the highest point of the area is at 4,075 m, located about 2 km north-west of Dodital whereas the lowest point is at 840 m, located at the confluence of Gamri *gad* and Bhagirathi River. The

curvature of the area is almost monotonous, most of the slope hill slopes show a concave upward shape, characterised by steep gradient/scarps in the upper parts, while the lower reaches of the valley slopes are mainly occupied by debris cones. The flat part of the slope is intermittently occupied by terraces along the trunk stream and at places along the tributaries. The area is drained by Bhagirathi River and its various tributaries, which together create a degradational regime. The overall flow direction of the Bhagirathi River is towards SSW. The drainage pattern varies from dendritic, rectangular to parallel types depending upon variation in lithology, structure, etc.

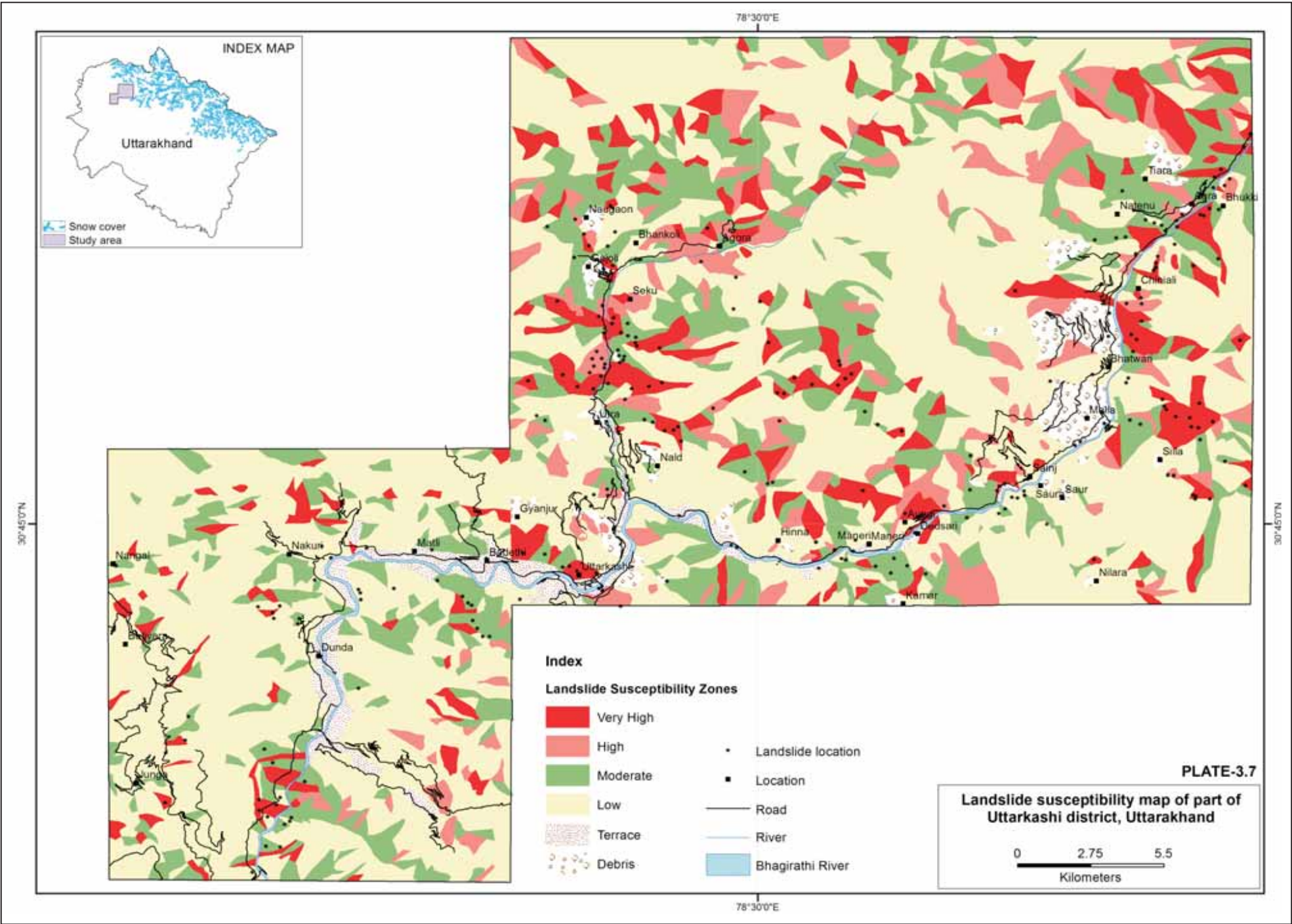
The Garhwal seismic block, defined by Kaurik fault in the west and Alaknanda fault in the east constitutes one of the highly active seismic domains of the Himalaya. Out of 79 major earthquake events recorded from this region, 25 are of magnitude equal to or more than 5 and less than 6; and 10 are of magnitude equal to more than 6 and less than 7. The cumulative seismic energy releases in the region bounded by latitude N 29°5' to N 31° and longitude E 70° to E 81°, has been of the order of 1023 ergs/decade. The focal mechanism studies have indicated that the majority of the events in the region were of thrust type and were clustered around the surface trace of the MCT.

The Uttarkashi earthquake of 20th October, 1991 created conditions of large dynamic shaking in the area and consequently put to test the performance of various slope segments. A total 115 landslides were identified and verified in the field. Besides, 26 landslides were mapped using IRS LISS II FCC imageries of 26th and 27th October 1991. The first incidence of coseismic slide was recorded in isoseist VII where the corresponding peak ground acceleration (PGA) was around 10% of gravity. Here, the small rock dislodgements were common but the failure of low terraced slopes was absent. A spurt in landslide incidences was observed in isoseists VIII and above encompassing a cumulative area of 441 km² where the PGA exceeded 25%-30% of gravity. A comparison of pre and post-earthquake satellite imagery indicated development of 63 large slide zones within isoseists VIII and IX. Of these, a cluster of 24 slides had developed between Utron and Saura in the vicinity of a WNW-ESE trending tectonic lineament. In the epicentral tract corresponding to isoseismal IX in MSK scale, the ground motions had caused shaving of low-level

terraces for considerable lengths.

A probabilistic approach has been used for landslide susceptibility evaluation. In this approach the operative parameters responsible for the failure of the slopes are established by first studying the set of conditions prevailing at the time of failure at all landslide incidences which could possibly be visited or studied and then analysing these conditions or parameters geo-mechanically to obtain the most common conditions associated with the highest frequencies of slides. The post-earthquake landslide susceptibility zonation was carried out by first establishing the critical angle of equilibrium based on the statistical analysis of slope parameters of the failed slopes, obtaining during the field work along sections of Bhagirathi River and its major tributary Assi Ganga. For this, the attributes of the failed hard rock slopes together with the number of failures on different slopes were processed with the help of pie-pole diagram. A total of 66 hard rock slopes with 81 slide incidences were considered for the analysis, which indicated the maximum number of failures or slides have taken place in the slope class with tangent value =0.9 (i.e., slope 41° and aspects between N125° and N160°; N200° and N245°; N290° and N325°, have been grouped as very high susceptibility category. Slopes with tangent value =0.84 and having aspects between N60° and N100° along with those slopes having tangent ratios =0.8 but <0.9 with aspects of high susceptibility category slopes have been classed in high susceptibility category, slopes with tangent values =0.8 but having aspects other than those described for very high susceptibility or high susceptibility categories, are in moderate susceptibility category and all other slopes having tangent ratios <0.8 have been separated as low susceptibility category.

Plate 3.7 shows the landslide susceptibility map of Uttarkashi district, covering 760 km² areas. Based on above criteria, the study area was grouped into four classes of varying landslide susceptibility. The area has been divided into 2,691 slopes of which 659 slopes have tangent ratio of 0.9. Such steep slopes are less frequent (22% to 23%) up to Gangnani and their frequency increases to 44% in the area upstream of Gangnani. Coseismic landslides are mostly in the form of rock falls or rock slides, and occur more in the meizoseismal area, whereas away from epicentral tract density of slides thins out, so much so that beyond



Landside susceptibility map of part of Uttarkashi district, Uttarakhand

isoseismal VII hardly a few earthquake-induced landslides occurrences have been noticed.

The geomechanical analysis of landslide occurrences vis-à-vis the slope parameters indicates that maximum number of slope failures have taken place in the slope class with tangent values ≈ 0.9 . Most of the slope failures in the hard rock appear to have taken place along the wedges formed by the intersecting joints. The study of the coseismic failures of the preferred slopes only indicates that away from the epicentral tract the slope failures are much more along those ridges which more or less have radial alignment to the epicentral area than those which have some sort of parallelism with the epicentral tract. A selective study of 16 ridges/peaks sections indicated that there exists a relationship between the slope failures induced by the dynamic shaking of an earthquake and the height to width ratio of affected hill mass, thereby, suggesting a direct influence of topography on the accentuation of seismic intensity.

3.2.8 Landslide susceptibility mapping of Nainital Town and its environs, Kumaon Himalaya

Landslide is a perennial phenomenon in the Kumaon Himalayas resulting disastrous natural calamities every year. The landslide susceptibility zonation of a 670 km² area in parts of Nainital district of U.P. Himalaya was carried out on scale 1:50,000 (toposheet: 53O/7). The work on was carried out during three field season programmes of 1982 and 1985 (Srivastava, 1985). In the mapping, only aerial photo interpretation approach was used without field checks.

Geologically, the basal stratigraphic unit of the study area is Deoban Group, which is represented by limestone of Betalghat Formation, basic volcanic rock of Bhowali Volcanics, quartzite, phyllite, slate, limestone and quartzite of Bhimtal Formation, Ramgarh Quartz porphyry and Amritpur Granite. The Deoban Group is overlain by Almora Crystalline Group, which mainly comprises different types of schists, phyllites and quartzites. The Almora Crystalline Group is further overlain by interbanded slate, phyllites and limestone of Krol and infra-Krol Formation of Krol Group, Lower (sandstone, claystone and shales), Middle (sandstone and claystone) and Upper (conglomerate and sandstone) litho units of Siwalik Group successively. The whole

sequence is overlain by lake sediments, landslide debris and fluvioglacial deposits of Quaternary Group.

The main geomorphological features of the study area that has been mapped from the aerial photo interpretation are landslide scars, landslide debris deposits, lake and water-bound areas, major stream with tributaries and river bed deposits. The geological structures and stratigraphy essentially controlled the geomorphic evolution of the area. A unique geomorphic feature of the area is that the terrain in and around Nainital is dotted with numerous lakes situated in a belt near the border of the "Sub-Himalayan Zone". Subsidence of rock fragments along faults and rockslides are believed to be the two main reasons behind the formation of these lakes. The old landslide debris may have blocked the exit of the ancient valleys and subsequently water accumulated in those depressions and gave rise to the development of lakes. In this case, apart from those geological factors, climatic condition of the area also played a key role in the origin of those lakes.

In this study more emphasis has been given to the litho groups and six such groups have been made and depicted in the ascending order of susceptibility, where the group 1 is the least susceptible and group 6 is the most susceptible. The selection of mapping units for different groups was based on the study of three thematic maps, including geological-cum-geomorphological maps, land use map and slope map. The groups are as follows:

1. Overburden, fluvial and outwash deposits of foothills having terraced cultivated fields, human settlements and forests. Boulder beds and soft sandstones interbedded with shale.
2. Overburden, outwash deposits, higher terraces deep gullies in Siwalik foothills.
3. Siwalik sandstones and claystones interbedded sequences quartzites, phyllites and slates and basic rocks.
4. Limestones quartzites sequence including Krol limestones, porphyritic granites, porphyries, phyllites and slates and basic volcanics and intrusive traps.
5. Slates and phyllites of Krol and Infra Krols.
6. This group is having highest potentiality of landslides due to presence of active slide scars and escarpments.

The first and second groups have been combined and defined as low susceptible zone while the third group as moderate susceptible zone and the combined fourth, fifth and sixth group as high susceptible zone, depending upon relative vulnerability of these groups to landslides.

Based on above criteria, the study area was grouped into three classes of varying landslide susceptibility condition (Fig. 3.5). The preparation of landslide susceptibility map of the area by aerial photo-interpretation can only be a qualitative approach and the map may be subjective and based on insufficient information. However, the zones delineated in the present scope may be studied in greater

detail with more field input to make the map updated and refined as a preliminary effort. The approach adopted may be followed for further improvement in the technique and collection of data; in fact, a multi disciplinary study is warranted for landslide problems and landslide zonation map preparation.

3.2.9 Slope stability assessment of Tehri reservoir rim, Garhwal Himalaya

The stability assessment of Tehri reservoir rim slopes was carried out around village Kangsali, Khola and Jalwalgaon South Almora Thrust separates Almora Crystalline from

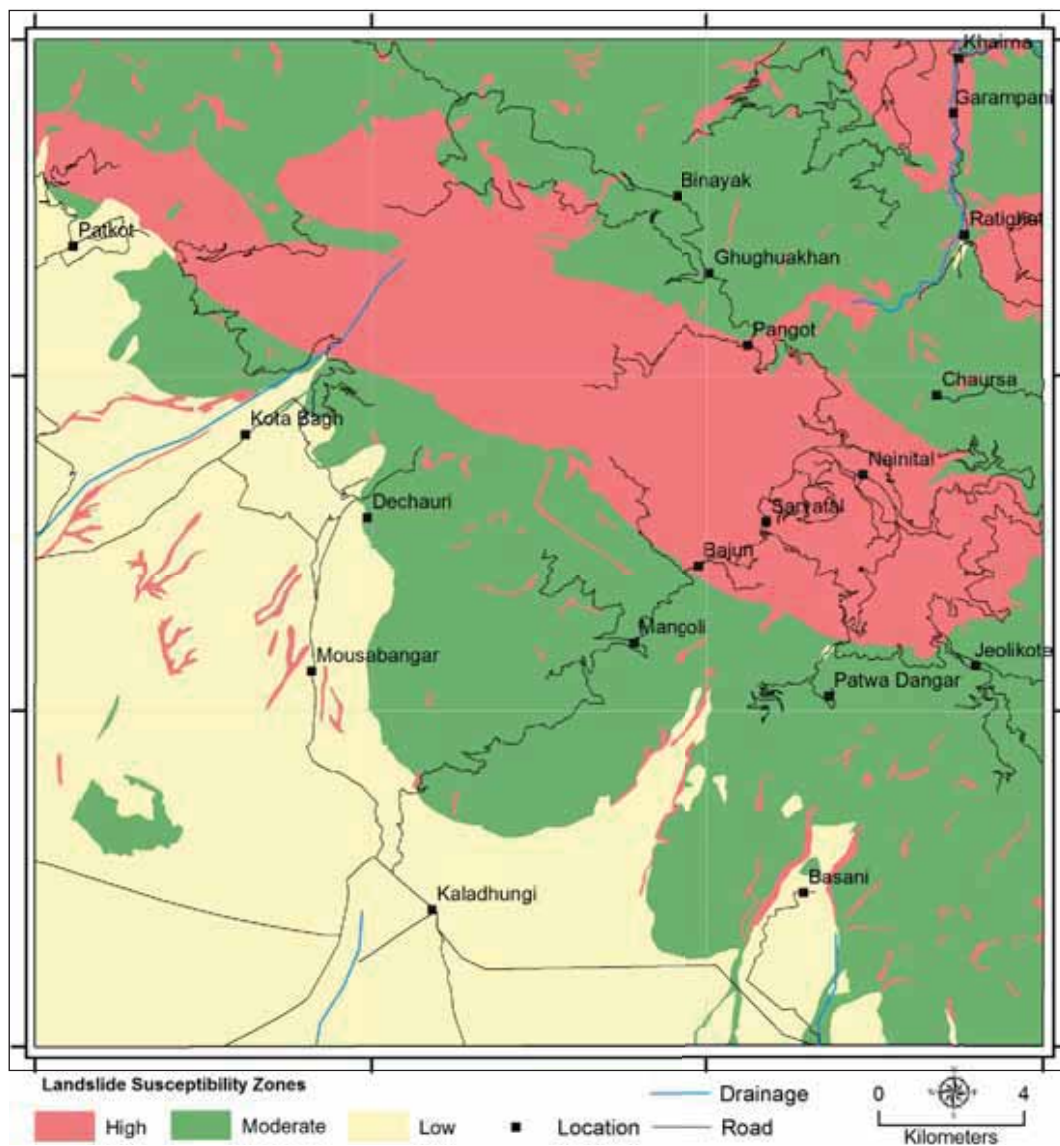


Fig. 3.5. Landslide zonation map of part of Nainital district prepared based on photo interpretation.

with an aim to access the stability condition likely to change with the impoundment process. For the purpose, geological investigations were carried out between Barola *gad* in the north and Sandana *gad* in the southeast by undertaking extensive ground checks on 1:25,000 scale (toposheet: 53J/7NE) covering 9 km² area; theodolite survey of 4.55 L. km along selected profiles on 1:2,000-5,000 scale; and collection of 5 representative soil samples for determining geotechnical properties. The work was carried out during field season programme of 2001 and 2002 (Sanwal and Gairola, 2003).

Geologically, NW-SE trending phyllites of Chandpur Formation, exposed on the NE limb of 'Tehri Anticline' in isolated outcrops, constitute the main rock type in the area. These are thrust over by Garhwal Group of rocks along the Srinagar Thrust, near Dharkot. Most parts of the slopes are covered by overburden material. Average slope in the area is 22°.

The stability assessment was based on detailed field observation. The following criteria were taken for zoning the slopes in different instability zones:

1. Slope Forming Material map - overburden mass comprising loose admixture of sand and rock debris cover most part of the slope. Based on back analysis of failed areas, the friction angle is taken as 24° and cohesion as zero for the saturated condition (worst case scenarios). Vulnerable section of failures are identified where overburden thickness is more than 5 m, slope more than 24°, bedrock profile is steep and contains overburden deposits and slope failure already taken place at downslope part.
2. Hydrological condition- instability induced due to pore water pressure is taken for slopes lying within the submerged level; deformed slopes lying immediately above High Flood Level (HFL); and interface of rock and overburden where displacement and ground sinking has initiated due to steepened rock profile.
3. Slope movements and their manifestation- it was observed that most failures are restricted to overburden mass; most active slide zone lie close to the submergence limit of reservoir; steeper valley faces covered with moderate to thick overburden mass are

highly vulnerable; and steeper rock-overburden interface are most vulnerable to failure.

4. Impact of reservoir impoundment on slope – it is assumed that high energy riverine condition will transform into low energy condition in lake environment; active bank erosion would cease; and toe support will be available through water column and silt load.

Based on above criteria, the study area was grouped into four classes of varying slope instability condition (Fig. 3.6). The unstable zones are where significant ground movements were recorded and are expected to remain sensitive after impoundment. These are mostly steeper slopes rimming the reservoir along its submergence line. Lower slopes of Barola and Nautar villages with intense ground deformation form part of unstable zone. Moderately unstable areas are active and potential slide zone located above the unstable class.

3.2.10 Landslide susceptibility mapping of Ranikhet area, Kumaon Himalaya

Ranikhet, an important tourist resort and a well known military cantonment, in Uttarakhand has of late, faced continued pressure for development. The increasing endeavour for development has involved, directly or indirectly, a change in existing landuse and slope form, particularly in the peripheral parts of the township resulting in slope instability. Landslide macro zonation of 100 km² area, on scale 1:25,000, in and around Ranikhet in toposheets 53O/6NE and 53O/6SE, was carried out to assess and zone the existing slope stability conditions. The work was carried out during field season programme of 2005 and 2006 (Sanwal, 2009).

The town is situated on a north facing arcuate ridge that acts as a water divide between the catchments of Ramganga River to the north and NW and Kosi River to the south and SE. Topography is smooth, gentle and rolling with markedly gently sloping spur lines.

Geologically, the area is bounded between North Almora Thrust (NAT) and South Almora Thrust (SAT), in Kumaon Lesser Himalaya and exposes meso-grade metamorphic rocks of Almora Group (Undifferentiated Proterozoic). The rocks are quartzite, schist, phyllite, migmatite, gneiss and

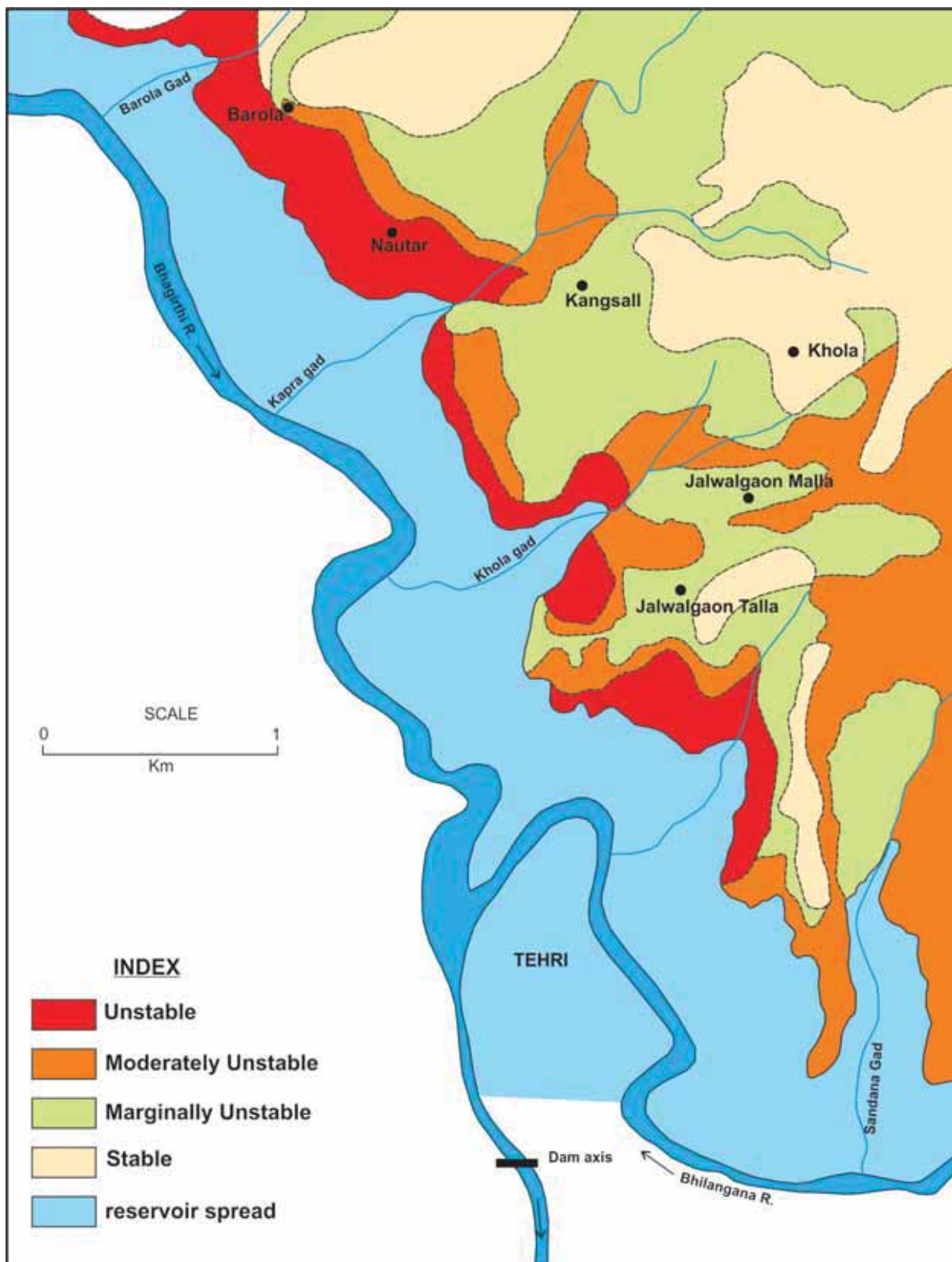


Fig. 3.6. Slope instability zones above HFL (El-835 m), in parts of Tehri dam reservoir rim around villages Kangsali, Khola and Jalwalgaon.

amphibolite. General trend of the rocks in the area varies from WNW – ESE to NNW – SSE, with northerly dips of bedding/foliation. North heading reverse fault, known as Bhimtal Formation in the southern vicinity of the area. The rocks in the area have undergone polyphase metamorphism which is possibly related to different periods of deformation. Bedrock is invariably overlain by shallow (<3 m) cover of weathered soil, derived from weathering of underlying bedrock. Khaki to deep brown coloured soil is semi-consolidated to loose in nature. Soil profile, most often, increases in the downslope areas, particularly in the fringing areas of the town.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer Section 2.1.4, Chapter 2). The study area was grouped into five classes of varying slope instability condition (Fig. 3.7). Out of the total 508 facets, about 65% of facets lie in low susceptible zone and only 5.5% together represent both high susceptible and very high susceptible zones. Most parts of the area in NE including twin towns of Ranikhet and Chaubattia lies in low to very low susceptible zones. The northern, northwestern, western and isolated patches in the southern part of the area fall under high susceptible zone. Very high susceptible zone lies in western and northwestern part, include area near Chinyanaula (slope failure is principally guided by valley facing joints, and has involved large part of the overlying loose debris) and near Kapina Village (deep gully erosion, entrenchment and failure along valley facing joints have caused several incidences of failure along 20°–25° inclined SSW facing slopes).

Between Chinyanaula and Biswa village, prominent high susceptible zones are recorded on SW facing slopes affecting weathered gneiss, schist and overburden material. Highest frequency of slides is encountered in this zone.

3.2.11 Landslide susceptibility mapping along Yamunotri Yatra route

Yamunotri shrine is located at the toe of Yamunotri glacier at an elevation of nearly 3,000 m above msl. The shrine is connected with Delhi by a 340 km long road, in which around 144 km long stretch falls under treacherous hilly terrain between Dak Pathar and Yamunotri, along the banks of Yamuna River. The route passes through parts of Dehradun, Tehri Garhwal and Uttarkashi districts of Uttaranchal and covers toposheets: 53F/14, 53J/1, 53J/2 and

53J/5. The landslide susceptibility mapping was carried out on scale 1:50,000, covering 288 km² area (144 km) during field season programme of 2000 and 2001 (Chandra, 2003).

Geologically a plethora of rock units are exposed along the Yatra route; these rock units are classified under Central Crystalline, Simla Group, Garhwal Group, Jaunsar Group and the younger most Siwalik Group, based on their geological age and lithological character. Main Central Thrust (MCT), North Almora Thrust (NAT) and Main Boundary Fault (MBF) are the major tectonic elements. MBF passing near Kalsi village separates rocks of Siwalik Group from those of Jaunsars, while the NAT separates the rocks of Garhwal Group and Simla Slates. The MCT, locally known as 'Wazri Thrust', separates the Central Crystalline rocks from the Garhwal Group.

The hilly tract of the Yamunotri yatra route between Dak Pathar and the Yamunotri varies widely in terms of geomorphology. Starting at 490 m elevation near Dak Pathar the route enters hills near Naro *Nadi* and passes through a rugged terrain of steep slopes, gorged deep valleys, serrated crest and generally angular peaks of mountainous country belonging to Lesser, Middle and Central Himalayas. The route ends at the Shrine itself, where it gains an altitude of 3,000 m. The main drainage across the route is represented by Yamuna River and its various tributaries. High ridges in the area are represented by Dhars (long ridges) running mostly on both the banks of Yamuna. Prominent among them are Banari, Pokhri and Kaneli Dhars running in NW-SE direction.

The landslide susceptibility map was prepared by adopting 'BIS approach' (refer Section 2.1.3, Chapter 2). A total of 137 landslide incidences have been mapped along Yamunotri pilgrimage route, out of which five each are noticed in Siwaliks and Mandhalis, 21 in Chandpur, 30 in Nagthats, 13 in Morar Chakrata formations, 16 in Simla Slates, 21 in Garhwal Group and 15 in Central Crystalline Group of rocks. 11 landslides were recorded in Recent deposits in the form of slumps. Majority of the slides are of debris type, followed by rock falls (18 slides), wedge failures (10 slides) and planar failures (10 slides). These occur mostly in slates, phyllites and quartzites of various litho units. Wedge failures occur mostly in quartzites. Table 3.5 gives brief details of 15 major landslides. Annexure-I provides an inventory of some of the major landslides.

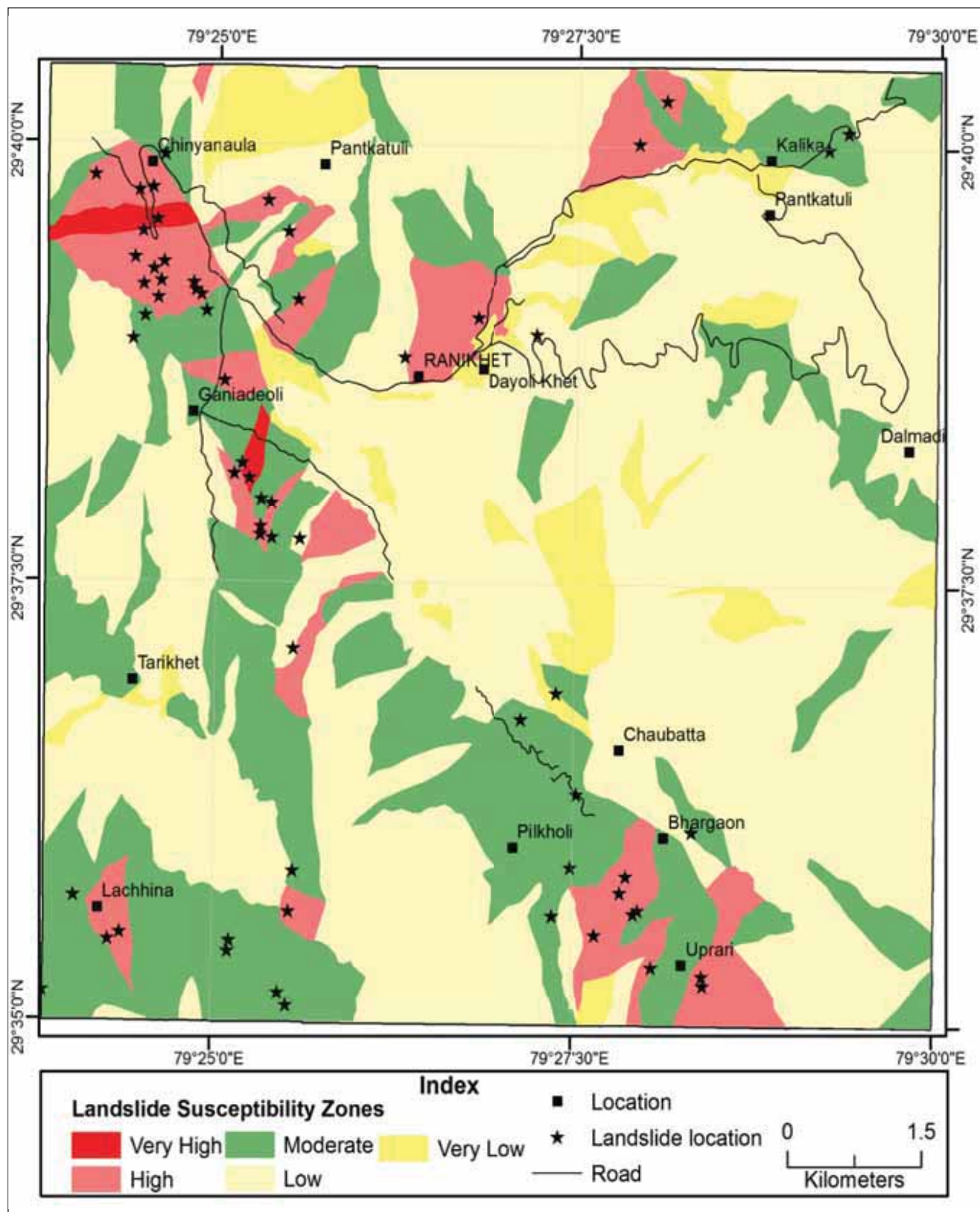


Fig 3.7. Landslide susceptibility map of Ranikhet area, Uttarakhand.

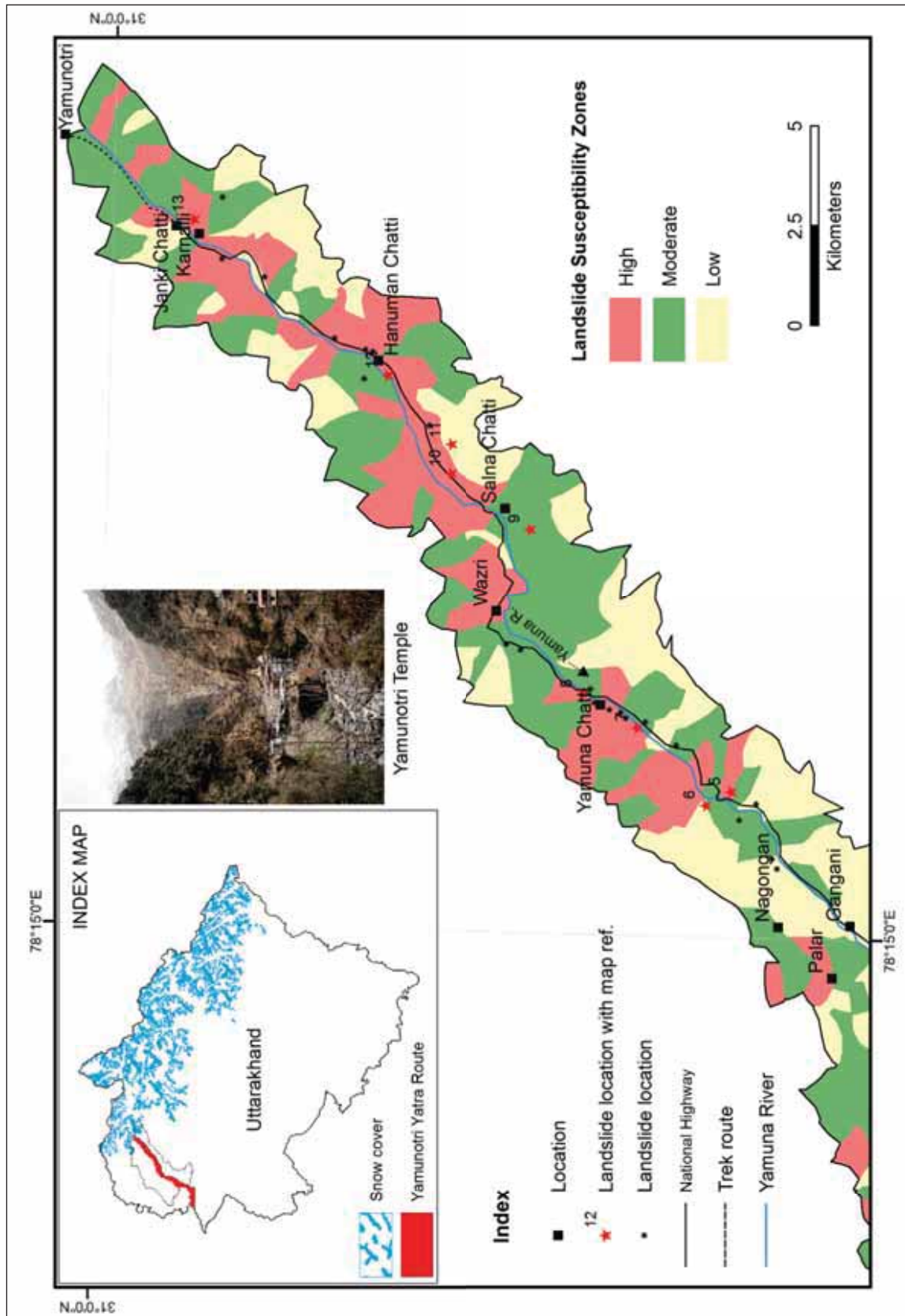


Fig. 3.8. Landslide susceptibility map of Yamunotri yatra route between Gangani and Yamunotri.

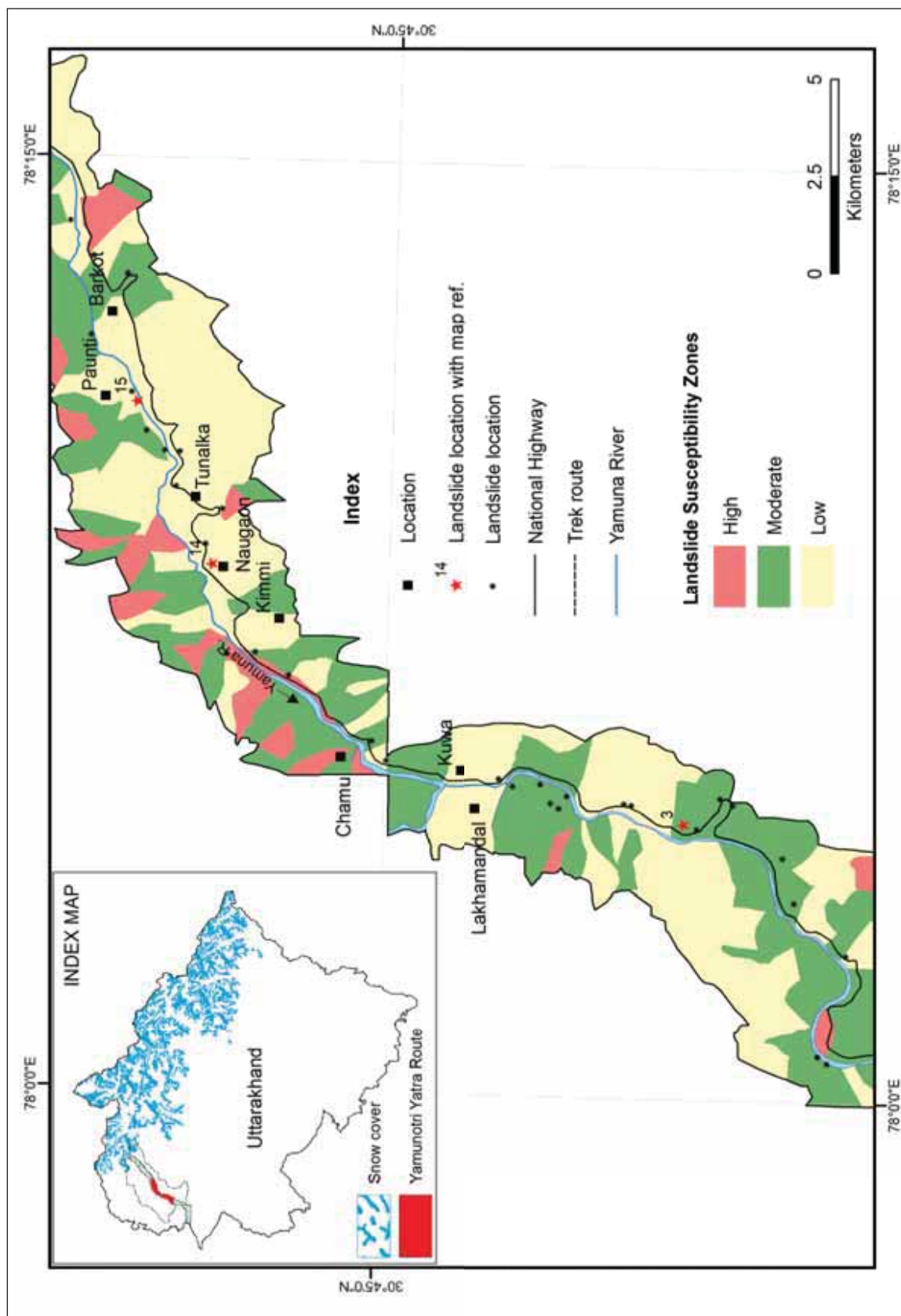


Fig. 3.9. Landslide susceptibility map of Yamunotri yatra route between south of Kuwa and Barkot.

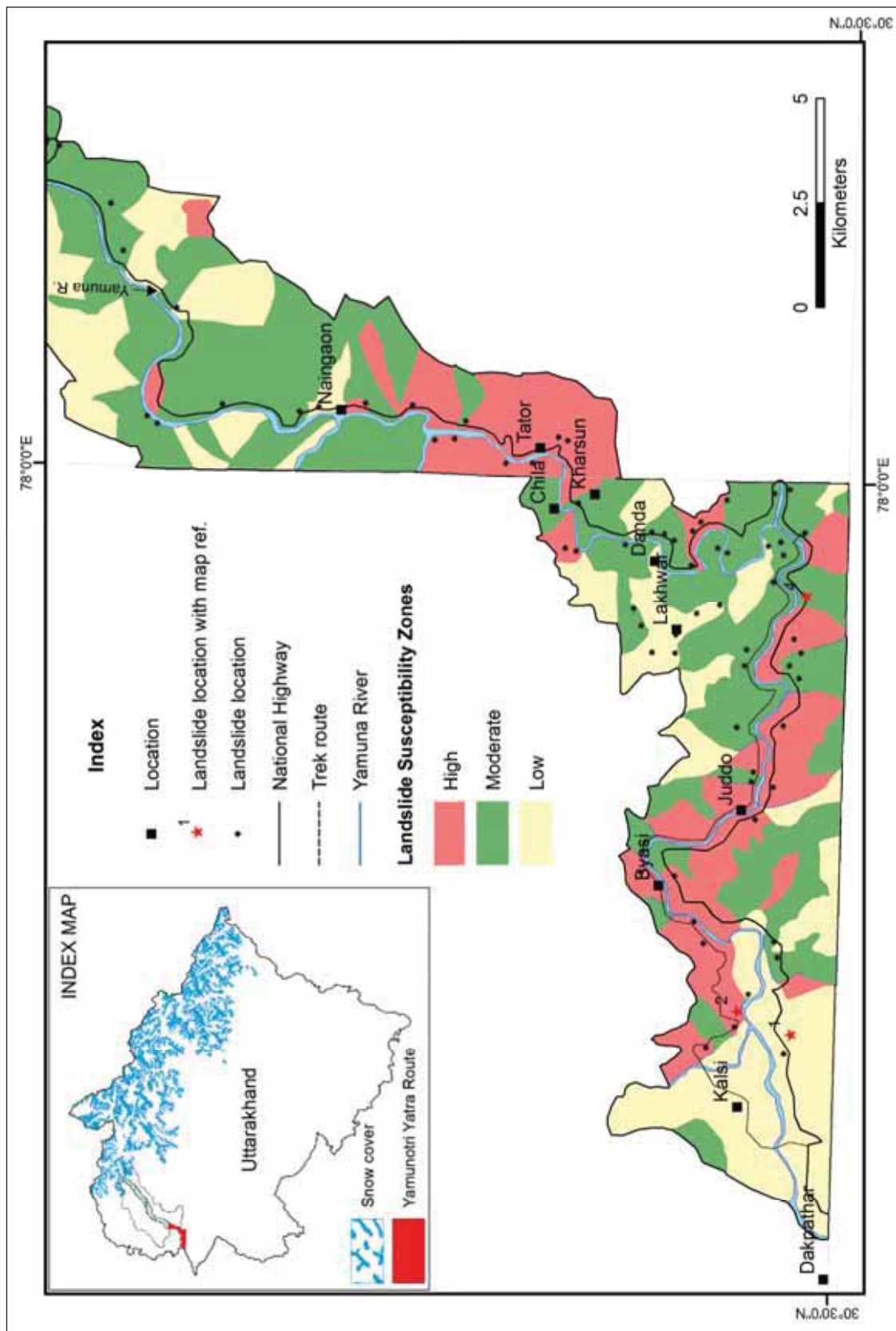


Fig. 3.10. Landslide susceptibility map of Yamunotri yatra route between Dakpathar and north of Naingaon.

Table 3.5. Inventory of major landslides along Yamunotri Yatra route.

Map Ref.	Morphometric characters of landslide	Landslide type	Geology
1.	80 m high and 150 m wide	Debris Slide	Sandstone of Lower Siwalik overlain by terrace material. Sliding has occurred in terrace material.
2.	140 m high and 150 m wide	Rock cum debris slide	Sandstone of Siwalik Group, quartzite of Mandhali Fm and Phyllite of Chandpur Fm. Main Boundary Fault passes through the slide.
3.	20 m high and 30 m wide	Wedge failure	Purple and grey quartzite of Morar-Chakrata Formation.
4.	30 m high and 20 m wide	Debris slide	Weathered quartzite of Nagthat Formation.
5.	30 m high and 80 m wide	Rock cum debris slide	Hard and jointed quartzite of Garhwal Group.
6.	80 m high and 100 m wide	Rock fall	Quartzite of Garhwal Group.
7.	25 m high and 20 m wide	Debris slide	Green phyllite and slates of Uttarkashi Formation (Garhwal Group).
8.	50 m high and 40 m wide	Wedge failure	Jointed quartzite of Nagnithak Formation (Garhwal Group).
9.	80 m high and 30 m wide	Debris slide	Weathered gneiss of Central Crystallines.
10.	150 m high and 250 m wide	Rock fall	Weathered gneiss of Central Crystallines.
11.	40 m high and 10 m wide	Rock cum debris slide	Weathered gneiss of Central Crystallines.
12.	40 m high and 30 m wide	Rock cum debris slide	Weathered gneiss of Central Crystallines.
13.	150 m high and 200 m wide	Rock fall	Hard gneiss of Central Crystallines.
14.	9 m high slump	Slump	Terrace material.
15.	30 m high and 30 m wide	Planar slide	Green phyllite of Simla Slates.

Map ref. is the slide number given in figs. 3.8, 3.9 and 3.10.

Figure 3.8, Figure 3.9 and Figure 3.10 show the landslide susceptibility map of parts of Yamunotri Yatra route, covering 288 km² area. The entire route between Dak Pathar and Yamunotri has been differentiated into 659 slope facets and based on TEHD values these are grouped in high, moderate and low susceptible zones. About 62 km² area falls in high susceptible, 123 km² in moderate susceptible and 107 km² area in low susceptible categories. The landslide zonation also indicates that rocks with maximum proneness to sliding belong to Chandpur Formation, Garhwal Formation and Central Crystallines consisting of jointed and weathered phyllite, gneiss, quartzite and Simla Slates. The High susceptible zones in these litho units occupy 20 km², 15 km² and 9 km² area, respectively. Near Khanera village, on left bank of Yamuna River, a huge debris slide (~80 m wide) was observed. In case of further movement, this slide

threatens blocking of River Yamuna and formation of an artificial lake.

3.2.12 Landslide susceptibility mapping along Tiuni-Harkidun road and trek route

Harkidun valley, known for its colourful flora, fauna and lush green alpine meadow is a popular destination for nature lovers. It is also an important route for trekkers and mountaineers. The road connecting Tiuni and Harkidun also hosts a number of minor and major landslides and subsidence; thereby causing immense damage to human settlements, bridges, roads, trekking route and cultivated land. The 175 km long stretch falls under treacherous hilly terrain between Tiuni and Harkidun, along the banks of Tons River. The route passes through parts of Dehradun and

Uttarkashi districts of Uttaranchal and covers toposheets: 53F/13, 53J/1, 53J/4 and 53I/8. The landslide susceptibility zonation work along this route was carried out on scale 1:50,000, covering 350 km² area (175 km) during field season programme of 2006 and 2007 (Kumar, 2008).

Geologically, a plethora of rock units are exposed along the route; these rock units are classified under Central Crystalline, Garhwal Group and Jaunsar Group. The litho-units encountered are mainly meta-sedimentaries comprising alternating bands of grey and pale green massive, current-bedded, friable, sericitic, jointed quartzite; mudstone/siltstone; grey-green phyllite and slate; stromatolitic limestone; massive, bedded limestone and dolomite; and numerous intrusive basic bodies. Litho-units belonging to Central Crystalline Group include quartz-mica schist, streaky gneiss, augen gneiss, porphyroblastic gneiss and tourmaline granite. The general trend of rocks in the area is NW-SE with moderate to high dips (30°-35°) in NE direction besides vertical at places. The 10-200m thick cobble/pebble/boulder deposits in the river bed along the valley are represented as valley fill deposits i.e. old terrace deposits. Prominent tectonic features encountered across the route are Main Central Thrust (MCT), Purola Thrust (PT) and Vaikrta Thrust (VT). Main Central Thrust delimits the southern boundary of the rocks of Crystalline Group and successively overlaps the Jaunsar Group.

Geomorphologically, the area exhibits highly dissected and rugged topography controlled by long ridges, deep and narrow valleys. The route starts at an elevation of 550 m and terminates at an elevation of 3,527 m at Harkidun. The main drainage is represented by Tons River and its tributaries such as Rupin Nadi and Supin Nadi. The river forms deep, narrow gorge and shows meandering at a number of places. Numerous small drainages cut through the mountainous terrain to join the various streams and tributaries to give rise to an overall dendritic pattern. The high ridges in the area are represented by dhars (long ridges) running on both the banks of Tons River. Prominent among them are Harkidun dhar, Gochatkhandha dhar, Chir dhar and Phasa dhar.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer section 2.1.4, Chapter 2). A total of 110 landslide incidences has been mapped between Tiuni and Harkidun, out of which 59

incidences are in the metasedimentary sequence of white massive sericitised quartzite, slate and grey and green phyllite of Jaunsar Group and 45 incidences in gneiss and quartz-mica schist of Purola Crystalline. Besides, six incidences occur due to terrace failure. Table 3.6 gives brief details of 12 major landslides. Annexure-I provides an inventory of some of the major landslides.

Fig 3.11 shows the landslide susceptibility map of Tiuni and Harkidun route, covering 355 km² area. The entire route between Tiuni and Harkidun has been differentiated into 641 slope facets and based on TEHD values these are grouped in very high, high, moderate, low and very low susceptible zones. About 2% area falls in very high susceptible class, whilst 34% falls in high susceptible. The moderate susceptible class covers 58% of the study area. Low and very low have the least distribution and cover only 6% area.

Some critical areas have been observed along the route at Miyan *gad*, Chibra *nala*, Phufraila *nala*, Halara *gad*, Purti *nala*, Giyan *gad*, Naitwar, Jhakol, Taluka, Dhatmir and Gangar localities due to occurrence of major slides. A major landslide incidence and development of badland have been observed at Naitwar Thatru market on the right bank of Tons River. The whole area of Thatru market of Naitwar including several villages has been affected. These are situated on agricultural terraces of different level at elevations between 1,500 m and 2,200 m. Slope failure has taken place in the form of debris slump movement which is manifested by development of transverse cracks in paddy fields on top, close to Gaichangoan and Deora villages; ground sinking up to 2 m at the crown, tilting of pine trees, tilting of cemented pillar and major cracks in houses (Fig. 3.12).

3.2.13 Landslide susceptibility mapping along Gangotri Yatra route

Gangotri where the river Ganges, the stream of life to northern India, touches the land for the first time is a highly picturesque pilgrimage site in Garhwal Himalaya. The main Shrine of Gangotri is located on the right bank of Bhagirathi River at a height of 3,042 m, above msl. The route leading to Gangotri and further to Goumukh, the birthplace of Ganga River, passes through parts of Uttarkashi district of Uttaranchal and covers toposheets: 53J/5, 53J/6, 53J/10, 53J/12, 53J/13, 53I/1, 53I/2, 53I/16 and 53N/1. The 100 km

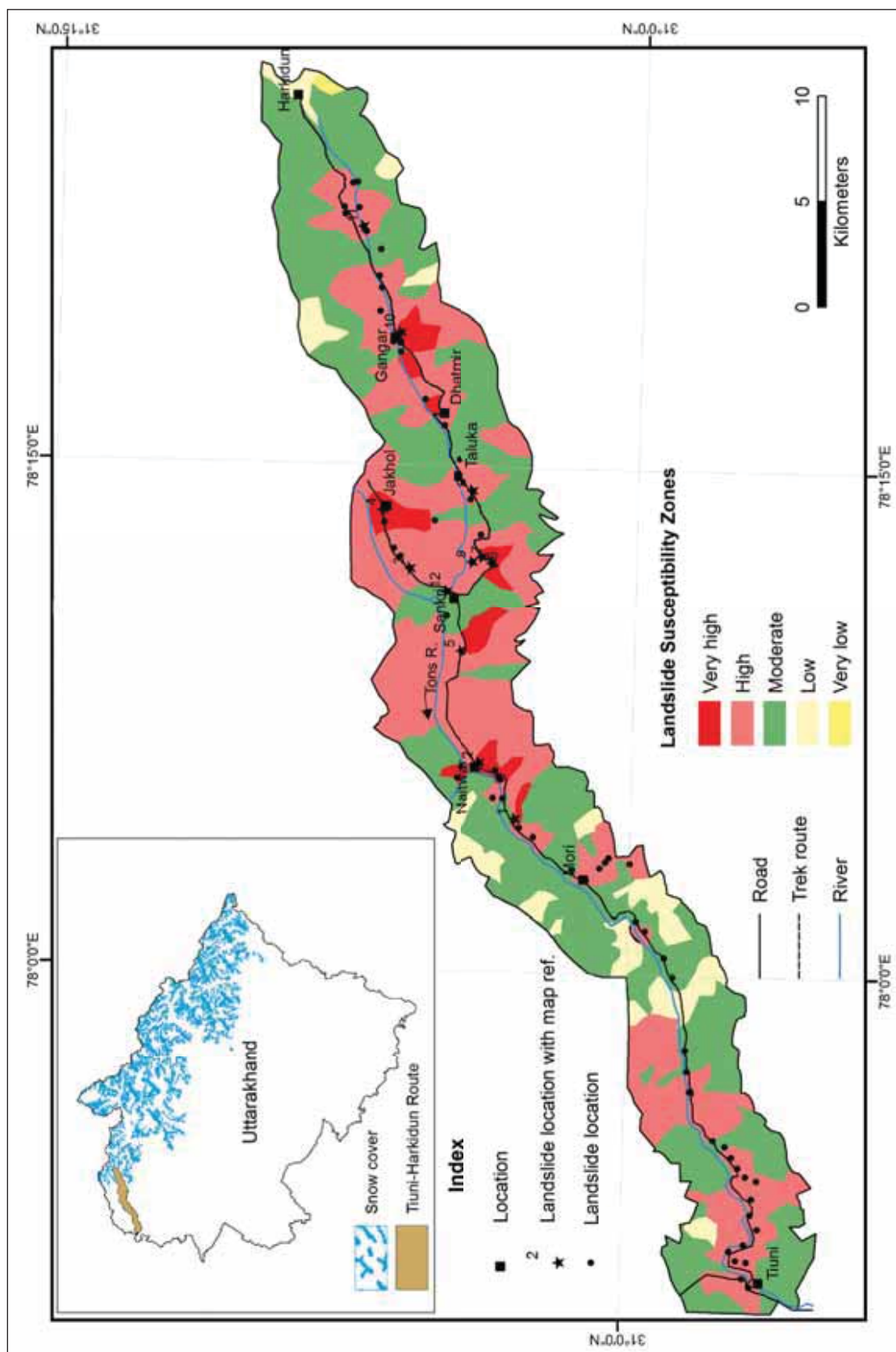


Fig. 3.11. Landslide susceptibility map of Tiuni-Harkidun route.



Fig. 3.12. Diagrammatic section showing landslide features with dip slope movement around Naitwar and adjacent village.

yatra route between Uttarakashi town and Gangotri is the National Highway road (NH-108). Further up to Goumukh, the yatra route is 18 km long mule trek. The road up to Gangotri is negotiated through steep slopes where landslides are a persistent hazard. The work on landslide susceptibility mapping of Gangotri yatra route was carried out on scale 1:50,000, covering 350 km² area (118 km) during field season programme of 2001 and 2002 (Bhatnagar, 2008).

Geologically, the yatra route forms part of Garhwal Himalaya represented by metamorphic rocks sequence of Central Crystalline and Garhwal Group of Proterozoic age. The rocks are generally covered with thin capping of slope wash debris, fluvial terraces sediments and glacial moraines and glacio-fluvial sediments in trek section of Uttarakashi to Gangotri. The Main Central Thrust (MCT) is the major tectonic element in the area. The MCT separates the Central Crystalline and the Garhwal Group of rocks, across the yatra route south of Bhatwari, trending roughly NNW-SSE with steep easterly dips.

The yatra route corridor area is represented by parts of Central Garhwal Himalaya along Bhagirathi River system and its tributaries having deep dissected rugged topography with a relief fall of about 3,500 m from Goumukh to Uttarkashi town. The topography is generally represented by strike and structurally controlled ridges having general trend of N-S to NW-SE. The ridges, at places due to degradational activities of glacial and avalanche loads, are transformed into knife-edged ridges with very steep to sub-vertical scarps. V-shaped valley and deep gorges have developed at places. At higher elevation where valley is U-shaped, both lateral and transverse glacial moraines occur on banks of

drainage lines, whereas at lower elevation, due to fluvial activity and reworking of sediments, small isolated terraces have developed.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer Section 2.1.2, Chapter 2). A total of 42 landslide incidences has been mapped along Gangotri pilgrimage route, out of which 29 incidences occur in Garhwal Group and 13 in Central Crystalline. Majority of the slides (15 slides) are of debris type, followed by rock cum debris slides (5 slides) and rock slide (3 slides).

Fig. 3.13 shows the landslide susceptibility map of Gangotri Yatra route, covering 350 km² area. The entire route between Uttarakashi and Gangotri has been differentiated into 338 slope facets and based on failure probability values these are grouped in High, Moderate and Low susceptible zones. About 4% corridor area falls in high susceptible, 9% in moderate susceptible and 87% in low susceptible categories. The high susceptible slopes are located north of Uttarakashi town covering Varunavat Parwat, around Maneri and north of Gangnani.

3.2.14 Landslide susceptibility mapping along Badrinath and Kedarnath Yatra routes

Badrinath and Kedarnath are most revered Hindu shrines of Northern India and attract lakhs of pilgrim between May and October when shrines and route are clear of snow. The Badrinath Temple is situated at an elevation of 3,113 m in the lap of Nar Narayan Parvat with the Neelkanth peak (6,597 m) in the background. It has been said that "there are many sacred spots of pilgrimage on the earth but none is

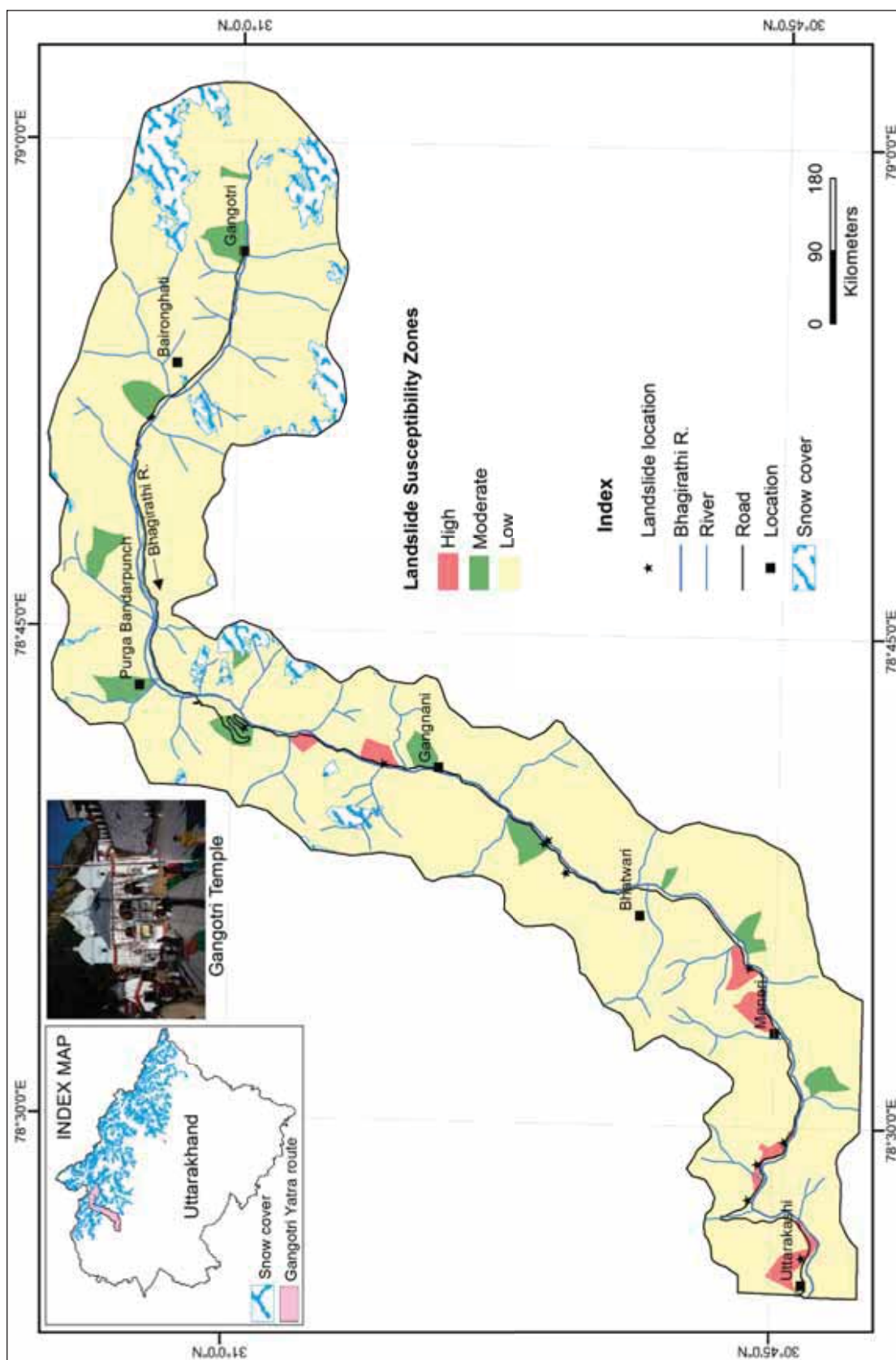


Fig. 3.13. Landslide susceptibility map of Gangotri Yatra route between Uttarakashi and Gangotri.

equal to Badrinath”. Legend dates the temple prior to Vedic age, though the present temple is believed to have been established by Adi Shankaracharya. The Badrinath pilgrim route, one of the hazardous mountainous routes, is approached by National Highway 58 up to the Shrine, which is 290 km from Devprayag.

The Kedarnath shrine, one of the 12 Jyotirlingas of Lord Shiva, situated against the backdrop of the majestic Kedarnath range, at an elevation of 3,581 m above sea level near Chorabari Glacier, the head of river Mandakini. The town is located in the middle of a wide outwash plain, surrounded by lofty snow-covered peaks. The Kedarnath

pilgrim route, one of the hazardous mountainous trek routes, is approached by National Highway 109 up to Gaurikund, which is 68 km from Rudraprayag. Further upslope the Shrine is connected by a 17 km trek route. This trek route was completely washed away due to landslides/floods in 2013. At present, a new trek route is being constructed with a different alignment.

The Badrinath and Kedarnath yatra routes pass through parts of Tehri and Pauri Garhwal, Rudraprayag and Chamoli districts of Uttaranchal and cover toposheets: 53J/12, 53J/14, 53J/15, 53J/16, 53N/2, 53N/3, 53N/6, 53N/7, 53N/10 and 53N/11.

Table 3.6. Inventory of major landslides along Tiuni-Harkidun route.

Map Ref.	Dimension		Type of slide	Causative factors and temporary remedial measures
	Width (m)	Height (m)		
1.	800	20-40	Debris slide	Failure of old terrace deposits of thick soil with boulders. Remove the loose falling material & retaining walls along the failure surface at road level were suggested.
2.	900	200	Debris slide	Caused due to extensive weathering and saturation of material. Remove the loose saturated and overhang material were suggested.
3.	75-100	40	Rock slide	Caused due to toe cutting material has moved along joints plane with overburden. Remove the loose falling and overhang material.
4.	150	150-500	Debris fall	Due to high saturation, about 2 km stretch is very prone to this type of slump movement. 2-4 m high retaining wall is required along road.
5.	1000	20-500	Rock cum debris slide	Debris flows due to lateral cutting along three <i>Nalas</i> . Retaining/Breast wall on the failure surface at the toe, lined drainage along roadside and lateral side of <i>Nala</i> for proper runoff of surface water were suggested.
6.	900	1200-1500	Rock cum debris slide	Activation of slide due to toe erosion during high flood of Phufraila and adjacent <i>Nala</i> . Retaining/Breast wall on the failure surface and wire mesh support on <i>Nala</i> to protect boulder movement were suggested.
7.	100	400	Debris slide	do
8.	200	150	Debris slide	Main road/Trekking route got damaged. Flattening of high angle slope, removal of loose slide material, retaining/Breast wall on the failure surface were suggested.
9.	1000-1200	100-200	Debris slide	Main Trekking route/road and concrete masonry bridge damaged. Removal of loose slide material, retaining/Breast wall along the failure surface at road level were suggested.
10.	800-1000	100-150	Debris slide	Main Trekking route got damaged. Retaining/Breast wall on the failure surface at road level was suggested.
11.	500-600	150-200	Debris fall	Retaining wall along the failure surface at road level has already provided.
12.	300-500	50-100	Debris fall	Caused due to slope cutting for road widening. Removal of loose slide material lying on road, retaining wall along the failure surface at road level were suggested.

Map ref. is the slide number given in fig. 3.11.

The work on landslide susceptibility zonation mapping for Badrinath and Kedarnath yatra routes was carried out on scale 1:50,000, covering 750 km² area (424 km) during field season programme of 1999 and 2001 (Bhatnagar, 2008). The road from Deoprayag to Badrinath; Rudraprayag to Kedarnath and Chamoli to Kund was covered.

Geologically, the yatra route forms part of Garhwal Himalaya represented by metamorphic rocks sequence of Central Crystalline, Garhwal Group and Chandpur Formation of Proterozoic age. The rocks are generally covered with thin capping of slope wash debris, fluvial terraces sediments and glacial moraines and glacio-fluvial sediments in trek section leading to Kedarnath. The Central Crystalline Group occurs in northern and eastern parts whereas Garhwal Group in central and southern parts and Chandpur Formation in the western part of the pilgrimage route corridor area. They are separated by two major tectonic elements of Garhwal region i.e., Main Central Thrust (MCT) and North Almora Thrust (NAT). Both these thrusts have roughly NW-SE trend with steep north-easterly and south-westerly dips, respectively. The MCT separates the Central Crystalline and the Garhwal Group of rocks, across the yatra route near Okhimath in Mandakini valley and about 1.5 km NE of Tangni in Alaknanda valley.

The Badrinath and Kedarnath yatra routes traverse through the Lesser and the Central Garhwal Himalayas, following the Alaknanda and Mandakini rivers, respectively. It exhibits deep, dissected, rugged topography having mountains with many cliffs and scarp faces consisting of very steep to moderate slopes along with glacio-fluvial and fluvial sub-horizontal terraces along the major drainage of the area. The area has rugged peaks with 'V' and 'U' shaped valleys. Majority of ridges are structurally controlled longitudinal strike ridges with intermittent valleys.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer section 2.1.2, Chapter 2). A total of 89 landslide incidences has been mapped along Kedarnath and Badrinath pilgrimage route, out of which 34 incidences occur in Central Crystalline, 48 in Garhwal Group and seven in Chandpur Formation. Majority of the slides (32 slides) are of rock cum debris slide type, followed by debris slide (26 slides), rock slide (15 slides) and 16 are bank failures.

Fig. 3.14 shows the landslide susceptibility map of Kedarnath and Badrinath Yatra route, covering 750 km² area. The entire route has been differentiated into 1,044 slope facets, out of which 409 occur in Central Crystalline, 505 in Garhwal Group and 130 in Chandpur Formation. Based on failure probability values these are grouped in high, moderate and low susceptible zones. About 8.4% corridor area falls in high susceptible, 16.4% in moderate susceptible and 75.2% in low susceptible categories. In Kedarnath route, the settlement area of Rambara is grouped under high susceptible zone. Other significant high susceptible zones are located north of Okhimath and Baraso area. The Joshimath town along Badrinath route is grouped under moderate susceptible class. Prominent high zones are located around Tagni, Pakhi and Gopeshwar area.

The landslide susceptible zones represent a generalized picture of slope stability conditions of the land use and other thematic condition at the time of mapping. Under the influence of natural or man-made changes, further alterations or modifications in the zonal boundaries, dimension and the vulnerability cannot be ruled out. The high susceptible zones should be considered for immediate mitigation measures for safeguard of the road network. For erecting any civil structure in high or moderate susceptible zones, site-specific landslide studies are recommended.

3.2.15 Landslide susceptibility mapping along Kailash-Mansarovar Yatra route

The mountainous terrain of Kailash-Mansarovar pilgrim route is beset with the problems of landslides. The pilgrim route, one of the highest pilgrimage sections in the world, is approachable by all-weather road up to Mangti. Beyond Mangti up to Lipu Lekh (EL 5,334 m) it is a 75 km foot trek traversing high altitude, hazardous section of Himalaya in Indian territory. The route beyond Lipu Lekh up to holy Mansarovar (EL 4,550 m) is under control of People's Republic of China. The last metalled road point to Mangti site is approachable either via Tanakpur or Almora. The distance between Tanakpur-Jauljibi-Mangti is 300 km, whereas that between Bhowali-Almora-Didihat is 303 km. The route via Tanakpur is most preferred by pilgrims.

A number of landslide prone zones occur along this yatra route, particularly between Askot and Lipu Lekh, which include the catastrophic landslide at Malpa in August 1998

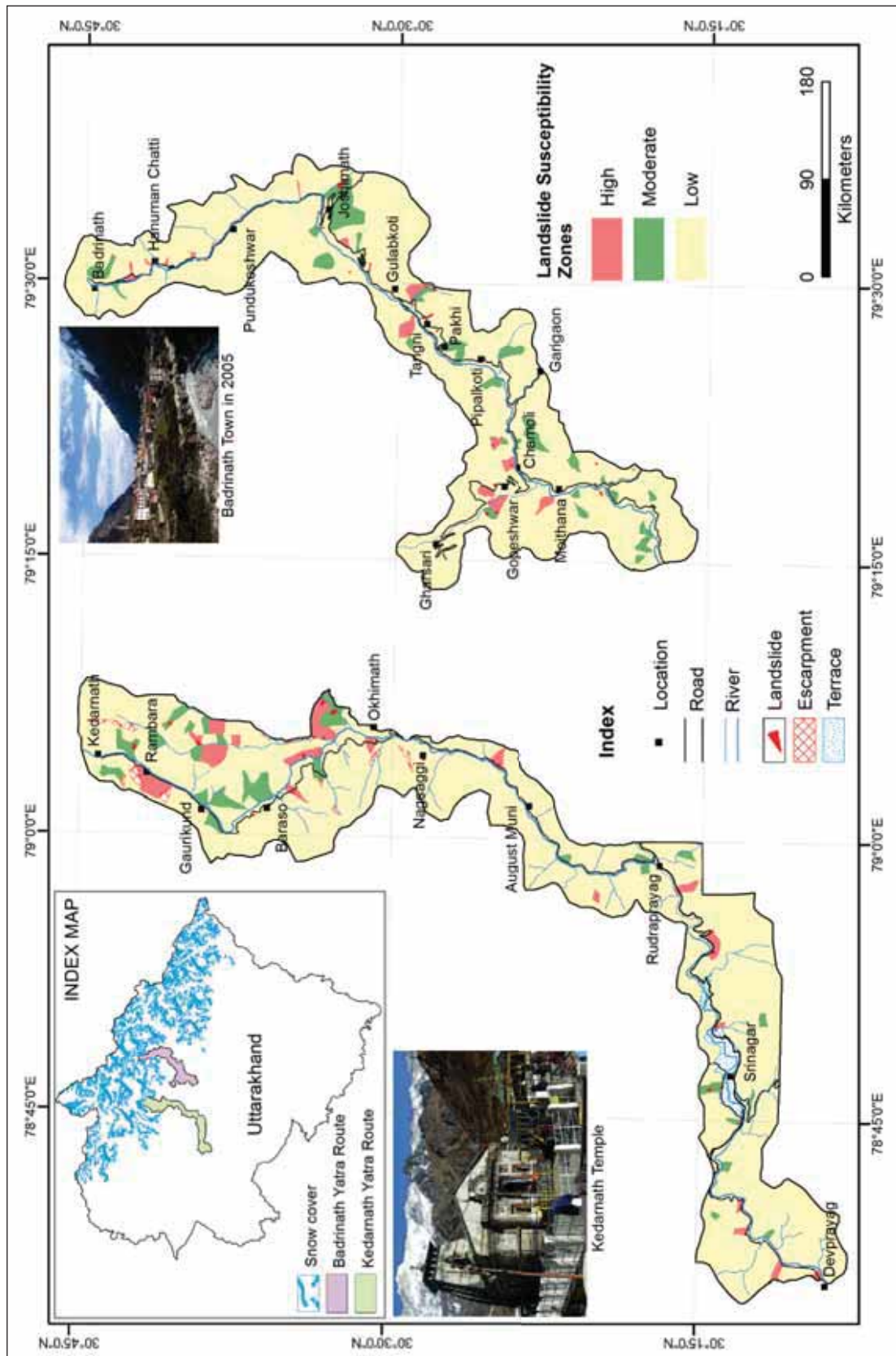


Fig. 3.14. Landslide susceptibility map of parts of Kedarnath and Badrinath Yatra routes.

killing over 200 people including 60 pilgrims. Rock fall near Tintola village also took lives of eight people in 1999. In August 2001, the same landslide killed three more people. The high altitude areas along this route are also prone to snow avalanches. Seismically, the route passes through the seismic zone IV and V. The area experienced two major earthquakes: Dharchula Earthquake of 29th July 1980 (M=6.1) and Indo-Nepal Earthquake of 5th January 1997 (M=5.5).

The Kailash-Mansarovar yatra route passes through parts of Nainital, Almora, Bageshwar and Pithoragarh districts of Uttaranchal and cover toposheets: 62C/2, 62C/3, 62C/4, 62C/5, 62C/6, 62C/9, 62B/12, 62B/15 and 62B/16 (between Tanakpur and Lipu Lekh via Pithoragarh); and 53O/6, 53O/7, 53O/9, 53O/10, 53O/11, 53O/13, 53O/14, 62C/1 and 62C/5 (between Bhowali and Didihat via Bageshwar). The work on landslide susceptibility mapping for Tanakpur and Pithoragarh route was carried out on scale 1:25,000 (toposheets: 62C/4NW, 62C/3SW, 62C/3NW and 62C/2SE), covering 370 km² area (185 km) during field season programme of 1999 and 2000 (Sharma, 2000). The work between Pithoragarh and Lipu Lekh was carried out on scale 1:50,000, covering 380 km² area (190 km) during field season programme of 2000 and 2001 (Sharma and Jaiswal, 2004a), and between Bhowali and Didihat, for 606 km² area (303 km), was covered during field season programme of 2001 and 2002 (Sharma and Jaiswal, 2004b).

Between Bhowali and Didihat, the yatra route exposes metavolcanics and quartzite of Bhimtal Formation; gneiss with bands of pink quartzite of Ramgarh Group; garnetiferous mica schists, slate, phyllite, quartzite and granite of Almora Crystalline Group; limestone/dolomite of Pithoragarh Formation and gneiss, schists and quartzite of Askot and Baijnath Crystallines. Between Tanakpur and Pithoragarh, sandstone, shale of Siwalik Group is exposed up to Sukhidang, and further north quartzite, schists and metavolcanics of Bhimtal Formation occur sandwiched between Main Boundary Fault (MBF) and Ramgarh Thrust (RT). The rocks in the proximity of the thrust is sheared and at places pulverised. Towards north, between Ramgarh Thrust and South Almora Thrust (SAT), phyllite, gneiss and quartzite of Ramgarh Group is exposed. Further north these are followed by Almora Crystalline Group. From

Pithoragarh to Ogla, the Yatra route traverses across the quartzite and phyllite of the Garhwal Group. This part also exposes thick alluvium deposits. Between Ogla and Askot, granite and granite gneiss of Askot Crystalline occur within thrust boundary. Further north up to Tapoban, the yatra route exposes the Garhwal Group of rocks (quartzite with metavolcanics, alternate phyllite, slate, limestone). The Main Central Thrust separates the Garhwal Group with the Central Crystalline just north of Tapovan. The rocks of the Central Crystalline i.e., quartzite, biotite gneiss and mica schist occur along the route up to Budhi where it has a thrust contact with the Tethyan Sedimentary sequence of shale, silt, quartzite, limestone, dolomite rocks. A pile of Quaternary deposits occurs in the form of fluvial terraces, fluvio-glacial and glacial deposits. A veneer of regolith, soil, debris/talus deposits also occurs in the area.

Geomorphological, the route in general exhibits rugged ridge and valley topography. 'V' and 'U' shaped valleys are the dominating physiographic features. Majority of the ridges are structurally controlled. The Birchuakot Dhar ridge trending NW-SE forms water divide between Kosi River and Gomti-Sarju river system in Almora area. Between Tanakpur and Lipu Lekh, the area forms part of Kali River catchment. River Kali nearly demarcates the Indo-Nepal Border. Between Tawaghat and Malpa, the River Kali flows in a narrow gorge; however, the valley opens up after Lamari and exhibits 'U' shaped profile. The upper reaches of the basin represent glacial landscape strewn with lakes, morainic ridges and other typical glacial landforms.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer Section 2.1.2, Chapter 2). For Bhowali-Bageshwar-Didihat, and Tanakpur-Pithoragarh sector, in order to demarcate landslide susceptible zones, the obtained probability values are grouped as follows

- i. Probability > 50% - High susceptible zone
- ii. Probability > 20%-50% - Moderate susceptible zone
- iii. Probability = 20% - Low susceptible zone

For Pithoragarh-Lipu Lekh sector, the following probability values are considered in order to demarcate the landslide susceptible zones -

- I. Probability = 80% - Very High susceptible zone
- ii. Probability > 50%-79% - High susceptible zone
- iii. Probability > 20%-50% - Moderate susceptible zone
- iv. Probability = 20% - Low susceptible zone

A total of 404 landslide incidences has been mapped along the Kailash-Mansarovar Yatra route, out of which a detailed inventory of 130 landslides has been prepared by incorporating the slide location, slide morphometry, slide type, slope, land use, cause, remarks, etc. Table 3.7 gives brief details of 21 major landslides. Fig. 3.15 shows field photographs of some of the important landslides. Along Bhowali-Bageshwar-Didihat sector, out of 218 landslides, 61% are rock slides, 29% are debris slides and 10% are of mixed type. Along Tanakpur-Lipu Lekh sector, out of 186 landslides, 72% are rock slides and 28% are debris slides. Annexure-I provides an inventory of some of the major landslides.

Fig. 3.16, 3.17 and 3.18 show the landslide susceptible map of Kailash-Mansarovar Yatra route, covering 1,356 km² area (678 km). The entire route has been differentiated into 2326 slope facets, out of which 41 occur in Siwalik Group, 184 in Bhimtal Formation, 120 in Ramgarh Group, 609 in Almora Crystalline, 813 in Garhwal Group, 78 in Baijnath Crystalline, 118 in Askot Crystalline, 236 in Central Crystalline and 127 in Tethyan sedimentaries. Based on failure probability values these are grouped in very high, high, moderate and low susceptible zones.

Along Bhowali-Bageshwar-Didihat sector (Fig. 3.16), about 3% corridor area falls in high susceptible, 14% in moderate susceptible and 83% in low susceptible categories. This corridor route encompasses important cultural heritage site such as Jageshwar and Baijnath temple complexes and Stone Age Lakhudiyar rock shelter. Though the temple complexes fall within low landslide susceptible zones, the site of rock cave paintings is at risk on account of rock fall/block dislodgement of projected rock ledges at the ceiling of the cave. It is suggested that protruded rock-mass needs to be supported by construction of columns; opening of joints at top is to be sealed and drainage is to be improved to control the ingress of water to protect the paintings in the rock shelter.

Along Tanakpur-Pithoragarh sector (Fig. 3.17), prominent high susceptible zones are identified between km

17 and km 20; near Sukhidang and near Chalthi, along left bank of river Ladhiya.

Along Pithoragarh-Lipu Lekh sector (Fig. 3.18), about 4% corridor area falls in very high susceptible, 16% in high hazard, 17% in moderate susceptible and 63% in low susceptible categories. The scatter of landslide prone zones along this route indicates seven prominent hazardous areas, viz. (i) Raungti *gad* slide zone, (ii) 200 m slide zone near Tintola, about 5.2 km north of Tawaghat, (iii) slide zone between km 6.5 and 6.7, north of Tawaghat, (iv) 400 m slide zone near Ghatiyabagar, (v) 8 km zone of rock fall between Dharajipti and Malpa, (vi) morainic slides near Lamari and (vii) Garbhayag subsidence. Yatra camping sites at Budhi and Kalapani fall within these identified landslide-prone zones and need to be shifted in low prone areas.

3.3 Mesoscale landslide susceptibility mapping

3.3.1 Joshimath Town, Garhwal Himalaya

Landslides are very common features in the fragile environment of the Joshimath area, Chamoli district, Uttarakhand. Most often they are triggered by rains on the slopes which are modified by anthropogenic activities such as construction of road, buildings and unsystematic use of blasting practices during clearing of the blockages along the roads and construction of new roads. Building of new hydroelectric projects in the area also contributes in destabilising the slopes.

The landslide susceptibility mapping of a 25 km² area of Joshimath Town and its environs was carried out in mesoscale on 1:10,000 scale (toposheet: 53N/10). The work was carried out during field season programme of 2007 and 2008 (Kumar, 2010).

Geologically, the area is occupied by Helang and Joshimath formations of the Central Crystalline Group, and older compacted colluvial material representing Alluvium. The main rocks exposed in the area are gneisses, quartzite and schist. The general trend is NW-SE to NE-SW with moderate dip varying from 40°-60° northerly. The major tectonic plane i.e., Vaikrita Thrust separates the rocks of Joshimath Formation and Helang Formation. Two set of faults trending NW-SE and NE-SW and three phases of folding have been observed.

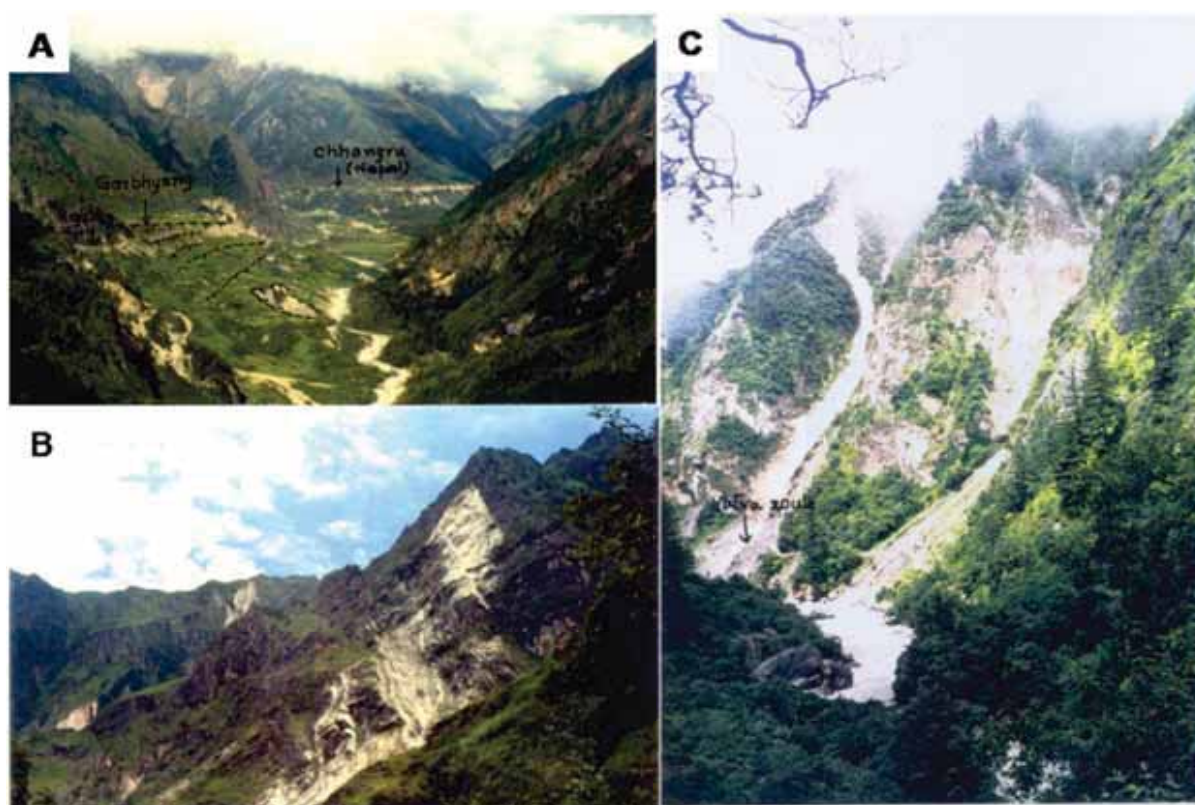


Figure 3.15 Major landslides along Mangti-Lipu Lekh yatra route: (A) subsidence on glaciolacustrine deposits (varved clay) at (Length=500 m; Height=200 m, slide no. 6 in Table 3.7); (B) rock fall caused due to adverse geological structures and pore water pressure at Malpa Length=300 m; Height=200 m, slide no. 10 in Table 3.7); and (C) debris slide (morainic material) at Lamari (Length=30 m; Height=75 m, slide no. 9 in Table 3.7) caused due to toe erosion by River Kali.

The landslide susceptibility map was prepared by adopting 'SMR based method' (refer Section 2.2.1, Chapter 2). All major landslides of the area were mapped. Annexure-I provides an inventory of some of the major landslides. Using SMR based method, the study area was grouped into five classes of varying landslide susceptibility condition (Fig. 3.19). The area has been divided into 369 slope facets of which 90% are confined on bedrock and 10% on overburden. The landslide susceptibility indicates that out of 369 facets, 10 facets (2.7%) fall under high susceptibility, 34 facets (9.2%) under moderate susceptibility, 305 facets (82.7%) under low susceptibility and the remaining 20 facets (5.4%) fall in very low susceptibility category. The high susceptible zones are mainly along major *nalas* (viz., Oucha, AT; due to gully erosion disturbing hill slope stability) and near Vishnuprayag (due to road cutting and toe erosion by Alaknanda River).

In the high susceptible zones, restrictions on

developmental work and discouraging the construction work on distressed slopes may be seriously considered especially near Raigaon, Auli and Marwari areas. The hydroelectric power projects, viz., Vishnuprayag Hydroelectric Project in the area contribute to the instability of slopes as it is observed that the slopes of Chui village adjacent to the power project are being adversely affected by the ground vibrations generated by the power plant, thereby disturbing the stability of the slopes.

3.3.2 Nainital Town, Kumaon Himalaya

During one and a half century of the recorded history, Nainital town has experienced a number of landslides, debris flow, avalanches and rock falls. The instability of the adjoining slope of the hills has always remained a source of anxiety to the inhabitants and the Government. RD Oldham (1880) was the first geologist of Geological Survey of India to investigate into the causes of failures of the slopes in the

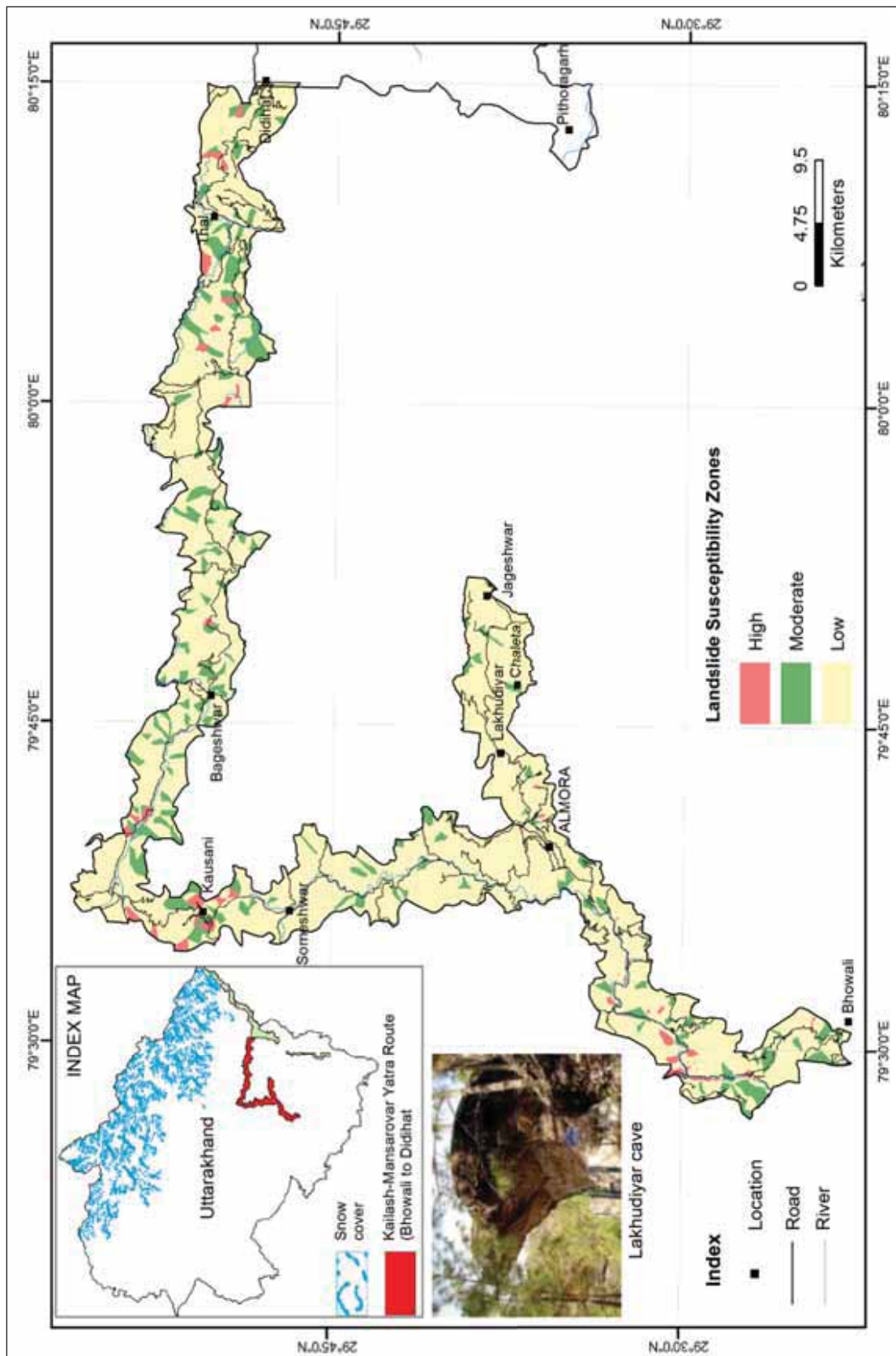


Fig. 3.16. Landslide susceptibility map of Kailash-Mansarovar Yatra route between Bhowali and Didihat.

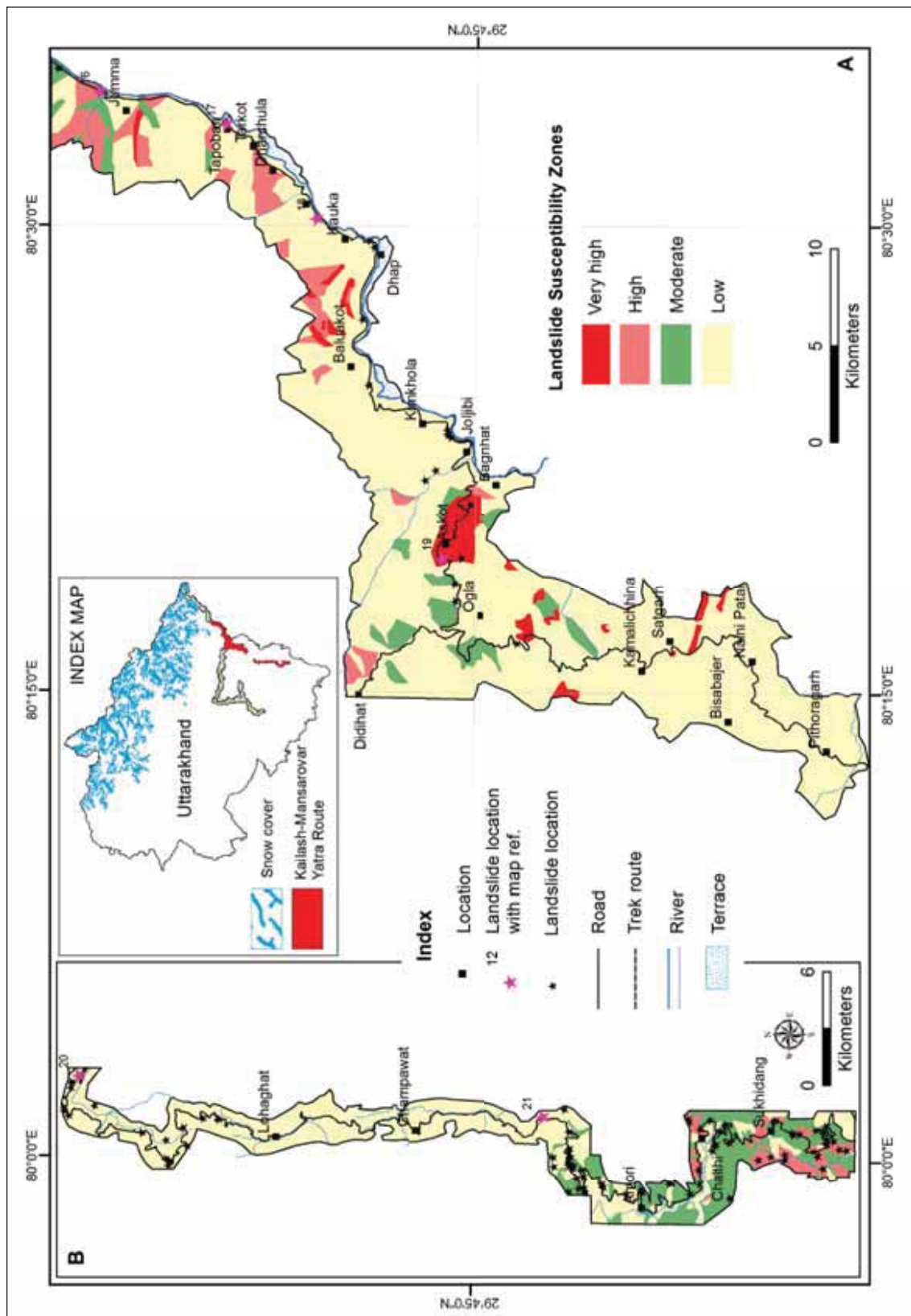


Fig. 3.17. Landslide susceptibility map of Kailash-Mansarovar Yatra route along Tanakpur-Pithoragarh sector (A) and Sukhidang-Lohaghat sector (B).

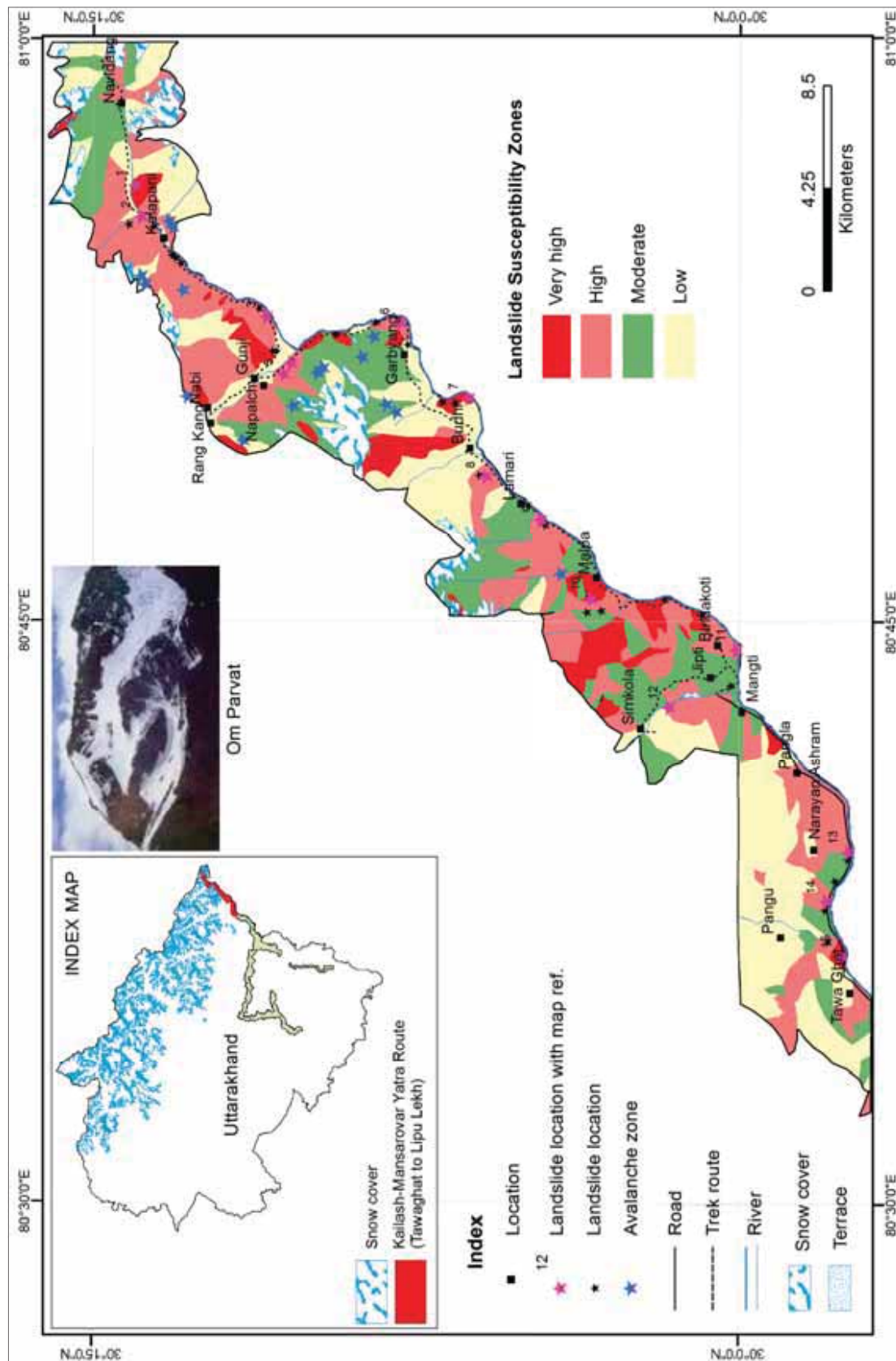


Fig. 3.18. Landslide susceptibility map of Kailash-Mansarovar Yatra route between Tawaghat and Lipu Lekh.

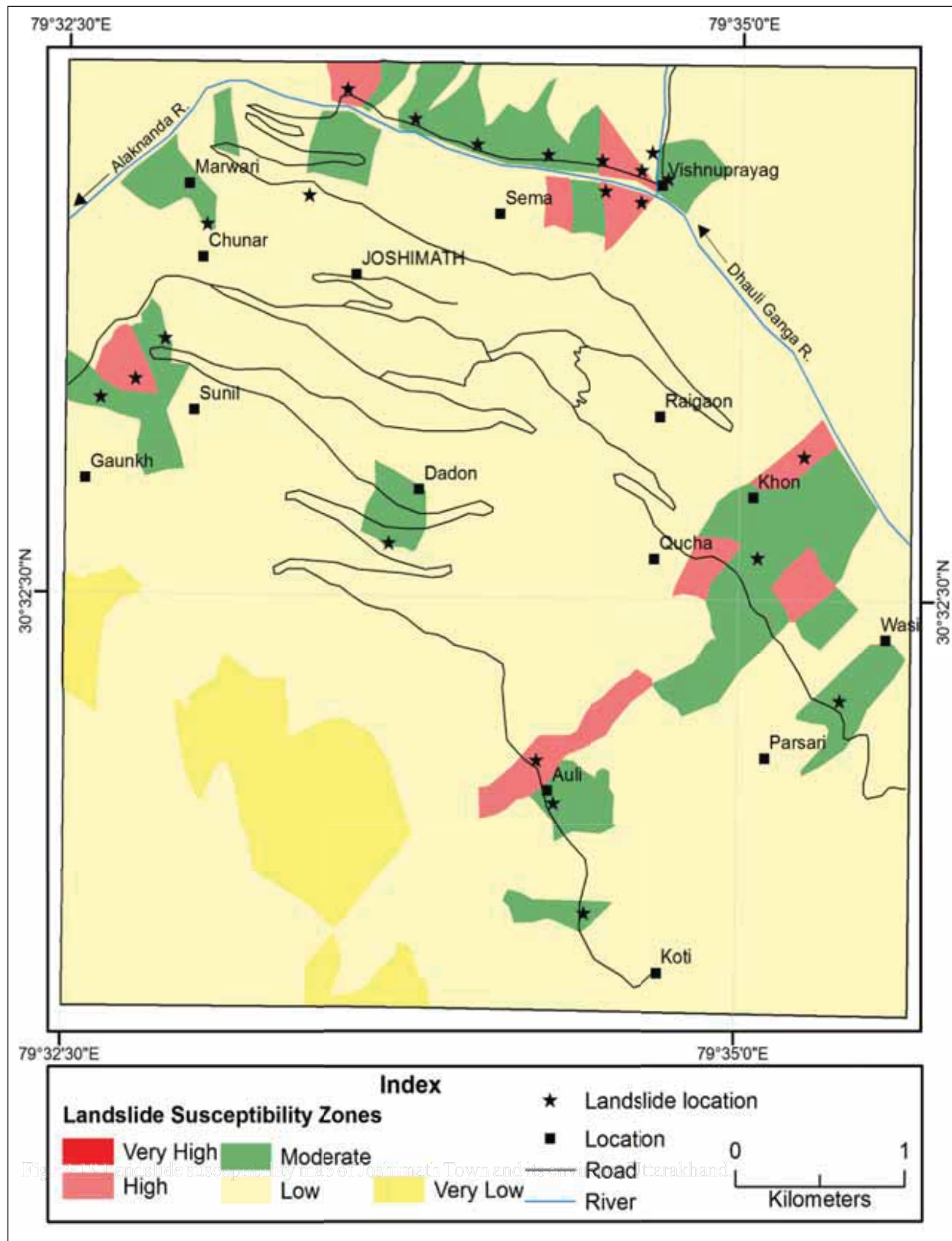


Fig. 3.19. Landslide susceptibility map of Joshimath Town and its environs, Uttarakhand.

Nainital valley. Subsequently, it was studied by other workers from GSI such as Middlemiss (1890), Greisback (1895), Holland (1897), Coulson (1928), Auden (1942), etc.

During mid-1990s, GSI again studied the Nainital valley with an aim to evaluate the geological environment of hill slopes with reference to the topographical setting and urbanisation and preparation of a detailed geological map on 1:5,000 scale, using Survey of India toposheet as the base map. Landslide susceptibility mapping of 10 km² area, on scale 1:5,000, surrounding Nainital town in toposheets 53O/7, was carried out during field season programme of 1993 and 1995 (Sharma, 1998).

Nainital town, a popular hill resort of Kumaon Himalaya, is developed around a 1.4 km long and 0.45 to 0.25 km wide lake extending in NW-SE direction and having a maximum depth of about 27 m. It is bounded by two hill ridges: Sher ka danda (2401 m) in the east and Ayarpatha-Deopatha (2329 m) in the west.

The Nainital area, situated at the southeastern extremity of Krol belt in Himalayas, has a complex geological set-up. The Lower Krol Formation is represented by thinly bedded, sheared variegated slates/shales, marls with subordinate bands and lenses of limestone in the eastern and north-eastern parts of Nainital. The western, south-western and southern parts peripheral to the lake are occupied by limestone/dolomite and red shale/slate of Upper and Middle Krol formations and slates and phyllites of Tal Formation. The Balia *nala* is occupied by dolomite/limestone, slates, red and purple shales of Krol Formation and slates of Infra-Krol Formation. The rocks are folded into a broad syncline plunging NW and the northern limb is truncated by NW-SE trending 'Lake fault'.

The landslide susceptibility map was prepared by adapting 'Probabilistic approach' (refer section 2.1.2, Chapter 2). Although the method is applicable for a macro-scale landslide susceptibility mapping, but since no standard methodology was available for mesoscale zonation mapping, the 'Probabilistic approach' was adapted in this case study and yielded a good result. For Nainital Town area, the following probability values are considered in order to demarcate the landslide susceptible zones -

- i. Probability = 80% - Very High susceptible zone
- ii. Probability > 50%-79% - High susceptible zone

- iii. Probability > 20%-50% - Moderate susceptible zone
- iv. Probability = 20% - Low susceptible zone

The area was divided into 1001 nos. of slope facets. A total 604 facets fall within a hard rock and 397 facets fall within overburden mass. Based on above methodology, the study area was grouped into four classes of varying landslide susceptible class (Fig. 3.20). Sher ka danda area in Snow view, Fairlight hall and Naina peak-Deopatha-Handi-Bandi sector, have very high to high order of susceptibility to slope failure. The inhabited areas in such zones and those falling into their debris avalanche routes are at higher risk in terms of landslide hazard. In Balia *nala* area, the slopes east of Hanumangarh and SW of Alukhet are in very high to high category. Such zones are also confined in most part of Balia *nala* section particularly from Harinagar-Fairy Hall drain up to the confluence of Balia *nala* with Sipahi Dhara *nala*.

Suitability zones for urbanisation in the area were delineated based on landslide zonation mapping (Fig. 3.21). Four types of zones were defined: (i) normal type urbanisation without much remedial treatment of slopes, (ii) zones requiring routine or moderate treatment measures, (iii) zones requiring extensive/higher treatment and (iv) zones where prohibitive cost would be involved for any developmental activities. The obtained maps are being used by the local administration for land use zoning regulations for Nainital township.

3.4 Microscale landslide studies

3.4.1 Surbee Landslide, Mussoorie, Dehradun district

The Surbee landslide, essentially a rotational debris slide, is about 230 m high and 170 m wide in the mid portion, and abruptly narrows beyond the toe of rupture to form an extensive "Run out" zone with a travel distance of about 1500 m. In recent time, the slide has progressed downwards for about 10-15 m. A number of new subsidence cracks have developed within the slide body and at the crown portion, reaching up to the Surbee Resort. Besides, huge accumulations of slide debris in the downslope areas have engulfed the fields around Rangaon village.

Geologically, the slide area lies in the rugged terrain of Lesser Himalayas, on the northern slopes to Mussoorie

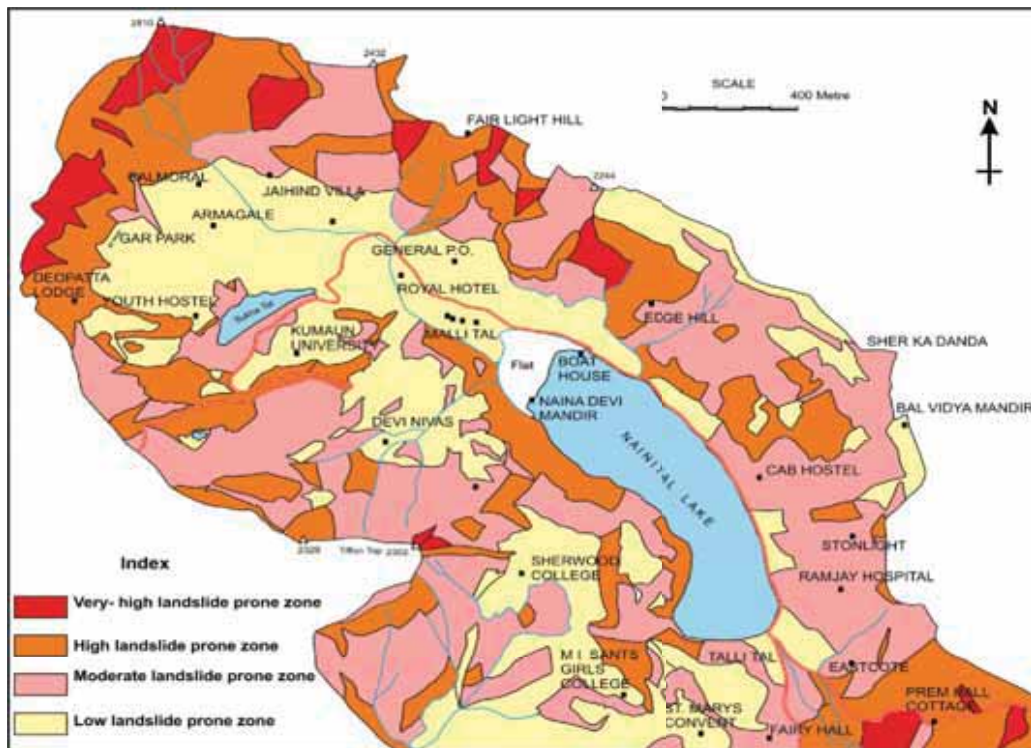


Fig. 3.20. Landslide susceptibility map of Nainital area, Uttarakhand.

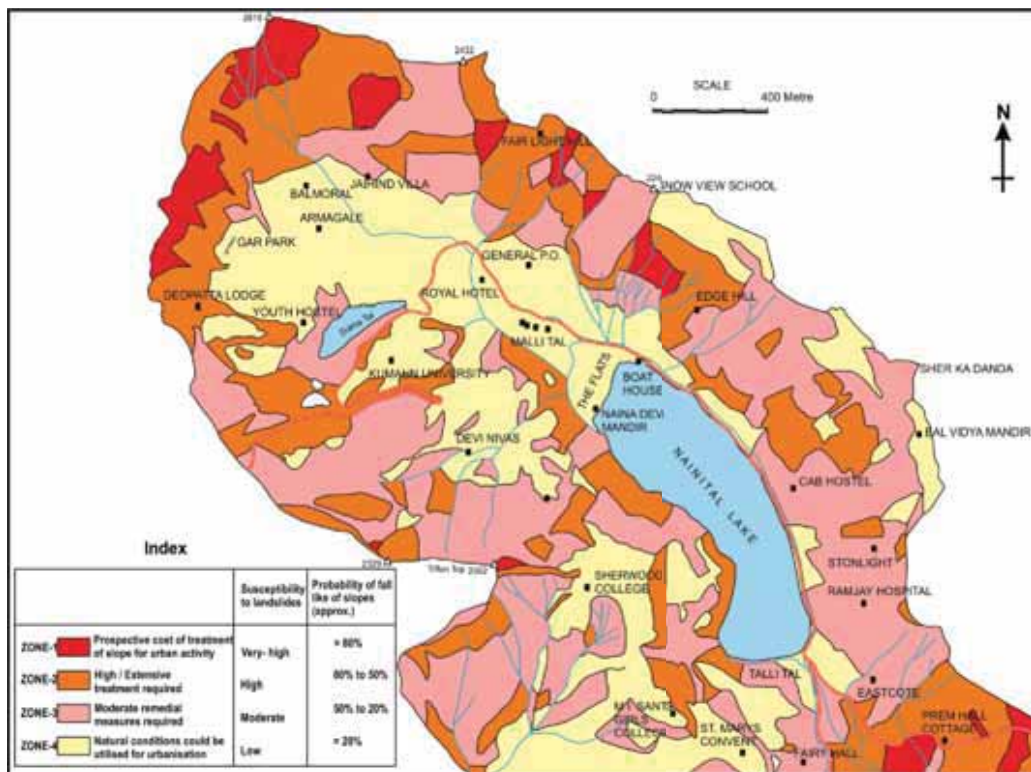


Fig. 3.21. Map showing suitability zone for urbanisation in Nainital.

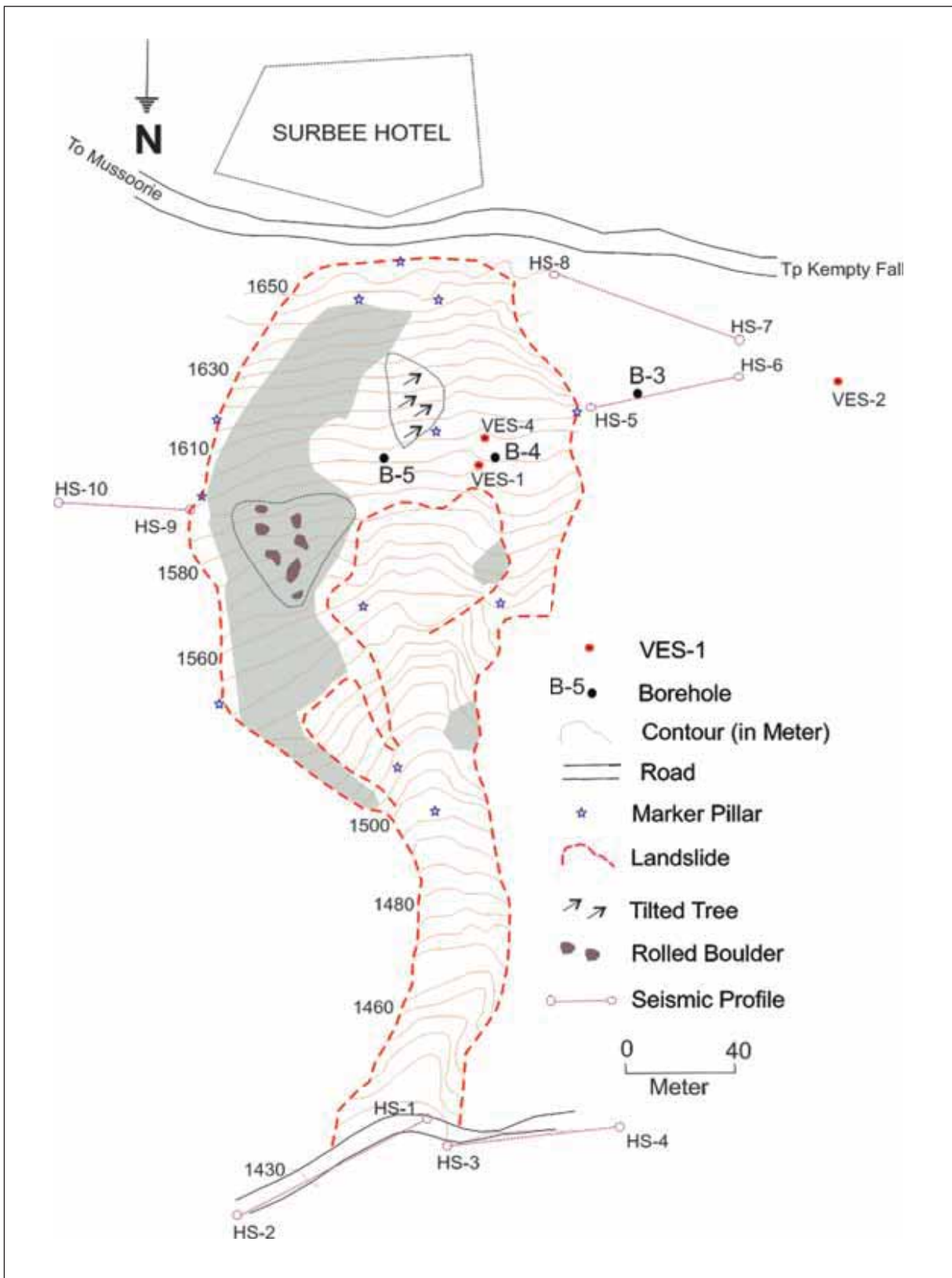


Fig. 3.22. Detailed geological and topographical map of Surbee landslide zone.

Table 3.7. Inventory of major landslides along Kailash-Mansarovar yatra routes.

Map Ref.	Dimension		Type of slide	Causative factors and temporary remedial measures
	Length (m)	Height (m)		
1.	175	60	Debris slide	Toe erosion and road cut caused the slide. It is an old slide zone.
2.	150	140	Debris slide	Toe erosion and road cut caused the slide. It's an old slide zone.
3.	300	350	Debris slide	Toe erosion and poor strength of Variegated shale. It's an old slide zone.
4.	200	500	Debris flow	Avalanche driven slide, active during snow and rainfall. It's an old slide zone; Napalchu village at risk.
5.	60	400	Debris flow	Avalanche driven slide, active during snow and rainfall. It's an old slide zone.
6.	500	200	Subsidence	Gradual subsidence due to toe erosion, different level of subsidence. Old subsidence area, recorded from 1930 onwards.
7.	1000	400	Debris slide	Toe erosion and gully erosion caused the slide. It's an old slide zone.
8.	150	200	Debris slide	Toe erosion by Kali River and gully erosion caused the slide. It's an old slide zone.
9.	30	75	Debris slide	Toe erosion by Kali River and gully erosion caused the slide. It's an old slide zone, road was breached.
10.	300	200	Rockfall	Rock slide due to adverse structural discontinuities. Killed 200 people in August 1998.
11.	280	120	Debris slide	Toe erosion.
12.	400	400	Rock cum debris slide	Toe erosion by <i>nala</i> and road cut caused the slide. It's an old slide zone.
13.	200	200	Debris slide	A number of debris slides developed due to <i>nala</i> erosion. It's an old slide zone.
14.	250	200	Rock fall (active shooting stone)	Rock slide due to adverse structural discontinuities. It's an old slide zone; 6-7 people died due to rock fall in 2000-01.
15.	150	280	Debris slide	Toe erosion by <i>nala</i> . It's an old slide zone now mobilised; slide breached the bridge during July-August 2001.
16.	400	250	Debris slide	Due to excavation of project. Excavated material dumped on slope slips during rains. Recent slide.
17.	400	200	Debris slide	Boulder dislodgement due to rain fall and aggravated due to road cut. It's an old slide zone of 1971.
18.	200	150	Debris slide	Scree deposited on slope move during rainfall. It's an old slide zone.
19.	250	240	Debris slide	Toe erosion by <i>nala</i> . It's an old slide zone, road sinking.
20.	200	100	Debris slide	Toe erosion by Punian-Ki-Gad. Creep zone.
21.	80-100	70	Debris slide	Toe erosion by <i>nala</i> . Creep zone.

Map Ref. is the slide number given in Figs. 3.17 and 3.18.

range, near Siyagaon. The area lies close to the axial trace of 'Mussoorie Synform' exposing rocks of Krol Group of Neoproterozoic age.

The Surbee slide zone covering 0.52 km² area was geologically mapped on scale 1:1,000 using total station (Fig. 3.22). New cracks in the crown and mid portion of the slide zone and subsidence up to 0.2 m have been noticed at

few places. A total of 12 stakes/pillars were installed on both flanks of the Surbee landslide for geodetic monitoring of ground movement using Total Station (Kumar and Sharma, 2011). The surface movement of the stakes planted within the slide body shows insignificant cumulative movement of the order of less than 1 cm in 3 years as monitored between 2007 and 2009 (Fig. 3.23).



Fig. 3.23. Ground displacement curve obtained using monitoring of stakes/pillars at Surbee landslide zone.

Several geophysical surveys including resistivity survey, thermal and natural gamma logging and temperature measurement, and drilling (six nos.) were carried out to understand the subsurface condition (Singh and Singh, 2009; Singh and Singh, 2009; Singh and Verma, 2009). No drill hole intersected fresh rock mass even upto 50 m depth. The core log indicates presence of overburden mass comprising coarse limestone/dolomite fragments with sand pockets.

Based on the initial study and detailed map (Fig. 3.22), several interim remedial measures have been suggested to mitigate the consequence of the sliding and to protect the slope against erosion and further activation. These include: constructing a retaining structure to improve sliding resisting at the crown so as to make the highway more safe and stable, constructing check dams along the narrow *nala* section in the run out zone, designing a proper top catch drain, at the road level and divert the drain water to a point well beyond the slide area and channelization of spring water, with horizontal pipes or drains in order to reduce the hydrostatic forces on the slope, as well as the risk of erosion and piping conditions.

3.4.2 Varunavat Parwat Landslide, Uttarkashi district

On 23rd and 24th July 2003 the heavy downpour in Uttarkashi resulted in supersaturation of the already fragile densely vegetated soil covered slopes of the Varunvat Parwat hills.

On 22nd and 23rd August 2003, after initial assessment carried out by GSI team, the district administration was immediately informed about the impending landslide danger and risk to areas lying below the slide (Masjid mohalla, Horticulture colony, Jal I (Sansthan) and therefore should be immediately evacuated to avert a major tragedy. This warning was also flashed on by daily Amar Ujala in its Sunday issue dated 24th August 2003. GSI along with local authorities demarcated a broad zone to be evacuated completely. The administration activated its machinery and warned the residents of the area of consequences.

On 24th September 2003, the first landslide occurred upslope of Ram Lila Maidan area. Subsequently, landslides in Tambakhani and Masjid Mohalla were activated. The slide completely destroyed many commercial establishments and residences on either sides of NH-108, but no casualty occurred.

The Tambakhani, Ram Lila Maidan and Masjid Mohalla slides are located very close to each other and these have a common crown (Fig. 3.24). The slide area was mapped by GSI on 1:1000 scale (Fig. 3.25). Highly weathered, decomposed and jointed quartzite, phyllite and metabasic rocks of Garhwal Group (Proterozoic age) are exposed around the area. The rocks dip into the hill (20°-45° in northeasterly to east direction). The slopes at higher level (crown portion) are gentler but become steeper at lower levels. The rainwater seeped into the cracks developed in overburden material and fractured rock mass which

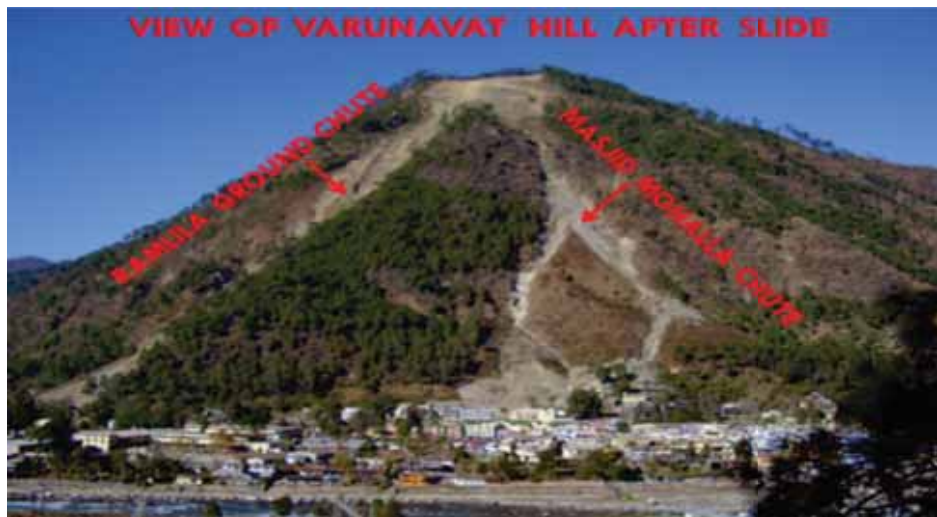


Fig. 3.24. Field photograph of Varunavat Parwat landslides.

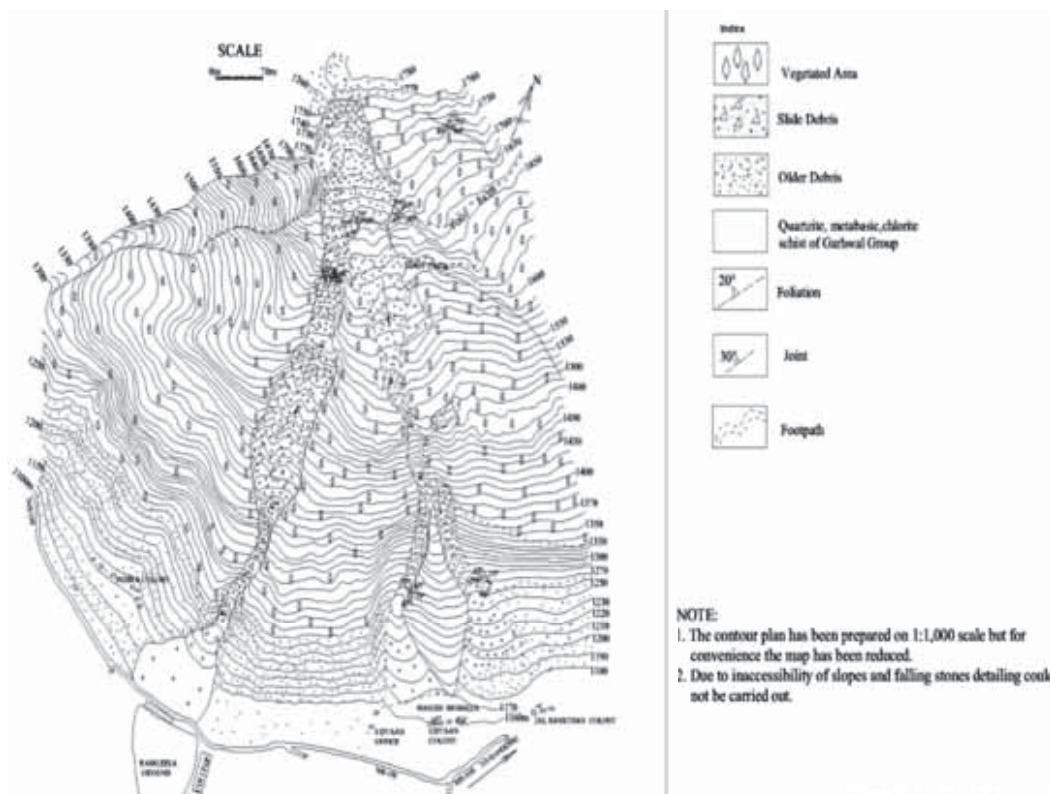


Fig. 3.25 Detailed geological and topographical map of Varunavat Parwat landslides.

lubricated and developed pore pressure triggering the slides. Creep has resulted due to seepage and gravity flow of cohesive material and also soft rock masses on moderately steep to steep slopes as indicated by straight tilted tree trunks. Once the slides were triggered it affected the densely vegetated forest zone leading to uprooting of some pine trees. The subsidence at the crown portion is progressive in nature (Fig. 3.25).

A comprehensive treatment plan was worked out in which GSI was involved to provide geological and geotechnical data input for design of the support and strengthening measures and THDC Ltd. was involved as an executing agency and to provide the engineering design of the protective structures. Based on the geotechnical input provided by GSI and other agencies, the following comprehensive treatment plan has been worked out (Ghildyal and Singh, 2010; Gajbhiye *et al.*, 2010; Gajbhiye and Bhattacharjee, 2010; Gajbhiye *et al.*, 2010; Chakraborty *et al.*, 2010; Chakraborty and Thapliyal, 2010):

1. Grading of steep overburden slopes, existing between El 1660 m and 1800 m, to a gentler slope ($<30^\circ$) with berms and covering it with biodegradable coir geotextiles which can shape itself to ground topography on which it is laid and also supports growth of vegetation.
2. Construction of platform at the interface of overburden and bed rock. Two platforms were proposed having width 25 m and 8 m at El 1670 m and 1660 m respectively in the entire length of the affected zone. These platforms are meant for arresting the muck to be dosed from crown during benching.
3. Erecting a retaining structure at EL 1660 m to arrest loose mass moving from the upslope.
4. Providing toe drains at every berm. Providing well-designed chute drains along the gullies developed due to mass movement during sliding above the Ramlila ground, Horticulture colony and Masjid Mohalla. At different locations, retaining structure is also to be provided across these chute drains. Providing retaining structures along the toe of the hill close to Ramlila ground, Horticulture colony and Masjid Mohalla.
5. Construction of steel barricading and construction of about 335 m long bypass tunnel below Tambakhani chute

as an alternative transportation route.

Fig. 3.26 shows the field photographs of the engineering slope stabilisation measures used in treatment of the Varunavat Parwat landslide.

3.4.3 Amiyan Landslide, Nainital district

On 2nd - 4th September 1992, the heavy downpour (105-175 mm) in Kathgodam area has triggered/reactivated a debris slide at Amiyan, about 5.5 km upstream of Kathgodam barrage on river Gola. The slide blocked the course of the river for about two hours in the night of 3 September 1992 and created a lake of about 500 m in length, 20-25 m in width and 4-5 m in height.

The Amiyan slide zone covering 0.05 km² area was geologically mapped on scale 1:1,000 (Fig. 3.27) in addition to traverse geological mapping of 20 km on scale 1:50,000 (Srivastava *et al.*, 1993). The crown is 117 m above the river level. The width at river level is 190 m; at mid portion, it is 100 m and at crown, the width is 150 m. The geological section (Fig. 3.28) shows variation in general slope amount with changes in the elevation, thus indicating a number of break in slope within the slide body. The slide is developed within alternate bands of sandstone, plastic clay shale and siltstone belonging to Lower Siwalik sedimentary sequence. The Lower Siwalik rocks are in contact with the Amritpur granite along the Main Boundary Fault which is likely to pass near the toe portion of the slide along the course of the Gola River.

The Amiyan slide progressively increased in size in course of time. It covered an area of 0.025 km² as per the toposheet of 1968. Afterwards it was grown to 0.320 km² as mapped from aerial photos of 1981 and then 0.0496 km² in 1992. The initial cause of failure is attributed to toe erosion of clay shale resulting in destabilisation of the overlying sandstone. The present slide has been observed within the thick accumulation of debris deposited by the old landslides.

Based on the detailed study it was recommended to create a toe wall such as boulder fill wire mesh wall to arrest the further toe erosion by the river. In order to lessen the relative height, it was suggested to carry out back dressing of the slope at two levels at 30 m and 60 m height and to provide surface drains for removal of water. Further creation of a



Fig. 3.26 Slope stabilisation measures used in Varunavat Parwat landslides: (A) stabilisation of failed slope by Concrete Cladding; (B) stabilisation of rocky slopes; (C) stabilisation of overburden mass by geo-net below El. 1640 m; and (D) channelisation of chute.

retaining wall at crown part was also recommended.

3.4.4 Lambagar Landslide, Chamoli district

Lambagar slide zone on Rishikesh-Badrinath road section in Chamoli district, Uttarakhand is one of the major trouble spots affecting approach to Badrinath Temple, strategic defence establishments and important hydel schemes in upper reaches of the Alaknanda River. This slide zone remains active especially during rainy season snapping the communication near Km 305.5 along the National Highway (NH-58). The slide reportedly activated for the first time consequent upon flooding in river Alaknanda on 2nd August 1997. Since then, it is consistently affecting the route.

The slide measuring 350 m along the road and 140 m high is confined in glacial morainic material of highly assorted nature. Lamination or layering of varved clay and pieces of wood (tree trunks) occur at places. The upper rocky slopes are steep with high relief conditions. The massive

quartzite/schistose quartzite (Pandukeshwar quartzite) occupies the higher slopes. The quartzite forms prominent dip slopes (30°-40°) in Khada Chadda, near the slide zone. Bedrock lithology exposes quartzite belonging to Central Crystalline Group.

The slide morphology is outlined by means of detailed geological mapping covering about 1 km² area on scale 1:5,000 (Fig. 3.29A). Three active slides in the entire slide zone have been demarcated (Sharma, 2009). These discrete active slides get enlarged after every spell of rainfall and thus, tend to coalesce into a major slide. The slide face, composed of blocks/boulders with highly assorted material, is steep that facilitates bouncing off boulders. The geological sections (X-Y and X1-Y1; Fig. 3.29B) across the slide indicate presence of a number of breaks in slope. The development of radial tension cracks in crown area reveals a deep plane of failure in the slide zone. Nearly flat area above elevation 2280 m is also marked by numerous breaks in

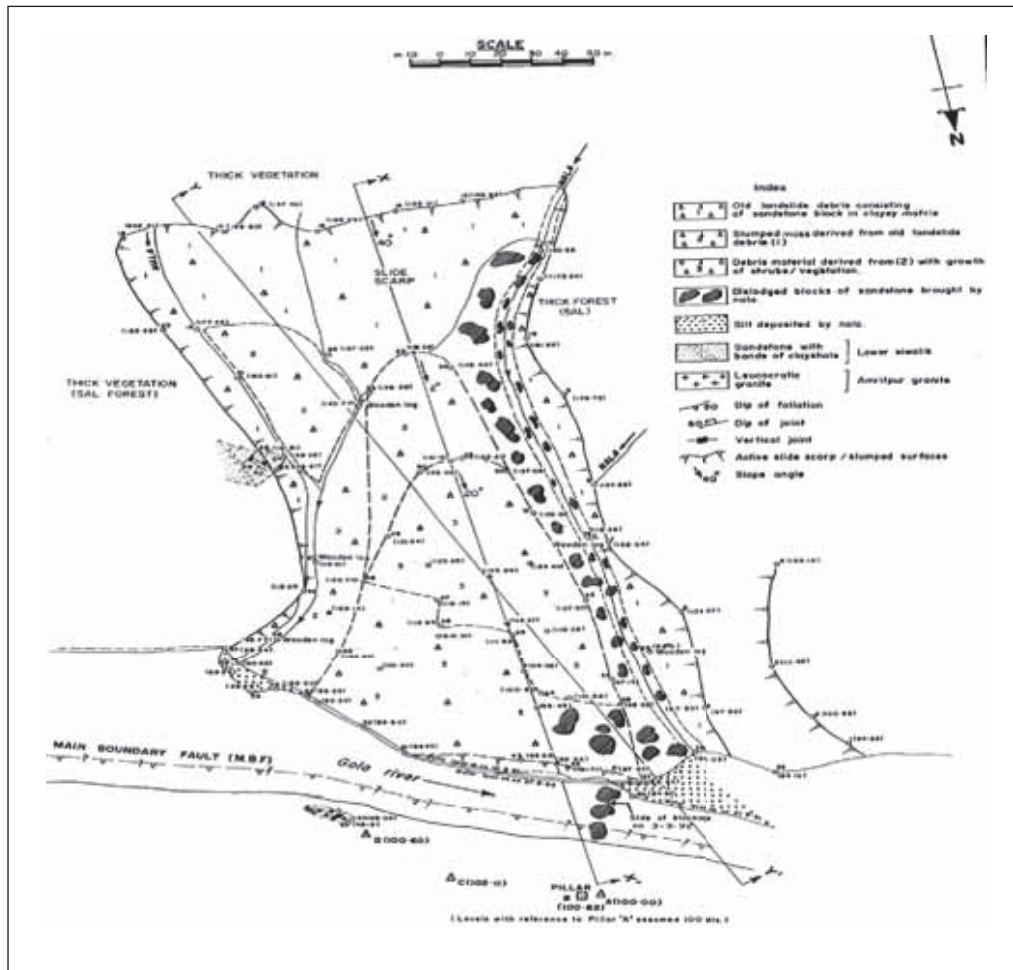


Fig. 3.27. Detailed geological and topographical map of Amiyán landslide.

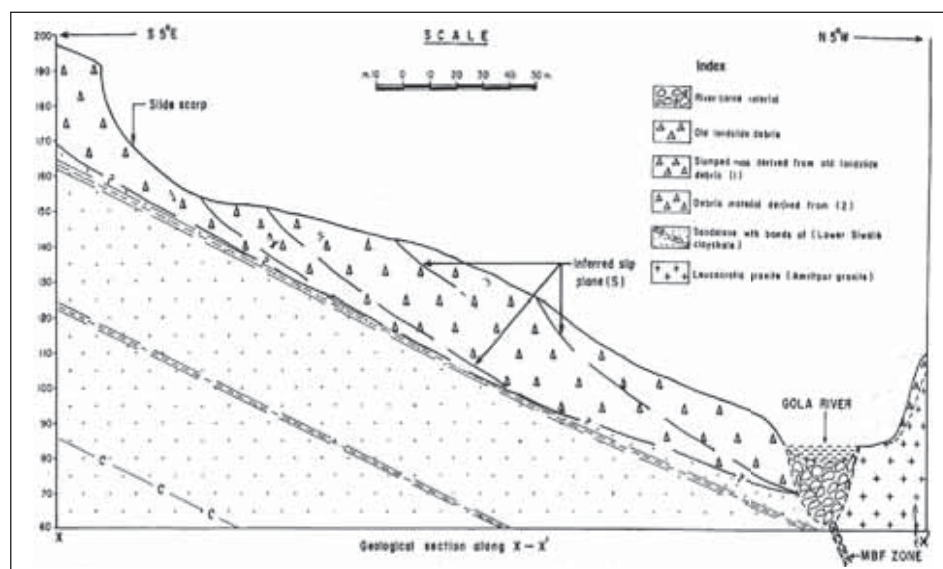


Fig. 3.28. Geological section of Amiyán landslide (for section line refer Fig. 3.27).

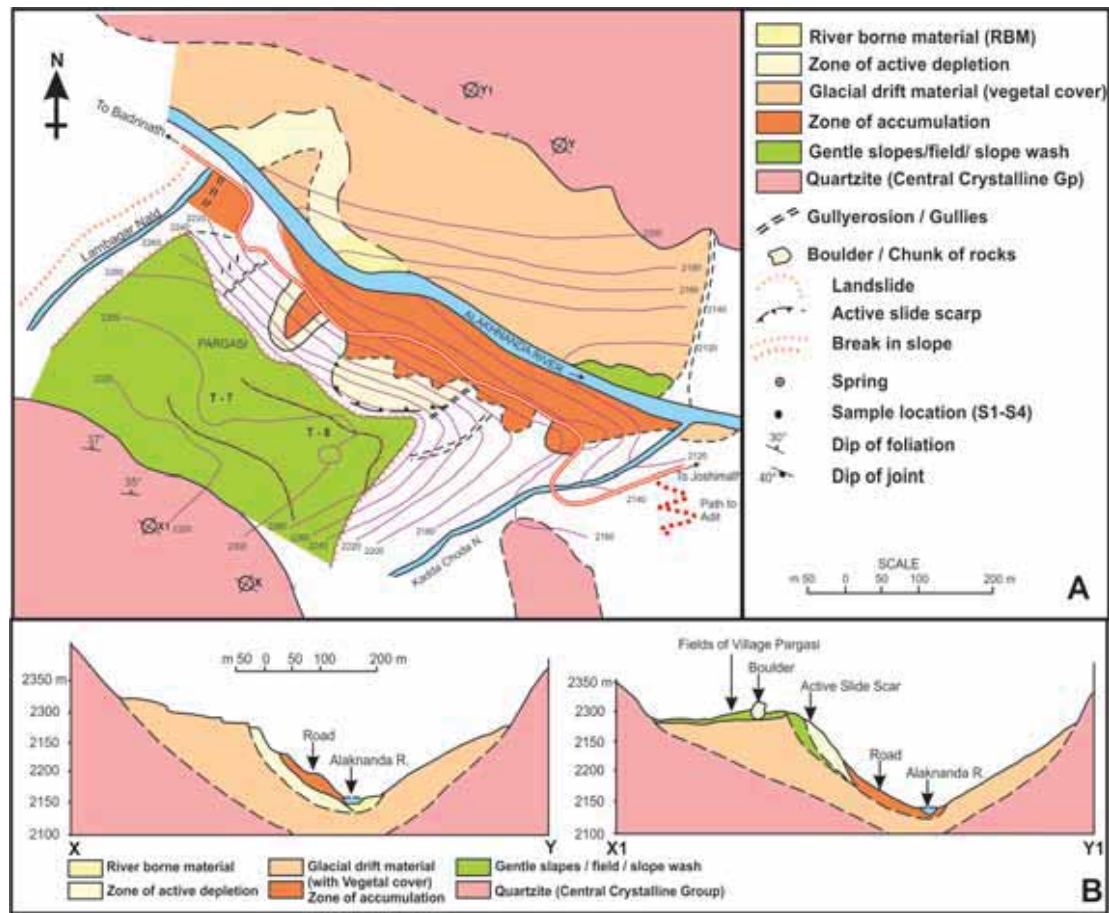


Fig. 3.29. Detailed geological map of Lambagar slide zone (A) and geological sections along XY and X1Y1 (B).

slopes, tension cracks and tilted trees. The area between 2250 m and 2280 m is the zone of active depletion of material. The boulders perched in the state of inequilibrium are prone to fall. The sliding in these blocks destabilises upper slope in cascading manner. Scooping out the finer part/matrix of slope forming material by gully erosion largely governs the bouncing mechanism of boulders embedded in slide face area. The zone of accumulations of slide material confined between 2250 m and 2140 m encompassing road section is high-risk zone due to shooting of stones from steeper slopes.

Heavy erosion in high gradient Alaknanda River at the site results in loss of lateral support in relatively softer morainic material with development of tension cracks in upper levels due to high mass movement. These cracks receive water and further decrease the shear resistance of the mass. The position of tension cracks at the crown indicates the limit of present state of displacement of slide material.

Causative factors contributing to failure are unconsolidated material of non-cohesive nature, gully erosion on slope face, and deep-seated toe erosion by Alaknanda River. It is suggested that protection against gully erosion is to be carried out by suitably unloading the slopes, constructing benches and berms, designed retaining structure and improvement of drainage.

3.4.5 Pipalkoti Landslide Zone, Chamoli district

Pipalkoti landslide zone (toposheet: 53N/7), located about 1 km north of Pipalkoti town, District Chamoli, Uttarakhand on National Highway (NH-58) leading to pilgrimage route of Badrinath and Hemkund Sahib, creates havoc due to disruption of NH-58. Detailed geotechnical mapping along with study of the sections of the slide zone has been carried out on 1:2,000 scale covering approx. 1 km² area to review the current instability conditions and to outline slide morphology and other specific ground features (Fig. 3.30).

Two geological cross-sections (A-B and C-D; Fig. 3.31) have been prepared (Sharma, 2010). The geological sections across the slide indicate presence of a number of breaks in slope. The zone is affected by development of slump cracks at higher elevation while erosion at the toe, close to river bed continues unabated. The discrete slides within the slide zone

are enlarging after every rainfall. The fall of boulders and debris above the road level and subsidence of road is conspicuous features of the zone. The sinking zones are bordered by the arcuate ground cracks making the road

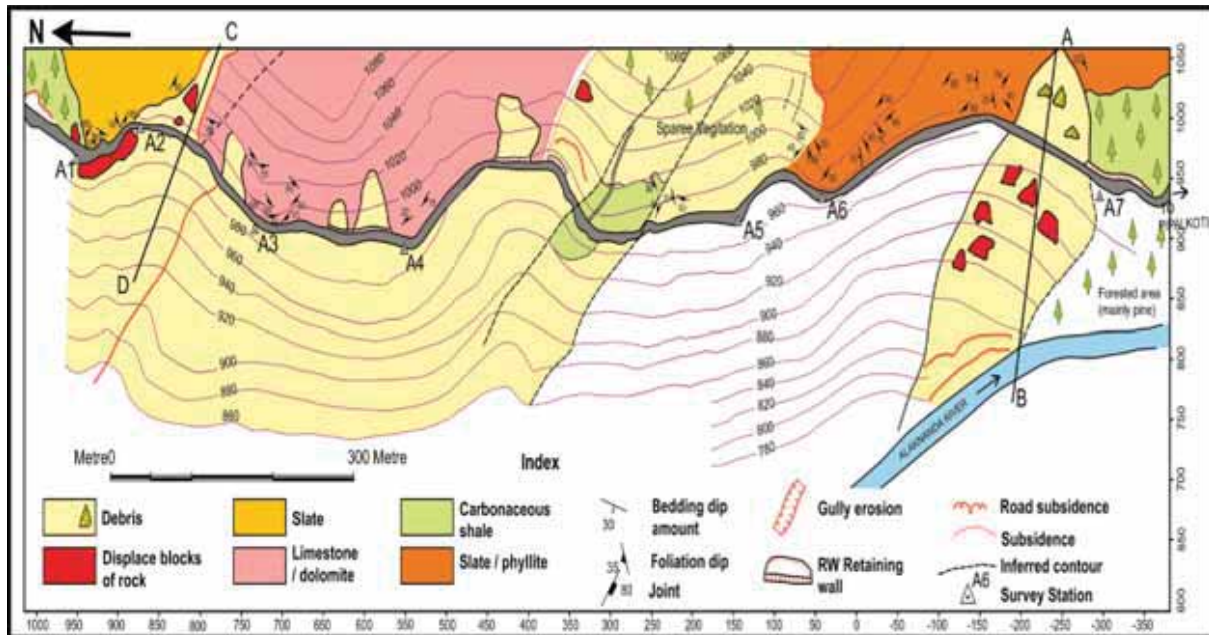


Fig. 3.30. Detailed geological and topographical map of Pipalkoti slide zone.

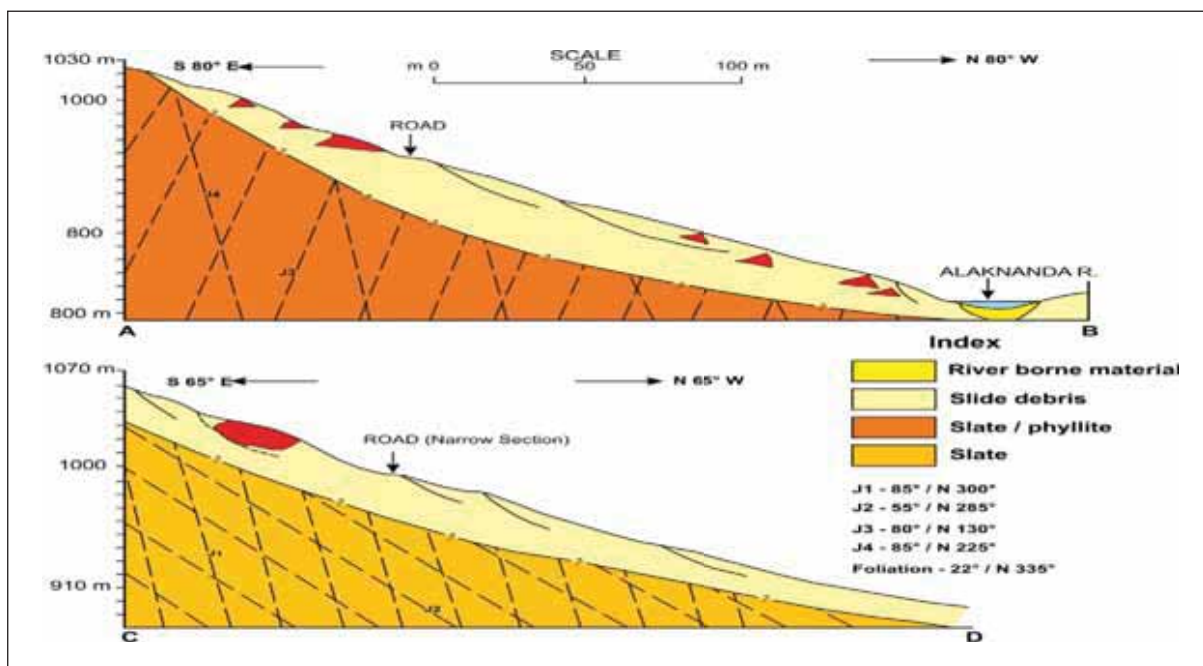


Fig. 3.31. Geological section along A-B and C-D in Pipalkoti slide zone (for section line Fig. 3.30).

highly vulnerable to failure.

The slide zone is confined within Garhwal Group of rocks represented by limestone/dolomite, slate, carbonaceous slate/shale and phyllite. Unconsolidated, heterogeneous, non-plastic debris in silty sand matrix occupies a large part of slope forming material. The instability conditions are governed by poor lithological conditions, highly jointed rocks, accelerated toe and gully erosion. Main Central Thrust (MCT) and Vaikratta Thrust, two important structural discontinuities of Himalaya, lie in proximity to the slide zone. The general trend of these rocks is N50°-70°E- S50°-70°W with low (8°-10°) to moderate (30°-35°) dips in northerly direction.

The slide zone has been divided into four distinct micro-zones from north to south, each zone having distinct characters of failure mechanism (Fig. 3.30). In Zone-I, gully erosion and river erosion are responsible for road subsidence. The Zone-II, in general, is prone to rockfall. Poor lithology and adverse disposition of joints result in 300 m stretch of Zone-III. The Zone-IV is the major trouble spot due to a huge debris slide.

Measures suggested to improve the stability include protection against toe erosion, providing buttressing effect at the toe and keeping enough provision for surface and subsurface drainage. It is recommended that for prediction or estimation of slope failure and to confirm the effectiveness of measures taken, a comprehensive monitoring system with the help of instruments and geodetic survey may be initiated. Monitoring through high-resolution satellite images, to keep pace with temporal and spatial changes, may be executed.

3.4.6 Dhak nala Landslide Zone, Chamoli district

The Dhak nala landslide zone is located near 12.5 km of the Joshimath-Malari road adjacent to Dhak village (Lat. 30°30'N: Long. 79°37'30"E). A total 4000 km² area was mapped by Shome (1971) during 1971 by tape and compass on the 1:5000 scale map provided by the DGBR authorities with an aim to evolve the cause of the slide and to suggest remedial measures (Fig. 3.32). The slide is a composite one with a slump at the toe in the overburden followed by a planar failure along the foliation planes of the garnetiferous gneiss.

The area exposes garnetiferous hornblende gneiss with interbands of quartzite and basic sills belonging to the Central Crystalline Group. The foliation dip varies between 30° and 50° towards N30°E, i.e., along the slope of the *nala*. The geological section along X-Y shows presence of glacial to fluvioglacial material, landslide debris and in situ rock (Fig. 3.33). The heavy flash flood of July 1970 in the Dhak nala, occurred as a result of cloudburst over the Kuanri Pass (Khal), has caused erosion of the overburden on the left bank of Dhak nala. This resulted in the slump slide, just behind the area exposes garnetiferous hornblende gneiss with interbands of quartzite and basic sills belonging to the Central Crystalline Group. The foliation dip varies between 30° and 50° towards N30°E, i.e., along the slope of the *nala*. The geological section along X-Y shows presence of glacial to fluvioglacial material, landslide debris and in situ rock (Fig. 3.33). The heavy flash flood of July 1970 in the Dhak nala, occurred as a result of cloudburst over the Kuanri Pass (Khal), has caused erosion of the overburden on the left bank of Dhak nala. This resulted in the slump slide, just behind the present road. The resulted debris flowed down Dhak nala and blocked the Dhauliganga River at its confluence.

It was suggested to realign the road section passing the slide zone, including the slide located at 9.2 km of the Joshimath-Malari road. Further, it was recommended to carry out rock bolting across the foliation planes of the realigned road to avoid planar failures.

3.4.7 Bhatwari Landslide zone, Uttarkashi district

On 17th August 2010, a part of Bhatwari township (Lat. 29°09'38"N: Long. 80°06'02"E; toposheet: 53J/9), District Uttarkashi, experienced subsidence and landslide due to heavy rainfall. The landslide damaged 38 buildings (houses and shops) and 100 m stretch of the Uttarkashi-Gangotri road (NH-108) resulting in disruption of vehicular traffic between Uttarkashi and Gangotri town. GSI carried out the detailed geological mapping of the Bhatwari landslide zone on scale 1:2000 covering about 1,54,000 m² area (Tripathi *et al.*, 2012).

Geologically, the area exposes rocks of Central Crystalline Group, comprising kyanite-garnet-mica schist, inter-bedded augen/porphyritic gneiss, garnet-mica schist, migmatite zone of mica schist, gneiss, granite, amphibolites and marbles/calc-silicate. The foliation dips 20°-45°

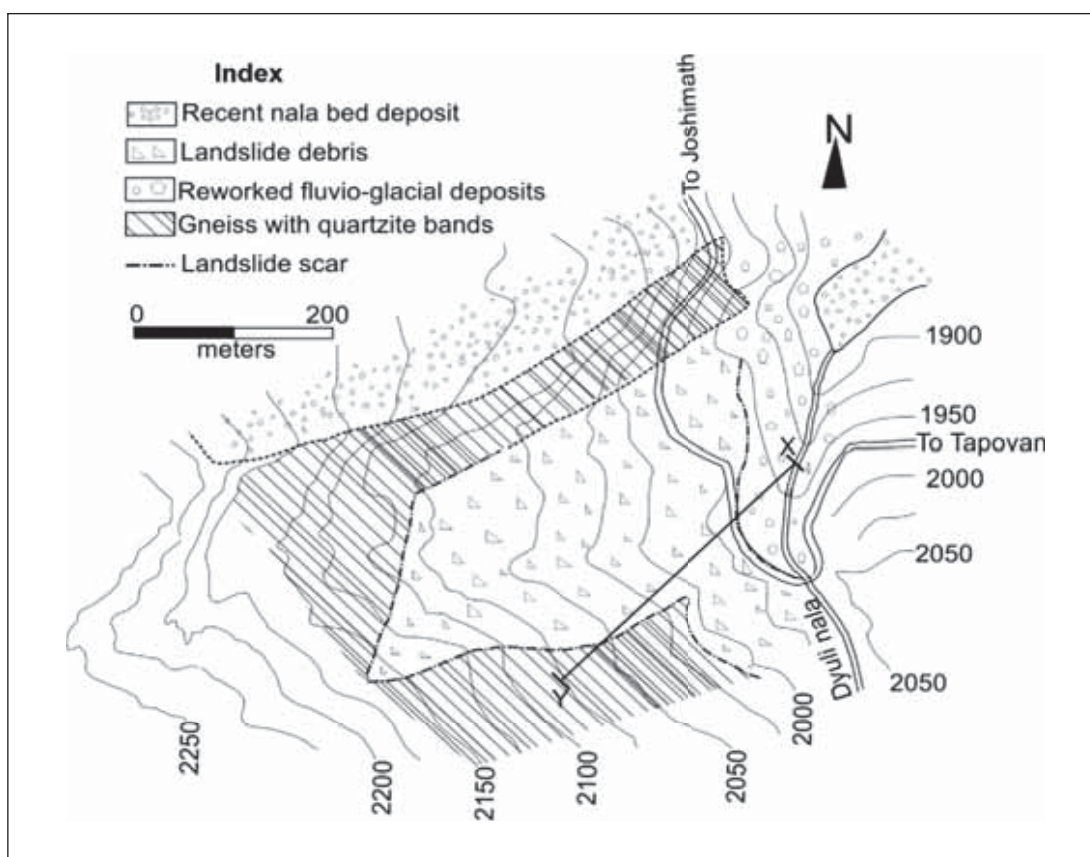


Fig. 3.32. Detailed geological and topographical map of Dhak *nala* slide zone.

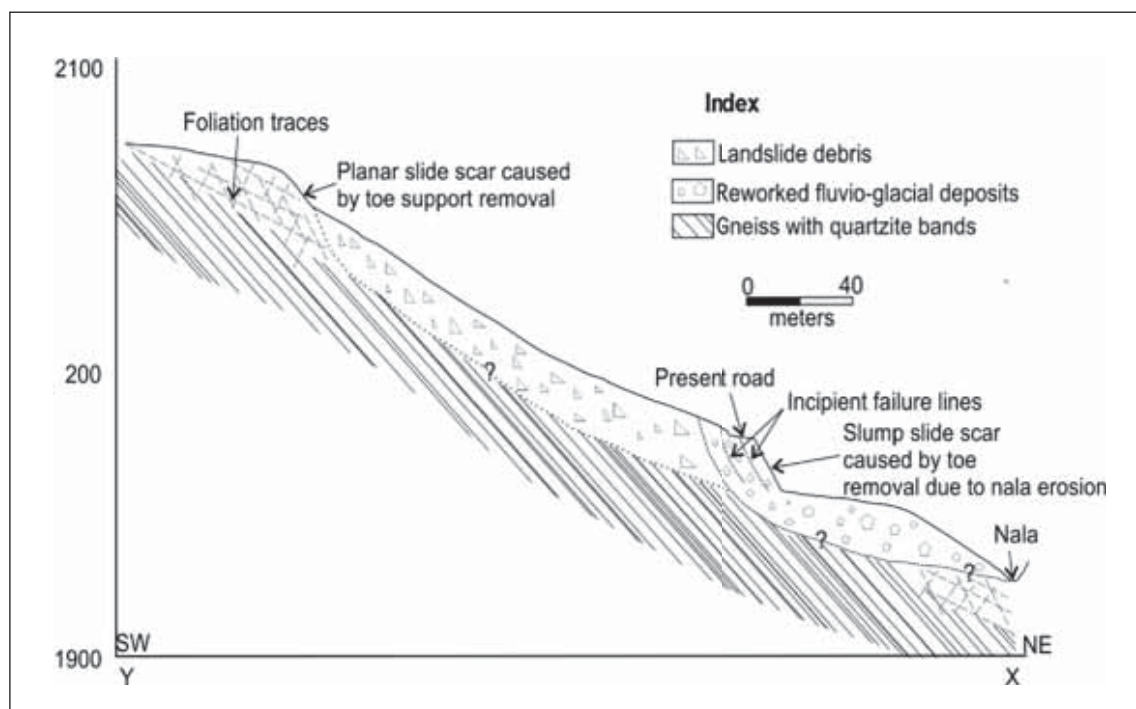


Fig. 3.33. Geological section along X-Y of the Dhak *nala* slide zone (for section line Fig. 3.32).

shaped pattern of fluvial origin is superimposed.

Fig. 3.34 shows the detailed geological map of Bhatwari landslide zone. The geological sections long A-A' and B-B' are shown in Figures 3.35 and 3.36, respectively. Indication of subsidence has been observed in the form of ground fissures, cracks in houses, tilting of structures, bulging of retaining walls etc. The direction of failure is towards S30°-60°E.

The following observations were made:

1. The overburden cover is thick (>5 m) and comprises rock fragments of quartz-biotite gneiss and quartz-mica schist embedded in mica-rich silty/clayey matrix. The in situ rocks are exposed at the river bed level marking the toe of the slide.
2. Seepage of water from the up slopes (Raithal road) is saturating the overburden mass in and around Bhatwari village. The percolated water might be getting accumulated in the trough portion in the middle part of the village, thus resulting in increase of pore water pressure.
3. The subsidence is about 7 m at the road level (NH 108). The slopes above the road have been affected by slips and slides. Arcuate cracks have been observed above the crown of the slide.
4. At the toe of the slope, an arcuate crack has been observed at the rock and overburden interface. Also, few freshly developed linear cracks, following the traces of prominent joints, have been observed near the river bed level.
5. In Gabbar colony area, the terrace bluff also exhibits development of slips and subsidence. The flood control wall provided at the river level has been damaged due to scouring and toe erosion by the Bhagirathi River.
6. The landslide zone is divided into six zones: Zone -1 (affected by the slide) and Zone-3 (left bank of Nahar gad) have been assessed as unstable. Zone-4 (near Forest Rest House) has been assessed as stable, whereas the remaining zones i.e., Zone-2, Zone-5 and Zone-6 have

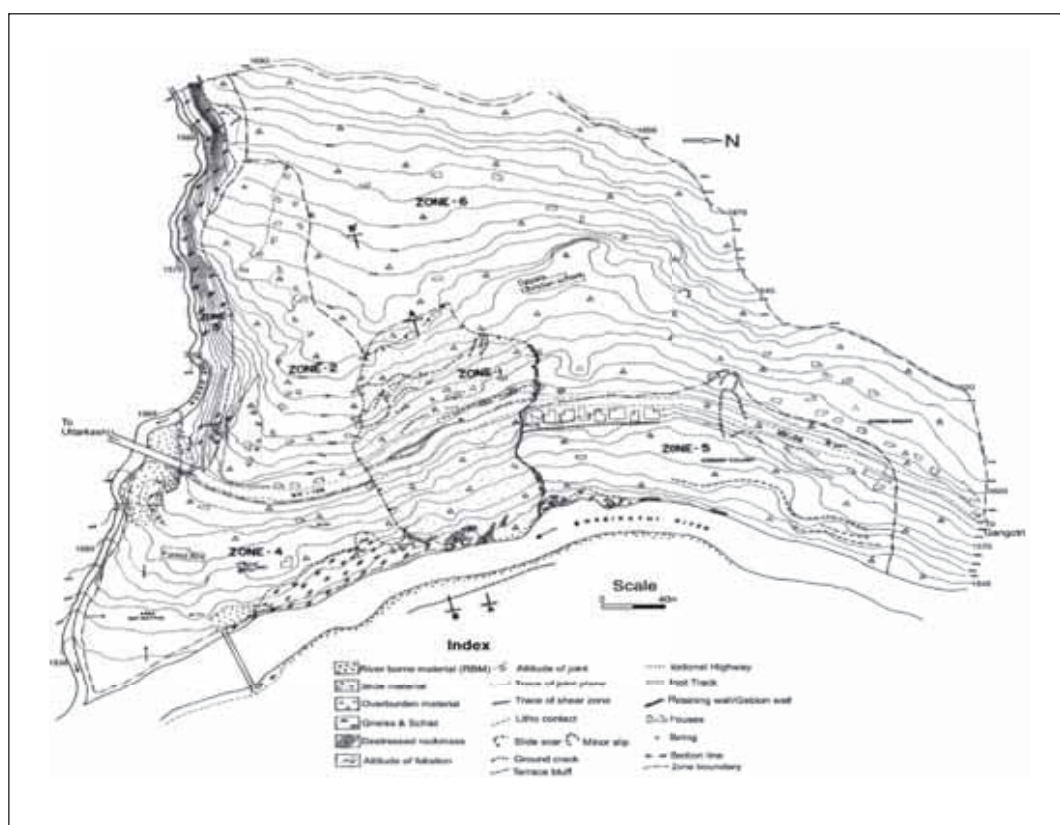


Fig. 3.34. Detailed geological and topographical map of Bhatwari landslide zone.

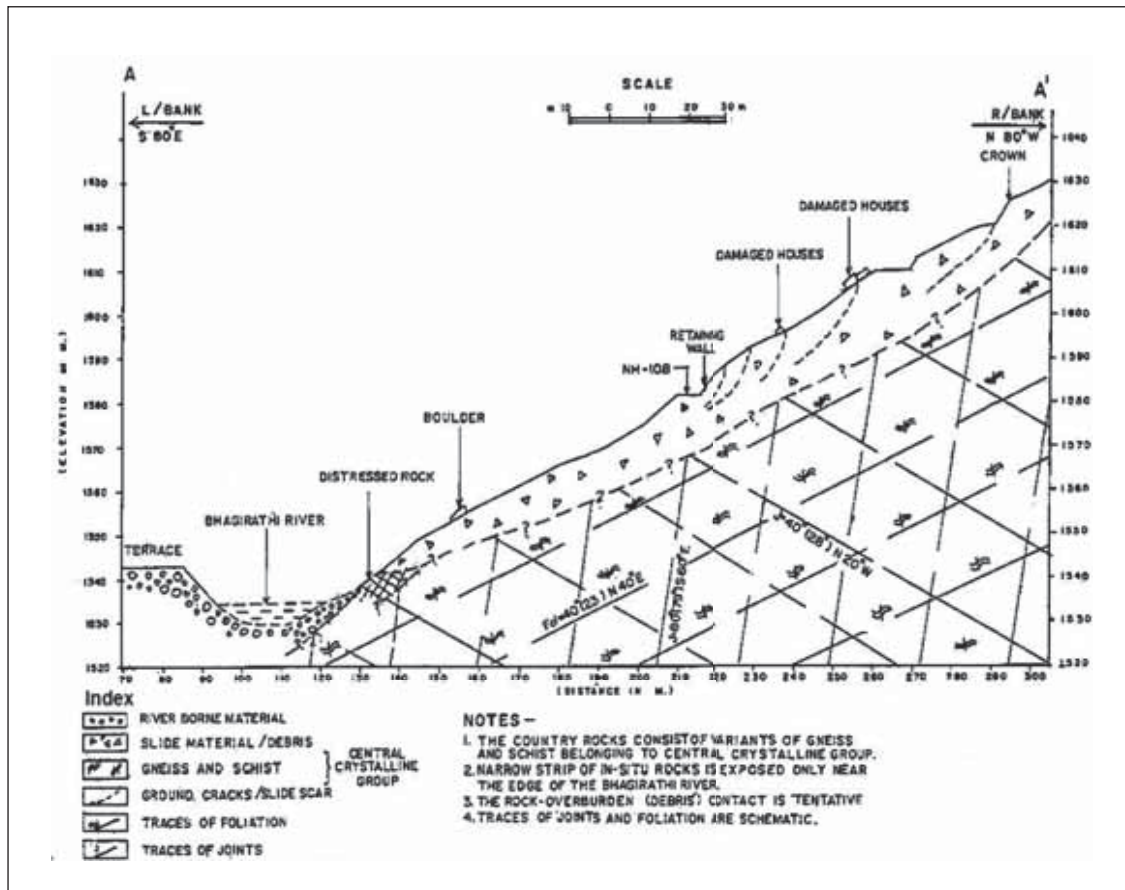


Fig. 3.35. Geological section along A-A' of the Bhatwari slide zone (for section line Fig. 3.34).

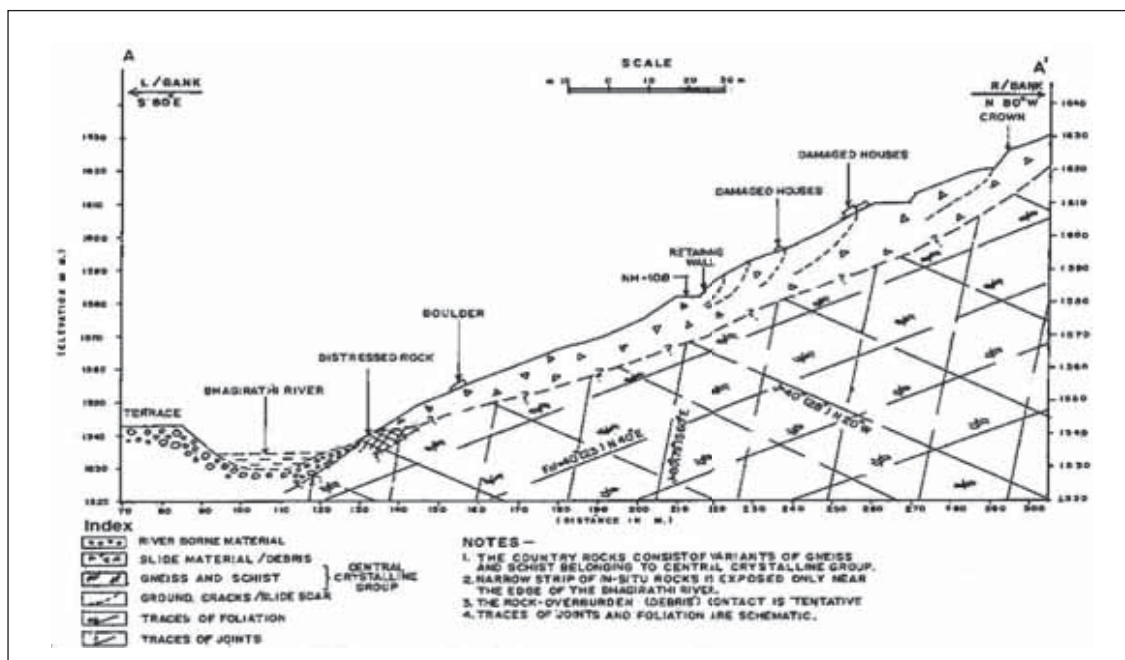


Fig. 3.36. Geological section along B-B' of the Bhatwari slide zone (for section line Fig. 3.34).

been assessed as metastable (Fig. 3.34).

7. Freshly developed cracks / fractures cutting across the foliation and opening of joints in bedrock exposed at the toe of the slide zone can be attributed to rock bursting due to load of the sliding mass and undercutting (scouring) of the toe by the high gradient Bhagirathi River during high flood during monsoon period. The main causative factors appear to be the toe erosion by Bhagirathi River, overloading of the slope by densely placed concrete structures/houses, over saturation of overburden material due to heavy downpour in the area and ingress of water (surface runoff). These disturb the critical equilibrium of the slope thereby leading to ground subsidence and landslide.

The following recommendations were suggested: 1. Channelizing the surface runoff away from the slide affected area by providing lined contour drainage and cross drains to drain the surface and underground water so as to release the pore water pressure, 2. Construction of suitably designed retaining walls with adequate weep holes at the toe of the slide, 3. Sealing of the ground cracks with clay or asphalt to avoid ingress of surface runoff into the overburden covered slopes, 4. Evacuation of the houses located above the crown and periphery of the slide area, 5. Houses located in the unstable zones (Zone -2 and Zone - 3) need to be immediately relocated to a safer place in the nearby area. The settlements located above the crown of the slide, near Dayara Christian Academy, also need to be shifted, 6. Construction of suitably designed concrete wall, on the right bank of Bhagirathi River at the toe of the slope extending from downslope of the rest house of GMVN Ltd to downstream of the toe of the slide, is recommended to prevent active toe erosion by the river, 7. A suitably designed toe wall, on the left bank of Bhagirathi River, is recommended in order to prevent active toe erosion by the river, which otherwise may destabilise the area on the left bank, which at present appears to be stable, 8. As a long term and permanent solution for maintaining the all-weather connectivity on NH-108 it is recommended that the existing NH needs to by-pass the Bhatwari landslide zone, by realignment of road segment, and 9. It is advised to restrict new constructions in the affected area.

3.5 Post-disaster landslide studies

3.5.1 Sinking of Garbhyang village, Almora district

Garbhyang village (Lat. 30°07'30"N: Long. 80°53'45"E; toposheet: 62B/16), located in Almora district (now Pithoragarh district) along Kailash-Mansarovar yatra route, is an important Bhotia village and centre of trade with Tibet. The first information on the sinking of the village was reported on 23 May 1956. A number of houses located on sliding plane have been damaged. Sinking of the floors, development of cracks on the walls and tilting of the buildings were reported. The slip in the central part of the village is traceable on ground for about half mile in N70°E-S70°W direction and has caused a vertical fall of 15 ft. The post-disaster geological assessment of the Garbhyang area was carried out during FS 1955-56 (Awasthi and Sharma, 1956).

Garbhyang is situated at an altitude of 10,320 ft. on an almost flat basin in the valley of the river Kali. The surrounding hills rise to altitudes ranging from 13,000 to 16,000 ft with an average slope of more than 45° towards south. The hills occurring immediately west of Garbhyang have slopes more than 60°. The trend of Garbhyang valley is roughly N70°E-S70°W. The main drainage is the River Kali, flowing in SE direction, which towards upstream of Garbhyang takes a very sharp bend towards SW.

The land on which the Garbhyang village is situated comprises four prominent descending steps towards the river Kali (Fig. 3.37). The slope on the right bank of river Kali is about 30° to 35° except due south of the PWD Dak Bungalow where the river takes a sharp bend. Here the right bank has steep slope of about 75° to 80° and is being actively undermined by the river. The bedrock is overlain by the lake deposits forming flat land of Garbhyang. The formation of lake is attributed to the damming of the river Kali at Api fall near Budhi village during Pleistocene time. As per the Patwari's map prepared at the time of Bikat Bandobast, it is reported that Garbhyang and Chhildu villages were once a continuous flat land, which later divided by sliding and river cutting some 80 years back.

The first evidence of sinking came after heavy rainfall in 1935-36 when a crack was developed through the village resulting in a vertical slip of about one foot. Another

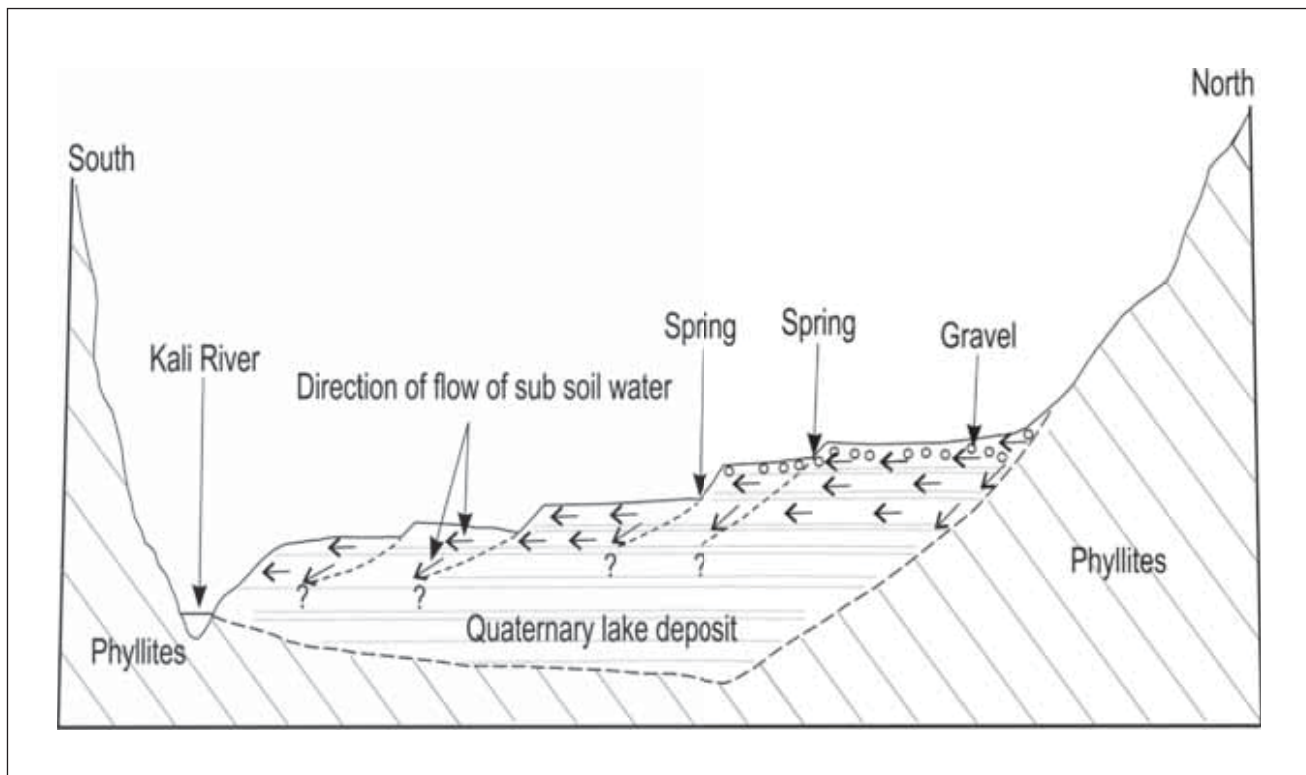


Fig. 3.37. Schematic geological section across Garbhayang village.

movement occurred after heavy rainfall in 1956 which intensified the old slip and developed a second major slip almost parallel to the old one resulting in a vertical fall of about 15 ft. The main lake deposits on which the village is located consist of sandy loam intercalated with brown, bituminous shales with an increasing percentage of clay towards bottom. Gravels with gritty sand constitute the topmost cover which varies in thickness from 10 to 20 ft. These absorb most of the rainwater coming down slope and allow easy access of water to deeper parts in the formation during heavy rainfall. The water thus absorbed emerges as springs at different levels in the area, some of which are big enough to cause rapid cutting and to effectively transport the eroded material to the river. The water reaching the lower horizons exerts a lubricating influence and increases the instability of the landmass. River Kali also actively contributes to landslide by eroding the toe of the slope.

For containing the landslide it is recommended to provide effective surface and subsurface drainage arrangement to arrest the percolation of water. It is also suggested to provide toe support at river Kali to arrest toe erosion. Plantation of appropriate shrubs and trees on the

slope of the sliding mass is also suggested. Alternatively, if possible the village can be relocated at Chalet Maidan, Sunkhola and Bong Bong.

3.5.2 20th July 1970 event in Alaknanda Valley, Chamoli and Pauri districts

On 20th July 1970, floods in Alaknanda River had resulted in immense damage to life and property, and warranted the need for realignment of the Rishikesh-Joshimath-Malari road. The post-disaster geological the need for realignment of the Rishikesh-Joshimath-Malari road. The post-disaster geological assessment of the slope stability problems was carried out during FS 1969-70 (Kumar and Shome, 1970). The damages include the following.

The Rishikesh-Joshimath road breached at km 228 (near Bhimtala, about 3 km from Chamoli towards Pipalkoti). About 1,000 m stretch of the road, made through a thick terrace deposit, was completely breached by the river, as a result of river erosion during flood. About 2 km stretch on the Chamoli side and 1 km on the Pipalkoti side of the approach road to Birehi Bridge abutment had been breached as a

result of change in the course of the Birehi Ganga within the region of its flood plain. The Birehi Ganga had changed course so markedly, that the bridge was left high and dry and the entire river was flowing to the left of it i.e. a shift in course towards the south by about 25-30 m. There could be two alternatives for the road alignment in this portion (i) to cut the road in rock, parallel to the old road, and approach the old bridge after diverting the river back to its original course, and (ii) to have bridge about 700-800 m downstream of the existing bridge on a freshly exposed rock hump, thereby saving the length of road to be reconstructed and avoiding the prospects of major landslides which were likely to be initiated by any side of the old road. The worst affected reach of the entire road between Km 247 to 256 where two girder bridges and nearly 4 km stretch of the road had been completely washed away. The river bed had silted up and rose by about 10.15 m and had changed its course drastically, which led to the complete wiping out of the habitation at Belakuchi. Large and old landslides had been reactivated by toe-erosion consequent upon the change in the river course and this had led to the removal of large portions of the old road and the fields of the Tangni and Sial villages.

The Joshimath-Malari road was breached at km 9.2 and km 12.2. In the former, nearly 20 m road was damaged due to a slide while in the latter nearly 2 km road stretch was badly damaged. The affected stretch of the road lay between the Dhak village and the Dhak *nala* crossing.

Some of the major landslides occurred include; (i) Sial Slide (width 300 m and height 150-180 m) shows a subsidence of about 5-15 m. The material affected is old landslide debris, containing pebbles and boulders of dolomite, limestone, phyllite and slate set in a clayey matrix. It is caused due to undercutting and toe erosion by the river; (ii) Hilang Slide, caused due to the toe erosion by Karmanasa stream resulting in reactivation of 0.175 km² of paleo-landslide deposits; (iii) Dhak Slide is characterised by a prehistoric landslide, as reported by Heim and Gansser in 1939. The slide-debris during this knot, had blocked the Dhauliganga and led to the formation of an epigenetic gorge at Tapoban. This prehistoric landslide had possibly originated due to the slipping of beds along the foliation plane of the gneiss dipping at an angle of 40°-45° due north on slopes inclined at a much steeper angle in this direction.

The Dhak *nala* had a very narrow section and during the heavy rains of July 1970, due to toe erosion nearly 0.2 km² of the old slide got reactivated, and a huge block slump-slide took place in which the subsidence was noticed to be of the order of about 45 m. The materials derived from this slump-slide and those brought down by the Dhak *nala* blocked the Dhauliganga river at the confluence, thereby creating a temporary landslide dam about 15-20 m in height across the Dhauliganga, (iv) Tangni Slide: the Pakhi-Tangni fault has so badly dissected the white dolomites exposed in this area that these rocks behave almost like debris, i.e., like slumps of rock held together by poor cohesion. Therefore, on saturation due to development of pore pressure, the material moves downslope like a debris slide, (v) Belakuchi Slide, was known earlier and had been in the nature of a planar slide along the slippery surface of a talc schist band. This time, the old slide got reactivated during the high floods in the Alaknanda and the consequent toe erosion in this slide area.

It was also proposed to realign the Rishikesh-Joshimath road towards the right bank of Alaknanda River. According to this alignment, the road would cross the Alaknanda River near Chamoli along the existing bridge on the road to Gopeshwar and climb up to a height of about 100 m above the river level to negotiate the slide zone seen just downstream of the Chinka village, which is itself located on presently stable, old slide debris. After reaching Chinka, the realigned road can go on the level up to the village Hat, where it has to climb up by about 6 m to come up to about El. 1400 m for the bridge-crossing of the Mena *nadi* and its western tributary. From here onwards, the road may have to go practically on even gradient upto the Kalpaganga *nadi*, cross it with a bridge and then cross the Alaknanda River by another bridge. Thereafter, this road will join the “zigs” now available along the present road for climbing up to Joshimath.

3.5.3 5th-6th August 1978 event and resulting blocking of Bhagirathi River, Uttarkashi district

On 5th-6th August 1978, River Bhagirathi was blocked for 10-14 hours about few km upstream of Gangnani in Uttarkashi district and later breached thereby resulting in floods at lower part of the valley. The blockade was caused due to massive debris flow along Kanauldia *gad*, a western tributary of Bhagirathi River flowing through glacial

moraines and debris. The blockade resulted in a formation of a 100 m high landslide dam with 250 m wide and 1500 m long lake.

The aerial survey of the area was carried out on 24 August 1978, which was later followed by field checks (Pant, 1978). Geologically, the area exposes granite gneisses with subordinate schists and basic rocks belonging to the Central Crystallines. The Bhagirathi River near the blockade area flows through a narrow valley. The right bank has steep rocky exposures, while the left bank is covered by old moraines and river deposits drained by *Kanauldia gad*. The *gad* has large catchment up to the snow line initiating at an elevation of 3050 m. Due to heavy rainfall, the loose morainic material and debris flowed downstream and choked the Bhagirathi River at its confluence with *Kanauldia gad*.

The breaching of the landslide dam occurred on 6th and 10th August 1978. The resulted floods caused widespread damage to the low-lying lands, houses, roads and bridges in the Uttarkashi district. The damage was severe in Raturi Sera and Ganganani village. The motor road between Raturi Sera and Uttarkashi and beyond upto the Dabrani bridge has suffered extensive damage.

Some of the known river blockade (landslide dam) mentioned in the report include: (i) Gohna Tal in Birehi Ganga created on 6th September 1893. The dam was 300 m high, part of which was breached on 26th August 1894; (ii) Gudiya Tal in Birehi Ganga created in 1869. The resulted flood affected Srinagar town; (iii) Dhauliganga River blockade in 1956. This created a 15 m high dam, near Joshimath; (iv) Rishiganga River blockade in 1967. This created a 30 m high dam, near Reni village; (v) Bhagirathi River blockade near Jhala which created a 300 m high dam. The siltation of this lake resulted in raising of the river bed by about 100 m and production of a river flat at upstream of Jhala; (vi) Bhagirathi River blockade near Maneri dam which created a 100 m high dam. This resulted in diversion of Bhagirathi River on which Maneri dam is located. The old course lies buried under the debris farther on the right bank; (vii) Patalganga River, a tributary of Alaknanda was completely blocked by a massive landslide. The river carved a new course; (viii) the Dhauliganga River was permanently blocked near Tapovan. The river carved a new course.

3.5.4 Subsidence at Gandhinagar, Chamoli district

Gandhinagar is situated on the right bank of River Pindar, just opposite Karnaprayag on Rishikesh-Badrinath motorable road. The subsidence in the area had started in early August 1978 and affected area for about 400 m in width and 500 m in length. It resulted in the formation of cracks, partial collapse and slight tilting of a few newly constructed houses. Subsidence of the order of 5 cm to 40 cm has also been noticed at some places along the road and in the debris near the foot of hill mass indicating a creep movement. The post-disaster geological assessment of the slope stability problems was carried out by GSI (Andotra and Kaistha, 1979).

Gandhinagar village and the motorable road have been entirely located on the thick cover of debris consisting of boulders, cobbles, pebbles and gravels of basic rocks and chlorite schist embedded in a clayey to silty matrix. The debris material is mostly unconsolidated and is mainly derived from an old slide which had taken place on the north-south trending hill mass located on the eastern side of Gandhinagar village. The joints dipping towards valley (glide planes) might have played a major role during the formation of the old slide. Small drainages die out in the debris over which the Gandhinagar village is located. Thus the debris-covered zone is being charged by these small drainages during the rainy season. This is evident from the fact that at a number of places in the debris covered zone seepage of water has been observed. The ground water in the debris-covered zone appears to have played a significant role in the subsidence of the area. The pore pressure developed in the debris, washing out of fine material from the debris due to infiltration of rainwater, is surmised to be the factor that had caused differential settlement of the foundation of the houses/ road in Gandhinagar area.

Remedial measure such as construction of diversion canal, drainage, etc. to arrest the subsidence in the area has been recommended.

3.5.5 14-15 August 1979 event in Sisna and adjoining villages, Pithoragarh district

The villages of Sisna, Gasila, Beti, Syankuri and Juma lying on the right bank of the river Kali and about 350 m to over 600 m above the Dharchula-Tawaghat motor road

Toposheet: 62O/9) have experienced the effects of devastating landslides on the 14 and 15 August 1979, after heavy rainfall. In Sisna village about 15 people got perished, besides huge loss to property. The post-disaster geological assessment of the slope stability problems was carried out by GSI (Agarwal and Sanwal, 1979).

The Juma slide lies between the Kulla and Rela *Gad*, whereas Syankari slide lie between the Rela *Gad* and the Rungti *Gad*. The Sishna, Betitok and Gasila slides lies upstream (i.e., north) of Rungti *Gad*. All these locations are on the right bank of the Kali River and are more than 60 m above the Dharchula-Tawaghat motor road except for Gasila which is about 350 m above the motor road.

The area exposes the gneisses and schists of the Central crystallines. Large areas are covered by extensive old landslide debris and these areas have been under widespread cultivation by development of terraced fields. A peculiarity of the area is that all along the right bank of the River Kali, rocks are exposed from the river to about 100 m higher elevation and thereafter again exposed for 700 m onwards. The intervening reach between 100 m to 700 m above the river level is marked by a thick accumulation of fallen rock blocks with fines on which extensive terraced cultivation has been developed with sporadic scale pleats or cliffs of in situ rock exposures.

Sisna village is situated on rock with the larger part being on fallen rock blocks along with fines and the slope is over 40°. After the heavy saturation the overburden failed in a slump slide and scooped out a spoon-shaped scar, 60 m wide at the top and about 30 to 40 m down the slope. Gasila village is located about 600 m down the slope from Sisna and the debris of the Sisna slide extensively damaged the fields of Gasila. However, the houses of Gasila village were saved from the debris flow of Sisna slide by a rock hump.

The entire stretch of the ground between Syankuri to Sisna and around Juma is old landslide debris. Heavy saturation and over-steepening of slopes by the rapidly eroding *nalas* have reactivated the partially stabilised landslide debris. The probable mechanism is first surface sloughing followed by slump and slip circle failures.

The villages of Gasila, Beti, Syankuri and the southern portion of Sisna are in a precarious state of equilibrium. To

stabilize these villages and their fields, extensive remedial measures requiring very heavy financial commitment shall be necessary and even then it would not be possible to guarantee their safety. Therefore it may be prudent to shift the habitation of these villages to some suitable and safer location.

3.5.6 16th-17th August 1979 event in Kontha village, Chamoli district

On the night of 16th - 17th August 1979 about 35 major and minor landslides triggered around Kontha village thereby causing severe damage to the life and property. The village Kontha (Toposheet: 53N/3) is situated in the Nil *gad* catchment of Mandakini River. The post-disaster geological assessment of the slope stability problems was carried out by GSI (Kaistha and Chauhan, 1979).

The topography around village Kontha is characterised by an amphitheatre like basin and appears to have been evolved as a result of past glaciation. Due to continuous rainfall since the evening of 16 August 1979, the movement of slipped material started at about 03:00 hrs damaging a few houses and leading to the blockade of the Kontha *nala*. At about 05:30 hrs, enormous quantity of debris, huge boulders measuring up to 3 m diameter and a few big tree trunks along with water flowed down making loud thunder with lightening on the hill slope side. The debris flow swept away the houses and buried them as well as the cultivated fields under a thick layer (1-3 m) of slush and boulders. This sudden influx as described by the local inhabitants was due to breaching of the temporary local blockade in Kontha *nala*. In all 39 human and 40 cattle heads perished in the disaster.

The immediate cause of these slides appears to be heavy precipitation on the night of 16th - 17th August 1979, leading to the oversaturation of the debris resulting in decrease of its shearing strength which was already in a precarious state of equilibrium. It is interesting to note (as the report goes) that a resounding thunder proceeded by lightening exactly coincided with the commencement of the major slide. However, there is no evidence of burning of the vegetation due to lightening. Locally deforestation and reclamation of slopes for cultivation have also contributed to the instability of the slopes. Even after the landslide, seepage of water through be water charged. The debris consists of boulders of granite

the slipped zones was seen indicating the debris continued to gneiss and basic rock with interstitial space filled with clay and silt. Perimeter cracks of 0.5 to 1.5 m width have been recorded on the slopes above the crown. Evidence of creep movement in some of the trees has also been noticed indicating slow movement of the ground. It appears that the detachment of debris started at such cracks by a slow movement along these potential slip surfaces, which was followed by a more rapid movement. The spread of the debris mass in thin layers at the topographic bottom of the area indicates that the debris was in a supercharged state with water.

Keeping in view the existing ground conditions, it is recommended that the area around Kontha should be declared unsafe for the habitation purposes though cultivation may, however, be continued for the time being at places away from the toe of the slopes.

3.5.7 24th-25th June 1980 event and Gyansu nala Landslide, Uttarkashi district

Gyansu settlement is located about one kilometre east of Uttarkashi Town. The main Gyansu *nala*, which divides the settlement into two parts on either bank (old and new Gyansu), joins the Bhagirathi River at the downstream. Thick accumulation of hill wash and debris occurs along the banks and along the *nala* course. The *nala* descends from about 1500 m above msl with a vertical fall of 20 m followed by the bed gradient varying from 40° to 15° at the lower reaches.

The detailed geological mapping of the area was carried out on scale 1:2000 covering 320,000 m² area (Rajagopalan and Agarwal, 1980). The exposed rocks are mainly quartzites belonging to Garhwal Group with minor slate bands and basic intrusive. Rocks are highly jointed and weathered at places. The Gyansu new settlement has been constructed on old slide debris by encroaching upon the banks of the *nala* and restricting its waterway immediately above the Tehri-Uttarkashi motor road where the *nala* gradient is gentle. The width of the *nala* has been restricted to 20 m at higher reaches and 10 m at the road level. During rainfall event of June 1980, the area, located between Bhagirathi River and 200 m upstream of the road, suffered severe devastation due to bank failures and debris flows.

The main cause of the Gyansu disaster was attributed to the faulty planning of the new Gyansu settlement wherein encroachment of the bed width of the *nala* at the shallow gradient level took place, thus restricting the flow of flood discharge. It was recommended to remove the settlement below the road and 200 m above it. *Nala* training measures should be adopted to minimise such disaster in future. This would include: (i) increasing the water way down to its confluence with Bhagirathi River by removal of loose debris lying along the *nala*, (ii) providing heavy stone crates on its banks to control erosion, (iii) construction of suitable debris traps across *nala* courses at various level, and (iv) afforestation in the affected area.

3.5.8 9th September 1980 event along Rishikesh-Gangotri road, Uttarkashi district

On 9th September 1980 (13-45 hrs), a landslide, measuring 400 m length, 80 m width and 30 m depth, took place about 4.6 km north of Gangnani (Lat. 30°54'20"N; Long. 87°40'53"E; Toposheet: 53J/9) on the left bank of the Bhagirathi River at km 193.860 on the Rishikesh-Gangotri road, opposite to the Kanauldia *gad*. The slide resulted in 13 casualties and washed away a portion of the terrace cut for the proposed realignment of the road between Gangnani and Dabrani. The post-disaster geological assessment of the slope stability problems was carried out by GSI (Rajagopalan *et al.*, 1980).

The rocks exposed in the area are mainly banded augen gneiss and garnet-mica schist belonging to Central Crystallines. The slide has taken place in an old landslide affected area probably due to reactivation of the movement owing to the following reasons: (i) gradual removal of fines and saturation in the successive monsoons, (ii) over-steepening of the slope due to newly cut terrace of the road and (iii) the incident of 5/6 August 1978 wherein huge material flowing down the Kanauldia *gad* which might have hit the slope on the opposite bank, making it unstable.

It has been recommended to negotiate this slide by means of two Bailey bridges as an immediate solution.

3.5.9 11th September 1987, 12th March 1988, 4th/5th July 1988 events in Naina Devi area, Nainital district

The history of Nainital town is replete with instances of

landslides and other manifestations of instability of slopes around the town. In fact, the famous "flats" of the town itself owes its origin to a massive landslide, which occurred on the 18 September 1880. During the year 1987-88, a series of three landslides emanated from the Naina Devi ridge, overlooking the Nainital Lake from the north. The post-disaster geological assessment of the slope stability problems was carried out by GSI (Pant, 1988).

The Naina Devi ridge is located about 2050 m towards northwest of the lake. It trends in nearly north-east-south-west direction and has Naina peak (EL. 2610 m) as the highest point. From the peak, the ridge turns in the easterly direction towards the "Snow view". The hill slope, rising from the lake (EL. 1940 m) and ultimately culminating on the Naina Devi ridge is initially very gentle (7° and 15°) up to the Upper China Mall (EL. 2150 m), a distance of about 1500 m. This part of the slope is very thickly inhabited. Thereafter, up to the ridge, except the cliff face which is nearly barren, the slope is thickly forested and gradually steepens from about 24° to 65° but again flattens to about 45° in the last 50 m. Lower Krol limestone occurs on the Naina Devi ridge. The rocks are represented by thinly bedded and jointed dark grey-green shales and slates, occasionally associated with thin beds of limestone and cherty layers. On the top of the ridge, (EL. 2550 m) a 3-5 m deep cap of highly clayey soil occurs over the rocks. The bedding planes of the rocks, expose near the top of the ridge with strike parallel to the ridge and dip about 45° in SE direction, i.e., towards the lake.

On 11th September 1987, a slide, measuring 75 m length and 15-20 m width, slumped down towards the lake along a series of four cracks. The material included soil and rock (Lower Krol shales and slates). The average vertical displacement ranged 1.5-2 m, with maximum being 4.0 m. The total cumulative displacement along the slide, i.e. between the lowest and highest benches was of the order of 10 m. Since the slope below the cliff face is inclined at 24° - 38° and is highly forested most of the finer fragments settled down in the vicinity of the base of the cliff. A few of the more resistance blocks rolled farther down and hit the trunk of one or the other tree, lost their momentum and came to rest. Immediate remedial options such as arrangement for drainage and levelling off topmost crack on the ridge were suggested.

Another landslide emanated from Naina Devi ridge on the 12th March 1988. Following heavy rains, a part of the slumped material left behind on the Naina Devi ridge by the landslide of 11 September 1987, came tumbling down on the night of 12 March 1988.

3.5.10 August 1998 events in Okhimath, Rudra prayag district

Between 11th and 18th August 1998 following heavy spells of rainfall, about 300 landslides triggered near Okhimath in Rudraprayag district in Uttarakhand (Fig. 3.38). As per local administration, the event resulted in 101 casualties, besides death of 422 cattle, damage to 822 houses and 411.55 ha of agricultural land. In 29 villages about 1395 families were affected. The slides occurred in Toposheet: 53N/2. Landsliding occurred in two phases: 11th-12th August 1998 and 18th-19th August 1998. The recorded rainfall (from Okhimath rain station) gives 1410 mm rainfall between 1 June and 12th August 1998. The data suggest presence of two long spells of heavy rainfall prior to the event. These spells lasting for 6 days (20th July to 25th July 1998) and 9 days (30th July to 7th August 1998) have 380 mm and 490 mm rainfall, respectively.

Geotechnical reconnaissance survey was carried out between 26th and 30th August 1998 covering 20 km² area within Mandakini, Kaliganga and Madhyamaheshwar river valleys (Rawat and Rawat, 1999). The reaches from the confluence of Mandakini and Madhyamaheshwar rivers up to Pondar village (now buried under slided mass) along the Madhyamaheshwar rivers and up to Kotma village along Kaliganga River are severely damaged. These reaches of the valleys are nearly 6 km long each. Landslides abound on slopes of the ridge between Madhyamaheshwar and Kaliganga rivers. Many slides have occurred on the opposite banks also in both the valleys. Sliding is also frequent on the banks of Mandakini River around its confluence with Kaliganga near Narayankoti and along Kyargad, a left bank tributary of Madhyamaheshwar River near Mansona. Numerous landslides had occurred earlier on 16th-17th August 1979 in the Mandakini valley, west of Augustmuni following heavy rains in a very short duration.

Geologically, Proterozoic rocks of the Central Crystalline Group occupy the affected area. The rock

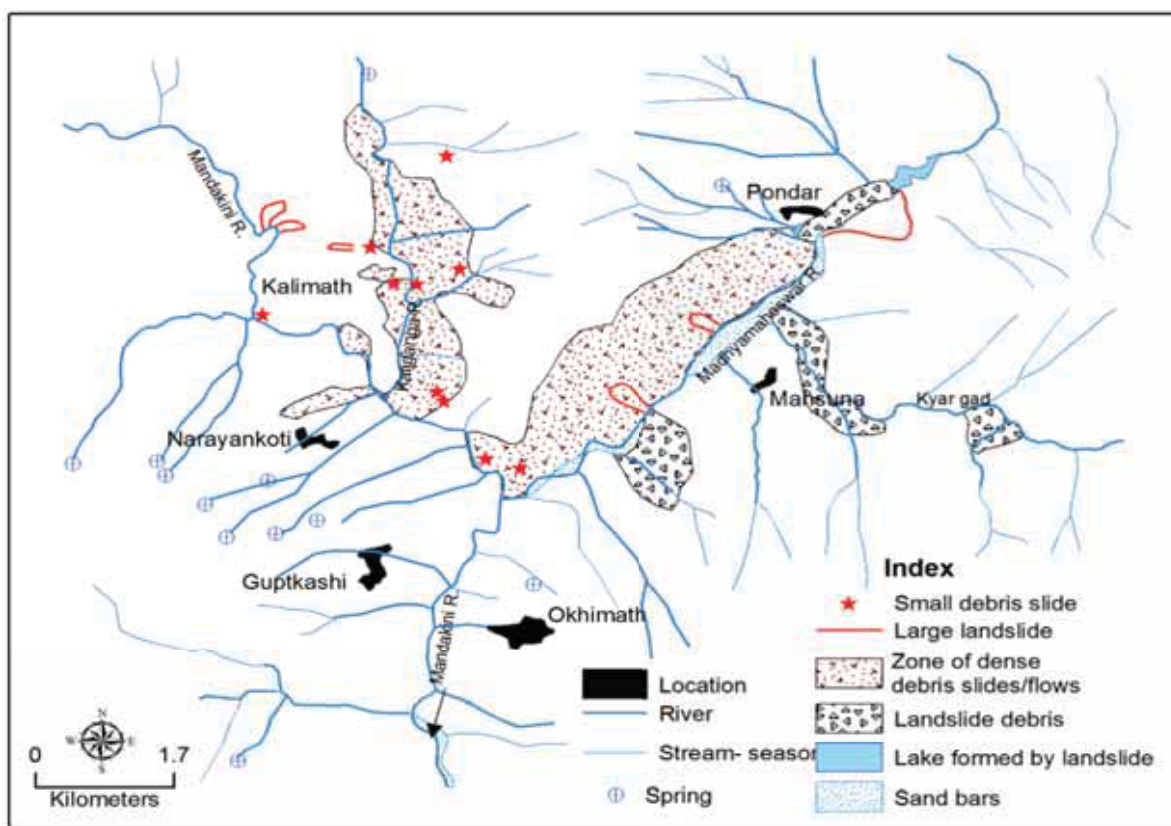


Fig. 3.38. Sketch showing landslide distribution triggered during August 1998 event in Okhimath.

includes granitic gneiss, quartz-sericite schist, quartzite, and garnetiferous mica schist. Foliation dips generally at moderate angles in NE to NNW directions. The overburden material is mostly transported soils (colluvial) derived from gneisses and schists. Fluvial degradation and soil creep are the main geomorphic mass wasting processes operative in the area due to high gradients and wide temperature fluctuations.

The present landslides are mostly debris slides and flows occurred between 11th and 12th August 1998. These have affected the terrace cultivated glacial deposits and relatively gentler slopes. Their size varies from few meters to few hundred meters. These landslides have developed on steeper and peripheral slopes. Ground condition in such slopes favoured higher velocity subsurface flow along the base of thin debris layer, which weakened the soil structure and the bond with bedrock by piping. Condition suitable for rapid and progressive soil failure was thus created which was necessary for development of debris flow.

The largest slide in the affected area is developed in bedrock, on the left bank of Madhyamaheshwar River in Kothi-Pondar area. It occurred on the night between 18th and 19th August 1998 during heavy rain. This slide extends to an estimated height of about 500 m above the erstwhile river bed. The original river bed along with village Pondar on its right bank is now buried under the slide muck spread over nearly half square kilometre area. This boundary muck extends to more than 50 m height on the right bank above the present river level apparently due to the momentum of rapid slide movement. The total volume of debris released is about 10 million cubic metres. This slide created a lake on Madhyamaheshwar River, measuring a kilometre long and 25 m in height. This slide is probably the result of daylighting of valley slide dipping large continuity weak planes of the rock mass, by rapid cutting by the high gradient river. Since these planes are not large enough to cause planar slip of such size, the upper weaker and probably more disintegrated rock mass failed in rotation after the toe failure. The fault along

the river may be responsible for rock fracturing. At high reaches, the disintegration of rock mass could be due to freezing and thawing action and root penetration.

3.5.11 July/August 2001 event along Dehradun-Mussoorie-Chamba road

During July/August 2001 due to heavy rainfall, incidences of landslides caused blockade of Dehradun-Mussoorie-Chamba road leading to disruption of tourist traffic and shortage of essential supplies in Mussoorie Hills. GSI carried out rapid post-disaster assessment of the landslide affected area during FS 2000-2001 (Ghildyal and Gairola, 2003). The slide near Galogi, located about 2 km from Kolhukhet toll gate towards Mussoorie, resulted due to toppling of massive limestone band overlying thinly bedded fractured limestone/ shaly limestone belonging to Krol Supergroup of rocks. The slide affected 50 m of the road and 70 m of hillslope. Remedial measures like masonry support wall at toe of slide, dressing of overhang blocks and proper dumping of muck had been suggested.

In the night of 22nd July, 2001, landslide incidences occurred between Bataghat 2 km and 4 km along Mussoorie-Chamba bypass road and resulted due to ongoing road widening activities and removal of rock boulders from the toe part of the steep slopes for use as road metal. The retaining wall supporting the motor road was also partially damaged. The rock formations exposed in the area are thinly bedded limestone, purple and red laminated quartzitic shale belonging to Krol Supergroup of rocks. The slide crown is about 15 m high and extends for 25 m along the road. Presence of tilted trees near crown is suggestive of further extension of the slide in near future.

3.5.12 August 2002 event (Khanera Landslide), Uttarkashi district

The Khanera landslide was developed mostly in the last five years on the old PWD road on the left bank of Yamuna River near Khanera village, about 14 km north of Barkot along Delhi-Yamnotri highway. The slide was reactivated in August 2000 during heavy rains and the slid material inundated the left bank and part of river Yamuna for about 300 m in length and 150 m in height. GSI carried out rapid post-disaster assessment of the landslide affected area during FS 2000-2001 (Negi, 2002).

This slide is possibly triggered due to toe cutting by the river Yamuna, along a very prominent joint set (N-S/50° W) dipping towards right bank. Another prominent joint 75°: N15°E set, which cuts across the former and makes wedge that facilitated block movement. The rock formations exposed in the area belong to Garhwal Group comprising white massive quartzite, quartz-sericite schist and limestone intruded by basic intrusive. Large ground cracks (15 cm wide and 10-15 m long) are developed in the slide mass and also on the firm ground above the head of the slide, up to about 50 m above the slide scar. The cultivated field above the slide zone are also traversed by tensional cracks and thus the area is quite vulnerable for sliding. In case of further activation of the slide, the Khanera village may also be in danger. It is worth mentioning here that the Yamnotri yatra route was earlier located on the left bank, but due to the formation of the slide and its subsequent enlargement, the road was shifted to the right bank of Yamuna river by constructing two steel bridges.

3.5.13 August 2002 event in Budhakedar region, Tehri district

On the night of 10th August 2002, intense rainfall and cloudburst triggered numerous landslides/debris flows in 25 km² area around Budhakedar region of Tehri Garhwal district (Fig. 3.39). These completely devastated 38 houses in 17 villages and damaged about 61 ha cultivated land and resulted in the death of 28 people. Geological assessment of the affected area was carried out by means of traverse mapping on 1:25,000 scale in toposheets: 53J/10SE and 53J/10SW between 27 and 30 August 2002, covering villages Agunda, Medh, Marwari and Kot (Sharma and Sanwal, 2002).

In Agunda, the houses on the left bank of Gupti *gad* were located much below the FRL of the *nala*, thus exposing the settlements to flooding during high discharge conditions. In the Medh *gad* section, toe erosion on the left bank caused failure of overburden mass and blocking of the *nala* course for 2 days (Fig. 3.40B). Resultantly, the houses on the left bank have become vulnerable to sliding and settlements on the right bank are more prone to flooding. The casualties in Marwari village were mainly due to faulty locations of the houses very close to the natural depression/dry *nala* (Fig. 3.40A and C). In Kot village, destruction was due to free flow

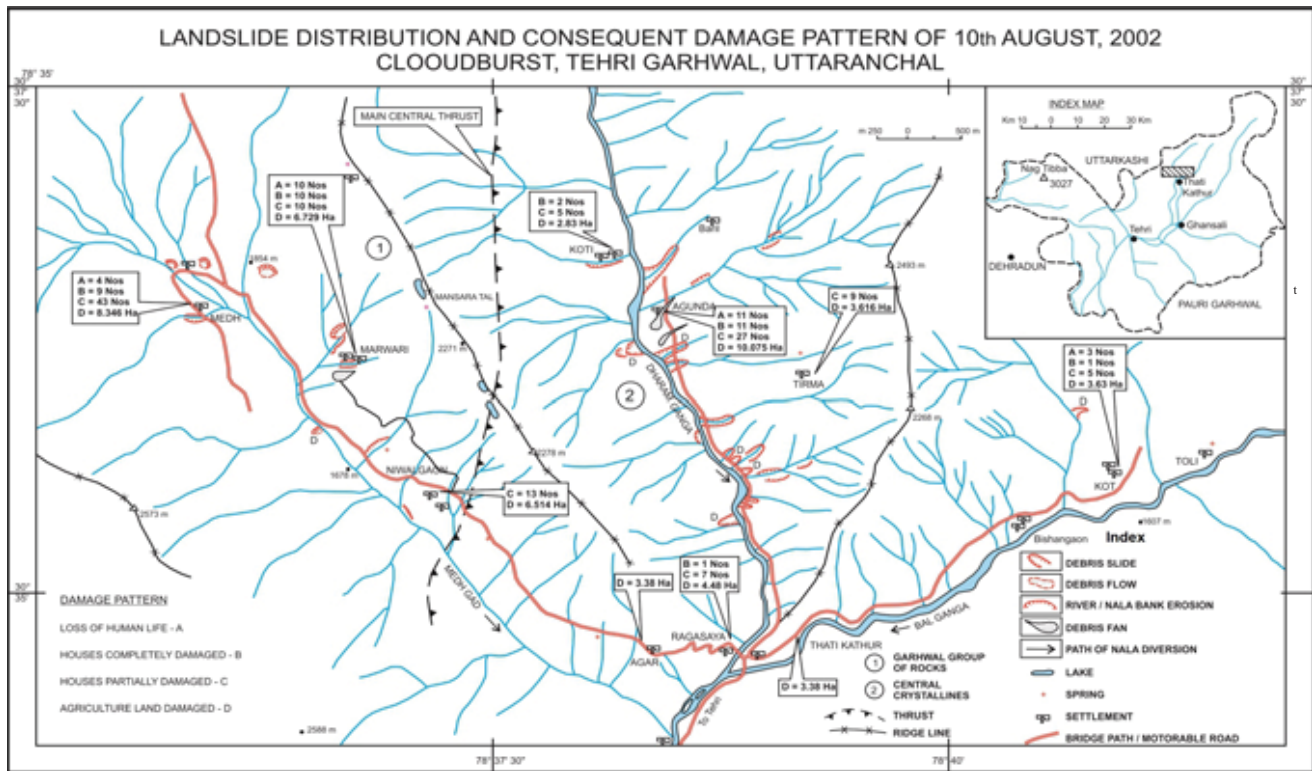


Fig. 3.39. Landslide distribution and consequent damage pattern of 10th August 2002 cloudburst, Tehri Garhwal, Uttarakhand.

of water charged debris along the slope.

3.5.14 Landslide on Hill By-Pass road near Mansa Devi Temple, Haridwar district

A hill by-pass road between Kharkhari and Lalitha Rao via downslopes of Mansa Devi temple passing through "Rajaji National Reserve Forest" area was constructed sometime in 1998-2000 compromising even the environmental aspect of the alignment. The 7 km by-pass road on both ends meets the main Haridwar-Jwalapur road which passes through the Haridwar town. The by-pass road is not operative at present due to damaged section between 2.10 km and 2.60 km and recurring rock falls at many locations (Fig. 3.41). The geotechnical assessment of the damaged area was undertaken between 20th and 23 September 2005, covering 10 km on scale 1: 25,000 (Sharma, 2006).

The by-pass road section traverses through an alternate succession of sandstone, clay shale, sandstone and siltstone belonging to Lower and Middle Siwalik formations. The general trend of these rocks is N55°W-S55°E dipping 20°-

25° in south-westerly direction. The rocks are generally friable, weathered and apparently have low compressive strength. The right bank slopes of Mansa Devi *nala* are governed by steep joints that result into escarpments. The northeastern portion of the left bank of *nala* is generally dip slope and is occupied by debris material with thickly vegetated cover. Most part of the area is covered with drift deposits comprising thick debris (approx. 10-15 m) and weathered soil. The debris has more weathered and clayey component which has apparently low friction especially under saturated conditions.

The critically damaged portion of the road between RD 2.10 km and 2.60 km, constructed over debris material, is the result of excessive toe erosion. The rock-debris interface as seen on left flank of *nala* (Fig. 3.42) section of Mansa Devi *nala* is particularly vulnerable due to low to moderate dips of bedrock over which the clayey debris material lies. The rotational type of failure in debris due to toe erosion is the major cause of subsidence and consequent breach of road section. The critical section of road damage on left flank of

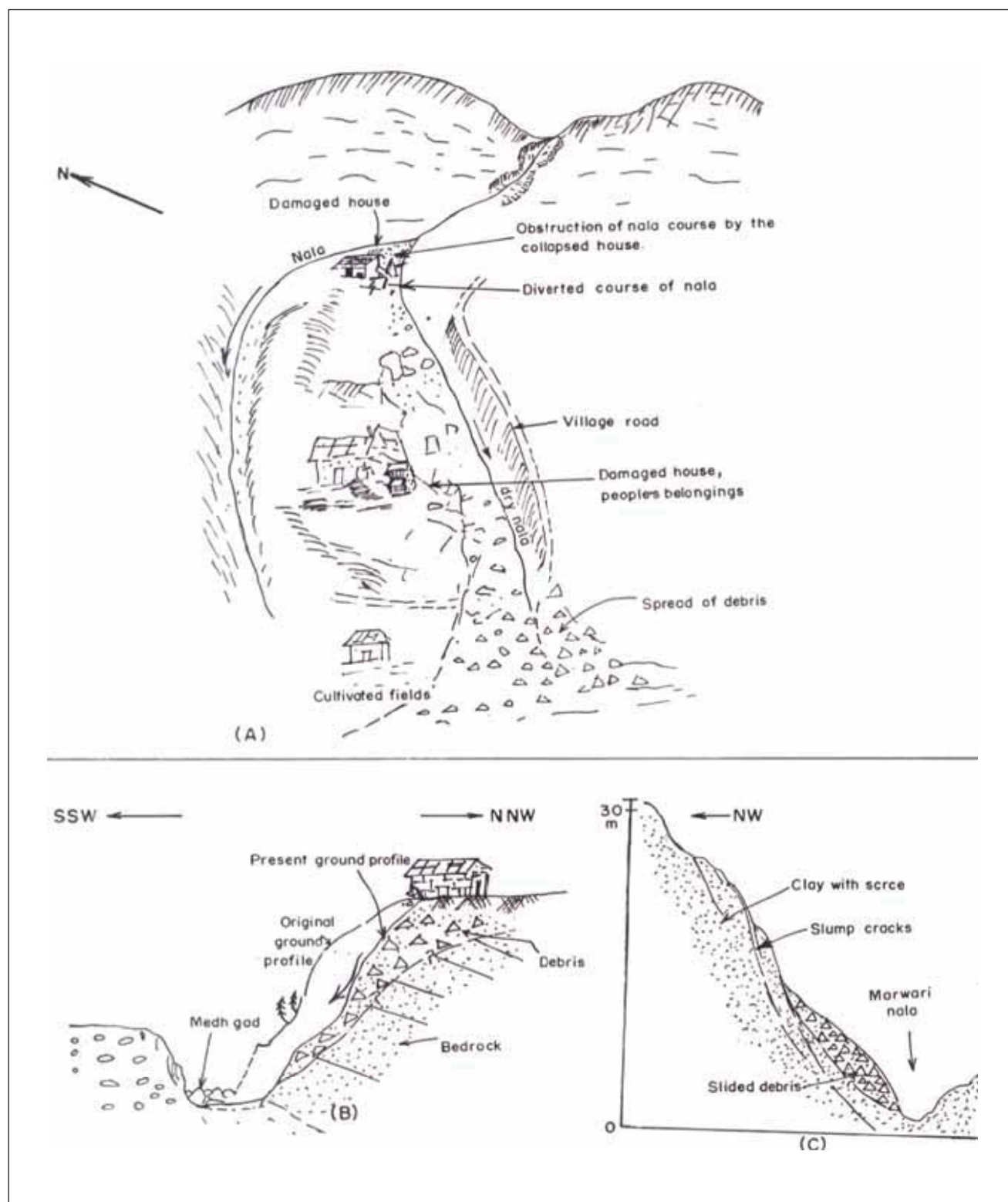


Fig. 3.40. Sketch showing path of debris flow, change of *nala* course and damaged house in Marwari village (A); Slope failure on left bank of Medh gad due to toe erosion has endangered the settlement (B); and slump in thick soil due to oversaturation on right bank of Marwari *nala* (C).

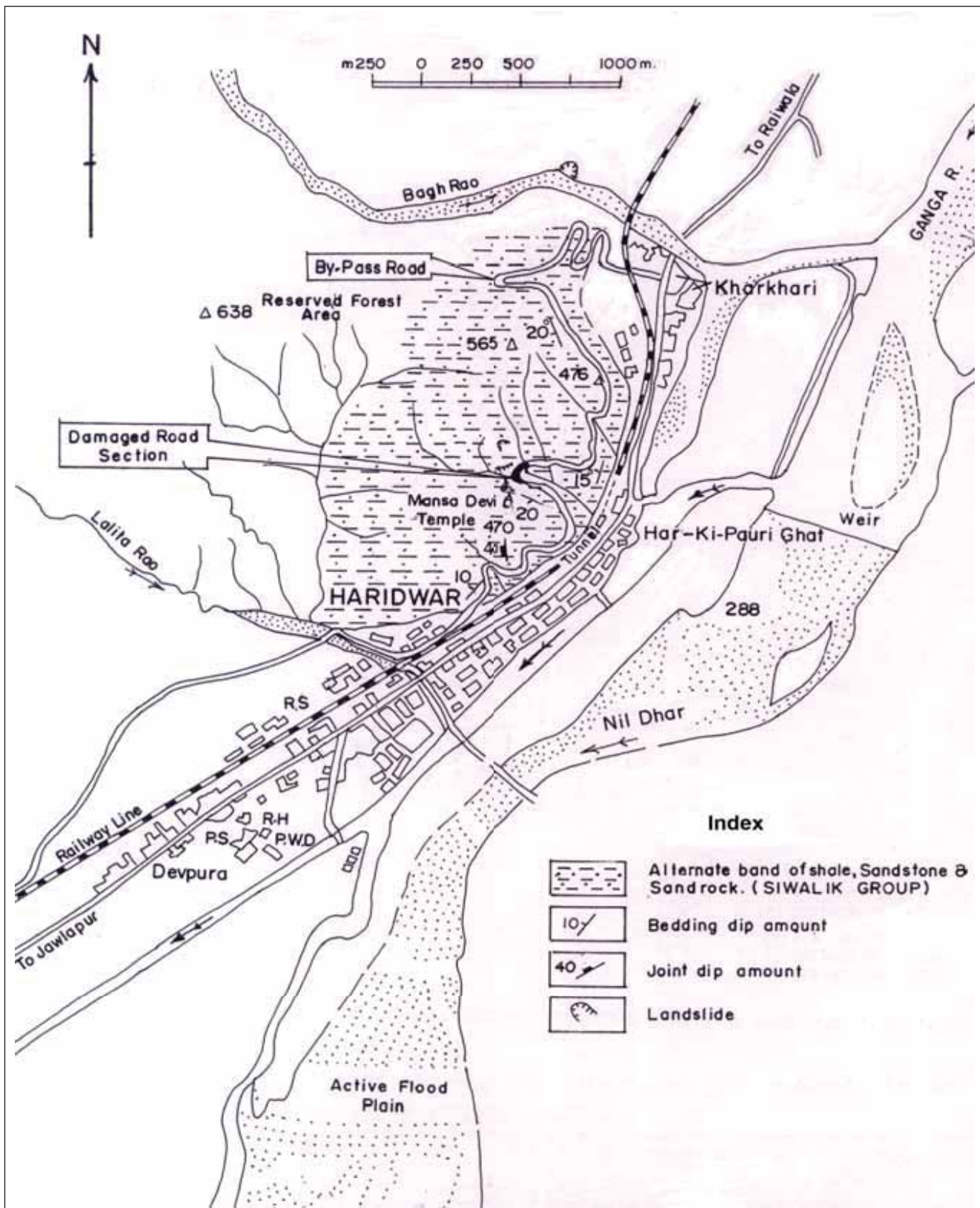


Fig. 3.41. Geological map of a hill by-pass road near Mansa Devi temple.

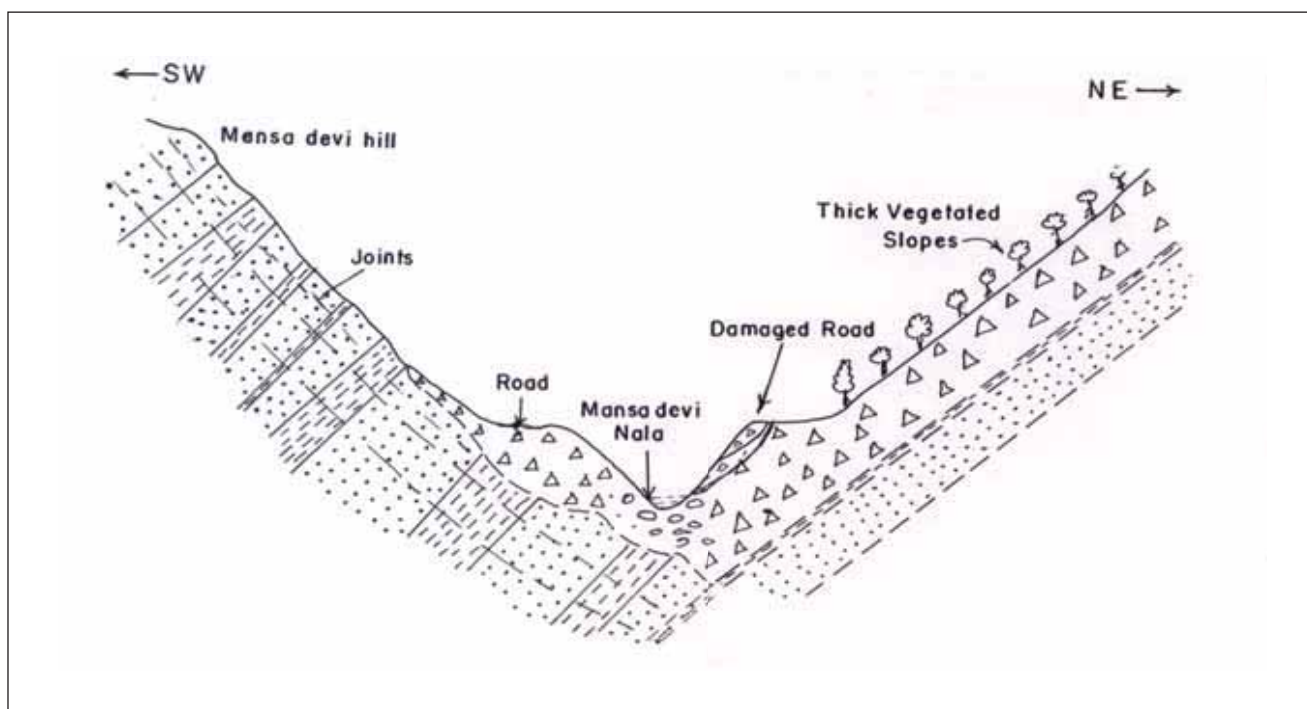


Fig. 3.42. Sketch geological section across Mansa Devi *nala* showing damaged portion of the road due to toe erosion.

the *nala* has a number of smaller streams that join the main Mansa Devi *nala*. Deep *nala* erosion in the main Mansa Devi *nala* and within these subsidiary streams on the left bank induce rotational type of failures in clayey debris resulting into sinking, tilting and sliding of 500 m road stretch and development of 2-3 m wide cracks.

It was recommended that monitoring of slopes was to be immediately taken up using instrumentation and by construction of some tell-tale marks to know the extent and rate of sliding in the area.

3.5.15 Monitoring of landslides along Pipalkoti-Badrinath road

A regular observation and monitoring of landslide incidences is of paramount importance as systematic monitoring greatly aids in understanding the geological and other factors responsible for the landslide occurrences and contributes significantly to hazard mitigation programmes. With this objective, monitoring of landslides that have (re)activated due to road widening along Pipalkoti-Badrinath pilgrim route was carried out in the month of January 2005 covering 140 km. The work was carried out on scale 1:50,000, covering toposheets: 53 N/3, 53 N/6, 53 N/7

and 53 N/10 (Jaiswal and Baruah, 2006).

The area forms part of the Higher Himalaya and is occupied by Proterozoic sequence of rocks comprising gneisses and schists of Central Crystalline Group and metasedimentary rocks of Garhwal Group. The Main Central Thrust (MCT), in the south of Helang village, separates both the groups from each other. The rocks are capped at places by loose, unconsolidated, Sub-Recent to Recent sediments.

A total of 35 new slide incidences were recorded which include 16 debris slides, 11 rock slides and 8 rock-cum-debris slides. Out of these incidences, a detailed inventory of 20 slides was prepared.

Along Helang-Hanuman Chatti sector, there were 17 landslides reported during earlier investigations. By January 2005, this number rose to 28, of which majority was the result of road widening activity. Some of the major slides are at Lambagar Chatti, Baldora, Patalganga and Belakuchi. The gneisses and schists of Joshimath Formation are most vulnerable to rock fall because the rocks are highly distressed. The steepening of the slope during road cutting has resulted into five notable rock falls/slides in this

formation such as Baldora slide zone. The Baldora rock fall is a typical testimony of uncontrolled toe cutting of steep slopes during road widening process. On this site, mostly gneisses, belonging to Joshimath Formation of Central Crystallines, are highly distressed and though dips are into the hill, wedge/planar failure is frequent due to vulnerable valley facing joint (25° - $45^{\circ}/220^{\circ}$). The recurrence of slide in past has modified the slope to 70° and reached up to a height of more than 100 m above road level, thus making the slide more dangerous and hazardous. The slide is still active and extending. Need for taking up proactive measures, in these slide affected areas, is strongly felt.

In Helang-Patalganga-Pipalkoti section, road widening is being carried out near Patalganga village, south of Helang and south of Belakuchi, the effect of which is manifested by the presence of huge rock fall at Patalganga and south of Helang, besides number of notable cluster of debris slides as well as rock falls. A massive slide at Belakuchi, is one that owes its existence due to the toe undercutting by *nala* rather than road widening. A rock fall cluster occurring south of Helang contains three rock slides of varying morphometry. All the three slides are resulted due to road widening activities involving removal of toe thereby initiating detachment of distressed and shattered rockmass along two joints sets and their intersection. This section of the route is now a persistent rock fall zone and its control seems to be difficult because of steep slope (80°) and great height (70-80 m).

3.5.16 July/August 2007 event in Tehri and Uttarkashi districts

A large number of landslides, landslips with subsidence and widespread cracks in cultivated terrace slopes and in houses developed at several places in the Narendranagar tehsil of Tehri district, and Dunda and Bhatwari tehsils of Uttarkashi district during July-August 2007. A preliminary investigation was taken up from 6-15 August 2008 to ascertain the probable causes of these incidences and to suggest preventive as well as mitigative measures (Kumar, 2010). The affected areas include Kandari village, Urgani toke of Bhaisark village and Bhitali toke of Phart village, Narendranagar tehsil, Tehri district (toposheet: 53J/8); Pilang, Jurab and Saura villages of Bhatwari tehsil, Uttarkashi district (toposheet: 53J/9); Siliyana toke of Jaspur

village and Paduli toke of Gyansu village, Uttarkashi district (toposheet: 53J/6).

The following general suggestion and recommendations have been given for mitigation of this problem. In Pilang and Jaurab villages, all the settlements on the distressed ground should be shifted to rocky and unsaturated foundation with gentle slopes away from the unstable slope. Secondly, the entire ground cracks affecting the agricultural field are to be packed with impervious soil. Suitably designed retaining wall/ breast wall is required to prevent the under cutting along the toe by Jaurab *nala* as manifested by tilting of trees. The movement of rock-cum-debris slide at Kandari village facing Bhitali toke can be minimised by slope moderation by benching of slopes at less than 15° . Plantation of some special type of plant species can protect and stabilise the slope to further movement. Damaged houses in Kandari village have already been recommended for evacuation by the district officials. It has been suggested to construct the retaining wall/wire crates in Bhitali toke of Phart village at all along the stream bank with deep foundation. These structures will protect the terrace from stream erosion by Chandrabhaga *nala* during high flood. The huge amount of debris material that has been deposited in Chandrabhaga *nala* should be removed manually so that channel/*nala* water can pass or flow easily. This practice will provide protection to Bhitali terrace from stream erosion. Urgani toke has also been facing same problem of ground cracks. Houses that have been affected are to be shifted to the safer place from the affected slope. Suitable designed retaining wall/ breast wall at the toe of the Saura rock fall/slide and Silyana village may be safer for houses which are situated at the toe of the slide. Secondly, in Saura and Silyana villages making suitable lined (cemented) catch drain for surface water and chute drains will be safer technique to prevent seepage as well as oversaturation of ground during the high flow of *nala* in rainy season. All the houses affected by development of cracks at Silyana village have to be vacated and shifted to a safer place away from the existing location. Secondly, the entire ground cracks affecting the agricultural field are to be packed with impervious soil. Inhabitants of Paduli have been suggested to seal the cracks developed in the houses in consultation with architect after blasting operations in tunnel are completely stopped/over.

3.5.17 8th August 2009 event in Pithoragarh district

On the night of 8 August 2009, heavy rainfall followed by cloudburst triggered widespread debris flows in about 30 km² area of Jhakula river catchment in Pithoragarh district, Uttarakhand in toposheets: 62B/4 and 62C/1. 43 people have reportedly been killed by the landslide, besides severe damage in Jhekla (Chachana), La and Rumidoula villages with loss of 39 houses, 120 cattle and part of agricultural fields. The communication route to Munsiyari was also severed due to number of landslides. Rainfall was particularly intense in the catchment of Jhekla *nala* (locally named as Sukalya rauli) and Runliya *gad*. Both these streams join the Jakula *nala* from right flank. GSI carried the post-disaster geological assessment in FS 2008-09 (Sharma, 2010).

The rocks occurring in the area belong to Central Crystalline Group and Garhwal Group. Separating these groups of rocks, a major tectonic element, Main Central Thrust (MCT) trending WNW-ESE, passes through the area. The valley slopes in the area are mainly occupied by thick pile of overburden deposits largely of glacial, fluvio-glacial and fluvial origin.

The most affected Jhekla *nala*, where severe bank erosion and series of landslides have taken place, is still in the process of degradation and posing threats to the adjoining slopes, habitation and road network. The close habitation near Jekla (Chechana) and Mandalkiya, is vulnerable to landslide hazard and needs suitable rehabilitation in safer proximal areas such as in Dor village. The landslides are widespread in the catchment of Runliya *gad* and its sub-basins. The right flank of Runliya *gad*, from river bed level to the elevation of 1600 m is in high hazard zone and habitation in the basin is highly vulnerable. These zones include select areas in Mahargaon, Sainrathi, Arkhet and Kimkhet. Here debris flow has affected agricultural and village land.

People's awareness programme is highly felt to educate them in regards to process of mass movement in heavy rainfall days. District level warning system and vigil in the environs where the minor rockfall situations are noticed ought to be the significant aspect of the mass contact programme. In addition, a suitable regulation for construction of houses in high relief hilly terrain and close

proximity to *nala* bed level is to be enacted to mitigate the consequences of the hazard.

3.5.18 18th September 2010 event in Almora district

At about 12:40 hrs of 18 September 2010, heavy rainfall followed by cloudbursts triggered numerous debris flows in and around the Almora town in toposheet 53O/10, reportedly killing 30 people besides inflicting damage to several houses, agricultural land and livestock. The debris flows also caused severe damages in Baltabari, Devli, Bhetuli, Pilkha and Joshiyara villages. GSI carried the post disaster geological assessment in FS 2010-12 (Sharma, 2012).

The most affected area was Baltabari and Devli villages. The large quantity of slope debris made up of unassorted blocks of rocks in sandy and clayey matrix, being highly susceptible to sliding under oversaturated condition, initially moved from higher elevation at approximately 1830 m near Baltabari village. After the initial slope failure compounded with bank erosion, the highly charged debris passed through narrow, elongated basin of Balta *nala* and caused deaths and destruction at Baltabari village (Fig. 3.43A-B). The run-out distance of debris movement is of the order of 500 m from its point of origin upto *nala*. A debris column of 3-4 m has been noticed in the zone of accumulation of the slide where most of the village houses were damaged.

The village Devli was affected due to slides that occurred at about 13:00hrs on 18 September 2010. Prior to that continuous rainfall had been occurred from 16th to 17th September 2010. The sudden movement of saturated overburden material in its run-out distance of about 1000 m up to Swal *nadi* resulted in damage and destruction of houses and reportedly killed 10 people. The slide failure got initiated in a surface stopping in S30°E direction at about 35° angle in the crown portion. The entire slope has number of kinks or breaks in slopes. The high momentum of debris mass from crown of the slide at an elevation of about 1540 m to the toe at 1200 m had a cascading effect of debris flow along a first order stream in which village settlements, village roads and other structures were located (Fig. 3.43C-D).

3.5.19. Monitoring of Sher-Ka-Danda Landslide in Nainital, Nainital district

Landslides have occurred in Nainital town time and again.

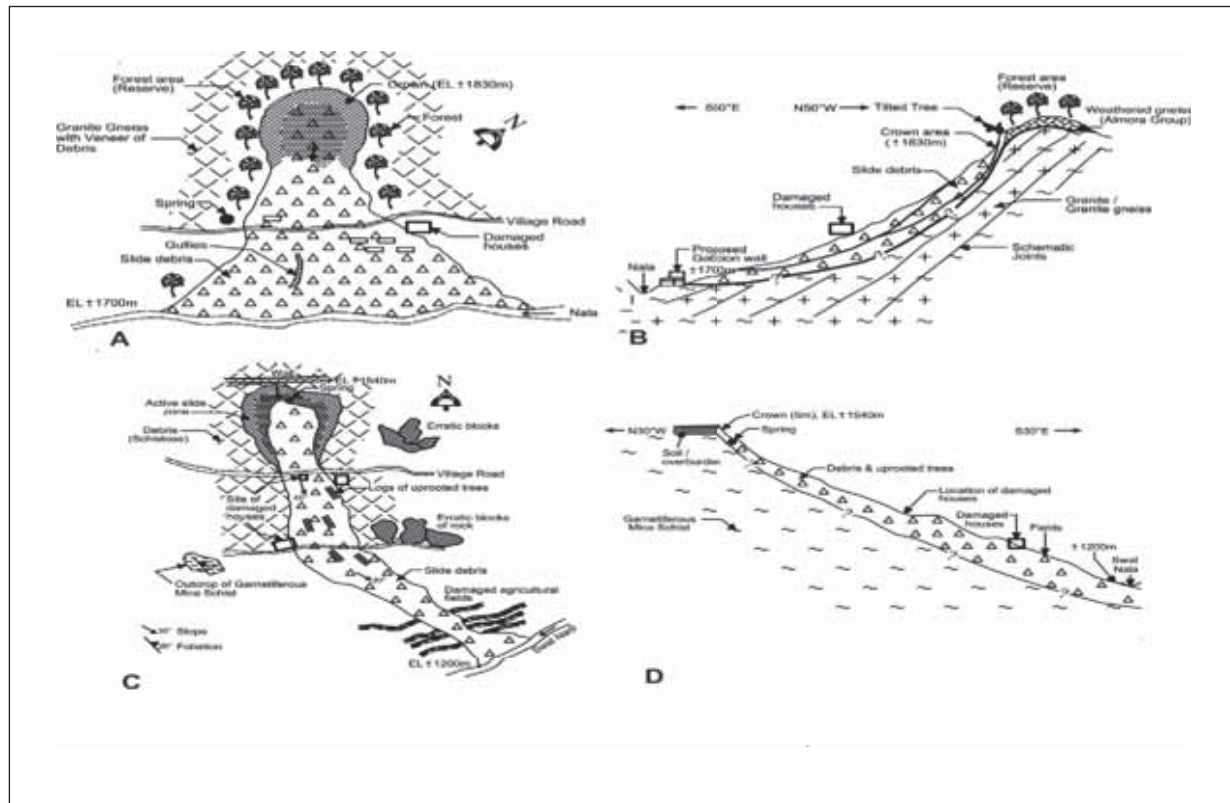


Fig. 3.43. Sketch geological plan (A) and section (B) of the Baltabari slide area; and sketch geological plan © and section (D) of the Devli slide area

In the past, major landslides have been recorded in the year 1867, 1880 (18 September 1880 took a toll of 193 lives) and 1889. A number of committees of Engineers and Geologists have studied the problems of the slope instability. The broad conclusions drawn from the geological assessment of the area stated that the slopes along Sher-Ka-Danda (SKD) were susceptible to shallow as well as deep-seated failure and the inferred deep-seated plane of failure was considered dangerous in the event of intense rainfall and seismic vibrations. The presence of main SKD fissure along top of the ridge was considered to be an important feature controlling the instability of the slope. They have recorded cumulative horizontal movement over a period of 60 years on SKD hill slopes of the order of 254 cm on pillar M located near Ravenswood while minimum cumulative movement of 2.54 cm during the same period has been shown on Ramsay Hospital spur of the hill.

During 2009-10, geological mapping was carried out on scale 1:5,000 for 1 km² area with the objective of planning

instrumentation in the SKD hill for developing an early warning system for the landslides, as per the requirement of the DST, New Delhi and CSIO, Chandigarh (Sharma, 2011).

The rocks occurring on the ridge comprise mainly thinly bedded, sheared, variegated slate, shale, marl and subordinate bands of limestone/dolomite belonging to Lower Krol Formation. Nainital lake fault running along the lake and beyond is a major tectonic dislocation close to the ridge. The SKD hill slopes are mainly covered by the overburden material with scanty outcrops.

In view of the potentiality of slope failures on the SKD hill zone, in spite of the absence of any active slide of considerable dimension in the zone, it is suggested that: (i) instrument (such as Piezometers, Inclinator system, In-place inclinometers, Crack meters, Tiltmeters and Rain gauge system) based monitoring of the zone may be taken up for measuring the creep, (ii) geophysical explorations (both resistivity and seismic refraction) are to be carried out to know depth of rock-overburden interface, (iii) exploratory

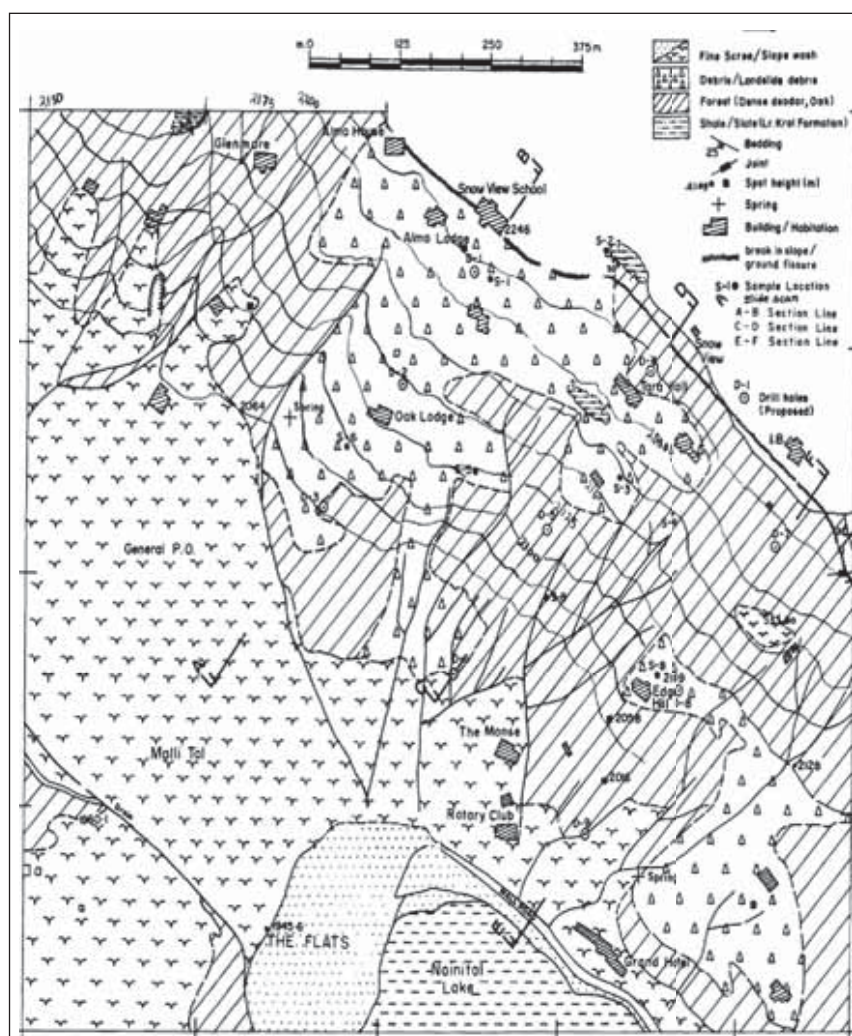


Fig. 3.44. Geological map of Sher-Ka-Danda landslide zone.

drill holes need to be drilled at nine locations (about 30-35 m depth) for obtaining the sub-surface information like depth and nature of overburden, contact between overburden and weathered rock and fresh rock, ground water level, plane of failure, etc. (Fig. 3.44).

3.5.20 July/September 2011 event along Rishikesh-Badrinath road (NH-58)

During the months of July, August and September 2011 following heavy spells of rainfall, a large number of reactivated and fresh landslides with subsidence developed at several places on Rishikesh-Joshimath-Badrinath National Highway (NH-58), in Uttarakhand. The event caused damage to human settlements, communication network, cultivated land and forest and also resulted in one

human casualty. The slides occurred in toposheets: 53N/3, 53N/4, 53N/6, 53N/7, 53N/10, 53J/12, 53J/15 and 53J/16.

The landslides occurred at Saknidhar, Bachheligaun (near Simswara village), Chamdhar, at many places on Nagrasu-Gauchar-Karnaprayag road, Dewali, Sirkot/Chinka village near Birehi, Kaliyasaur, Patalganga/Belakuchi, Helang and Painsi, Elephant Mountain (Hathi Parvat), Taiya bridge, Pihola, Lambagad, Lambagad nala/Kachara nala and places between Hanuman Chatti and Badrinath, on NH-58.

A detailed inventory of 17 landslides has been prepared by incorporating 41-point parameters, such as location, dimension, type, history, casualties, causes, remedial

measures, etc. (Kumar, 2012).

Attention is required to arrest the recurrence of old major landslides, which occur every year. Patalganga/Belakuchi, Shirobagad/Kaliasaur and Lambagad slides are some of the recurring landslides. In these zones construction of cut-and-cover type short length traffic tunnel (about 300 m – 400 m length) has been suggested as a long time solution. For other locations, suggested mitigations/remedial measures include improvement of drainage by providing contour and longitudinal drains, plantation, channeling of perennial streams, construction of check-walls and retaining-cum-breast wall and river training works etc. The slopes of these slides can also be moderated by benching of failed slopes at less than 15°.

3.5.21 16th - 17th June 2013 events in Uttarakhand, Rudraprayag, Uttarkashi, Chamoli, Bageshwar and Pithoragarh districts

The state of Uttarakhand experienced flash flood disaster on 16th and 17th June 2013 caused by intensive rain in the region. The flash flood induced numerous landslides causing widespread human, material and environmental losses besides affecting society in many ways. GSI initiated the post-disaster slope stability assessment in the five worst-affected districts of Uttarakhand viz., Uttarkashi (Dangwal et al., 2014), Rudraprayag (Thapliyal et al., 2014), Chamoli (Singh et al., 2014), Bageshwar (Kaistha et al., 2014), and Pithoragarh (Bishwapriya et al., 2014) with an aim to collect geo-parametric data of landslides for updating the landslide inventory and to examine the geological causes of flash flood induced landslides, and the nature and extent of damage pattern, in order to evolve futuristic plans for further detailing of landslides vis-a-vis effective mitigation measures through close interactions with all stakeholders.

In Rudraprayag district, geological assessment was carried out in three major river valleys namely Mandakini, Kali Ganga and Madhyamaheshwar Ganga spread over three Tehsils viz. Rudraprayag, Jakholi and Okhimath. A detailed assessment was carried out in the Kedarnath Township, covering approximately 0.5 km² area. Glaciological, Geophysical and Ground Penetrating Radar (GPR) studies have been carried out in Kedarnath Township including holy temple complex. GPR profiling, covering 385.56 line meters, was taken with help of 17 traverses around the

Kedarnath temple premises. The undulatory topography below the temple premises has been interpreted by using GPR data. Prima facie, the GPR survey also reveals that there has been no major damage to the foundation of Kedarnath Temple. The temple structure and sanctum-sanctorum found to be safe. There has been only minor damage to the outer part of the main temple structure. In view of the religious, cultural and strategic significance of the Kedarnath area, various safety measures and protection works have been recommended. In addition, geologically suitable location, downstream of the present Kedarnath temple has also been identified for development of new Kedarnath Township.

The study covered most of the roads including NH-109 and 58, SH-15 and 36, Pradhanmantri Gram Sadak Yojana (PMGSY) roads etc. Total 98 major landslides have been inventoried in Rudraprayag district, out of which 66 are located between Rudraprayag and Gaurikund on NH-109. Out of 98 incidences, 56 are debris slides, 17 are rock-cum-debris slides, 3 are rock slides, 19 are river bank erosion and 3 are subsidence. Geological assessment of 38 villages has also been carried out. The worst affected villages are Kedarnath, Rambara, Gaurikund, Sonprayag, Chandrapuri, Ganganagar, Baniyari, Vijaynagar, Agastmuni, Silli and Sumari located in the Mandakini valley, and Kalimath and Kunjethi in the Kali Ganga valley. The Mandakini valley is one of the worst affected areas in the district as well as in the state where many people were killed; and several houses/commercial buildings and parts of National and State Highways and villages/townships were swept away in the flash flood of Mandakini and its tributaries such as Kali Ganga and Madhyamaheshwar Ganga. A number of helipads have also been badly damaged due to which the initial relief works/rescue operations were severely obstructed. Several bridges (suspension and steel girder) have been washed away and a number of remote villages have been cut-off from the Tehsil and District headquarters.

Prima-facie, the main causative factor responsible for triggering the swarm of landslides is the heavy and incessant rain enhancing the discharge of Mandakini River and its tributaries to unprecedented levels. Blockade of natural drainage by means of anthropogenic encroachment has been one of the most important factors leading to heavy loss of life and property, particularly in the areas located close to the

river bed and active flood plain. Suitable recommendations for preliminary stabilization of hill slopes, restoration of road connectivity, realignment of road network and relocation of affected villages have been made at each location.

In Uttarkashi district, geological assessment was carried out along NH-108 (Dharasu Bend to Gangotri) and NH-134 (Chinyalisaur to Yamunotri). Total 60 landslide incidences were recorded and 20 disaster affected villages were geotechnically studied. Out of the 60 landslides, 62% are debris slide, 37% are rock-cum-debris slide and 1% are rock slide. It is concluded that the most important factors responsible for the landslides were abnormal downpour in the area (180 mm). The mass movement has been caused due to toe cutting, saturation of slope forming materials and road cutting. Encroachment in the river/ *nala* bank and unplanned urbanization has aggravated the hazard and damage in the district.

In Chamoli district, geological assessment was carried out along National Highway, State Highways and major district roads covering a length of about 230 km. A total 65 landslides have been recorded. Besides, geological assessment of 6 affected villages namely Lambagarh, Aruri, Govindghat, Pulna, Bhiundhar and Pakhi-Jalguwar have been carried out. The worst affected areas in the district are Lambagarh–Binakuli sector, Govindghat, Birehi in the Alaknanda valley, villages in Bhuindar valley and Pinder valley. The preliminary assessment has revealed that the maximum slope failure/landslide incidences have occurred either in the river terraces or in the road cuts, particularly where slope wash/debris cone materials were resting over steep slopes. The main causative factor responsible for triggering landslides is the heavy rainfall enhancing the discharge of Alaknanda River and its main tributaries and also causing saturation of the overburden/debris/weathered rock material along river banks, thereby, reducing their shear strength, ultimately leading to the failure of the slope. Encroachment of human settlements (residential and commercial buildings) into the river channel/active floodplain and along river banks close to HFL has also contributed to the mass destruction to civil structures in the area.

The area exhibits intense structural deformations as

reflected by highly folded, faulted, crumpled and jointed rocks owing to the trace of MCT in the proximity. The slopes, in parts of toposheet: 53N/16 in Sumgarh-Dhakuri-Khati-Dwali section, are found covered with glacial deposits and severely affected by landslides/subsidence. The area in and around Kapkot and its north has been frequently experiencing the phenomenon of cloud burst due to sudden rise in elevation (orographic high). The concentration of incidences of landslides and debris flow is also high due to heavy precipitation in the catchment areas of Revti Ganga, Gason *gad* and Khir Ganga-Andheri *gad*. The rainfall data shows that Bageshwar district received exceptionally heavy precipitation in the months of June and July 2013 (600.83 mm and 509.83 mm), which appears to be an important contributing factor towards triggering the landslides in the region.

Total 104 landslides have been inventoried, out of which 81 are old and reactivated slides and 23 are fresh slides (10 debris slide, 8 rock-cum-debris slides, 4 debris flows and one rock slide). In total there are 50 rock-cum-debris slides, 28 debris slides, 17 rockslides, and 9 debris flows. About 55% landslides are due to road cutting, 41% due to bank/toe erosion and 4% on natural slopes. The main causative factors for slides/subsidence are found to be unprotected slope cutting/excavation for road construction, thick overburden material covering the steep slopes, presence of highly jointed rock mass, opening/day lighting of discontinuities forming wedges on the free face of the steep slopes and effect of major tectonic feature (MCT)- giving rise to pulverized rock mass particularly in the northern part of the area. The impact of these landslides and debris flow on the infrastructure facilities includes blockade/damage to roads and bridges severely affecting supply to remote areas, settlements located on the affected slopes, minor irrigation system network in the area and damage to forest cover and cultivated land on the slopes and on the terraces, on either side of the major drainage. The remedial measures suggested include retaining and toe protection walls along drainage network; breast walls with weep holes and gabion walls along subsidence zones, shotcreting of slopes and lining of drainage in the affected zones on communication routes.

In Pithoragarh district, the prominent glacial fed rivers viz., Dhauliganga, Goriganga and Kali rivers played havoc causing heavy damage to life and property, particularly, in

the downstream areas. The rivers with unprecedented discharge swept away many communication routes, settlements/houses located in the villages on the banks of these rivers and led to emergence of new slides and reactivated the old slides.

The geological assessment was carried out in parts of toposheets: 62B/4, 62B/8, 62B/12, 62 C/1, 62C/2, 62C/5, 62C/6, 62C/9 and 62 O/14. The area exposes rocks of Central Crystallines, Garhwal Group and acid intrusives intruding into the Garhwal Group of rocks. The rocks of the Garhwal Group and Central Crystalline are separated by a major tectonic dislocation known as Main Central Thrust (MCT), which strikes in NW-SE direction. Preliminary geotechnical studies were carried out in 14 road sections viz. SeraghatThal (road section), Thal-Munsyari (road section), Munsyari- Milam, Munsyari-MadkotJauljibi (along Goriganga, road section), Tawaghat-Dharchula- Jauljibi (along Kali river; road section), Jauljibi-Didihat-Thal (road section), Thal-Pithoragarh (road section), Rameshwarghat-Raiagar (along Ramganga River, road section), Pithoragarh-Jhulaghat (road section), Pithoragarh-Askot (road section), Thal-Pankhu-Chaukori (road section), TejamRaton (along Ramganga, road section), Tawaghat-Sobla-Tejam (along Dhauliganga, road section) and Tawaghat-Garbadhar (along Kali, road section). Total 92 landslides have been inventoried. Out of 92 incidences, 52 are landslides, 32 are river bank erosion due to high floods and 8 are land subsidences. Out of total 60 landslide/subsidence incidences, 40 are debris slides, 19 are rock-cum-debris slides and one is a rock slide. Out of total 92 incidences, 21 are new landslides and 39 are old reactivated landslides and all 32 river bank erosions are new. Approximately 21.67 km of the road stretch in different sectors is affected and about 20.80 km of road needs the proper realignment. Other salient description of preliminary and detail investigations are provided in Annex - II.

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Chapter 4: Landslide studies in Himachal Pradesh

4.1 Introduction

Himachal Pradesh, which literally means "Snow-laden Region", is a mountainous state located within the NW Himalayas. The state covers about 55,670 km² area, of which about 42,000 km² forms part of mountainous terrain of the

Himalayas, excluding the permafrost region. All of its 12 districts fall under such mountainous region (Fig. 4.1), where landslides are one of the common and perennial natural hazards. The state is bordered by Jammu and Kashmir on the north, Punjab on the west, Haryana on the southwest, Uttarakhand on the southeast and by the Tibet

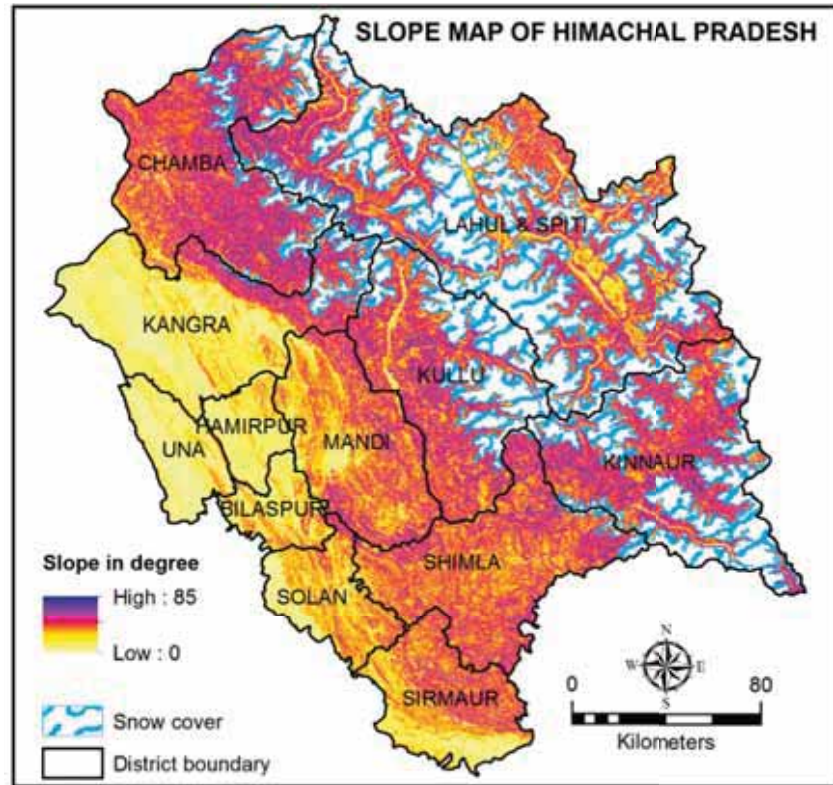


Fig. 4.1. District boundary of Himachal Pradesh shown over the slope map prepared from Aster DEM.

Autonomous Region on the east.

4.1.1 Geology and Geomorphology

Geologically, Himachal Pradesh is covered by the rocks ranging in age from Precambrian to Recent. The normal order of superposition of the rocks in the Lesser Himalayas has been affected by later events of thrusting linked to Himalayan orogeny. The Proterozoic rocks represented by Jutogh and Vaikrita groups mostly constitute the Lesser Himalayan terrain in Himachal Pradesh. Rocks of Jeori-Wangtu Banded Gneissic Complex and other groups namely Kulu and Rampur (≈Naraul≈ Sundernagar) represent the Paleoproterozoic period in the state. The Jeori-Wangtu Granitoid Gneiss is strongly foliated with well-developed augen-gneiss, mylonitic gneiss and

porphyroblastic biotite gneiss with non-foliated granitoids in the central part. These are the oldest rocks exposed in Himachal Pradesh forming the basement for the Rampur Group of rocks. The Mesoproterozoic rocks are classified into two stratigraphic groups- Shali (Deoban) and Larji. The Neoproterozoic sequence in the state has been divided into the Lower and the Upper Neoproterozoic divisions. The Jaunsar Group, Simla Group and Batal Formation of Haimanta Group represent the Lower Neoproterozoic division. The upper Neoproterozoic era in the State is represented by Manjir Formation, Katarigali Formation, Baliana Group and Krol Group. The Tal Group represents the Lower Cambrian sequence in the Lesser Himalaya. It occurs in the core of Nigali Dhar and Korgai synclines. Thick pile of fluvial, fluvioglacial, glacial, lacustrine and

gravitational sediments exposed in Beas, Banganga, Soan-Sohan, Spiti, Giri-Yamuna, Sutlej and Sunder Nagar valleys represents post-Siwalik Quaternary deposits, which are divided into Older Alluvium and Newer Alluvium formations.

Geomorphologically, the state of Himachal Pradesh displays prominent features characterized by lofty mountain ranges incised by deeply dissected valleys carved out in slopes of various descriptions. The large areas within Kangra, Una, Hamirpur, Bilaspur and Solan are characterised by low slopes ($<15^\circ$). The northern area has rugged topography with slopes more than 25° (Fig. 4.1). The elevation above mean sea level varies from 320 m in Una district to 6975 m at Leo Pargil Peak of Kinnaur district. Physiographically, the state can be divided into five distinct parallel zones. From south to north these are: Alluvial Plain, developed at the foothills of Siwalik Range in the vicinity of Indo-Gangetic Alluvium; Siwalik Foothills, the outermost Sub-Himalayan mountainous zone of Himachal Himalaya with altitude ranging from 345 m to 1500 m; Lesser Himalayan Zone, a zone between Sub-Himalaya and Central Himalaya up to altitude of 3000 m; Central Himalayan/Great Himalayan Zone, comprising a zone of snow-capped peaks ranging in height from 4000 m to 5000 m; and the Trans-Himalayan zone, a rain shadow area, having height varying from 3000 m to 6000 m. The mountain ranges in general trend in NW-SE direction. Majority of the drainage of the state belongs to the Indus River System. The Sutlej, Beas, Ravi, Chenab, Spiti, Parbati, Pabbar, Tons and Giri are the main rivers of Himachal Pradesh. Of these, the Sutlej, which rises in the highlands of Tibet, is an antecedent river.

4.1.2 Landslide hazard

Landslide is a common natural as well as a man-made hazard in Himachal Himalayas, particularly occurring during monsoon. It not only causes direct loss of life and property, but also imposes indirect loss by blocking the transportation routes and corridors. In the recent past, due to extensive road construction and other developmental activities, the frequency of anthropogenically-triggered landslides has increased manifold in Himachal Pradesh.

Landslides are common and periodically affect roads, particularly along Ravi River basin between Gehra and Brahmaur in Chamba district. The road alignment in this

stretch passes through jointed rock mass belonging to the Chamba Formation, represented by interstratified sequence of slates, phyllite and subordinate schist; Manjir Formation, comprising pebbly siltstone, slate and bands of limestone; and Katarigali Formation composed of interstratified sequence of slates, phyllites, siltstones and beds of thinly bedded limestone. The Hindustan-Tibet road (NH-22) between Jeori and Khab, passing through slope wash, debris, jointed gneiss is another sector which is widely affected by landslides in Kinnaur district in Sutlej valley. Shimla has been frequently experiencing landslides, with slips and subsidence, commonly occurring within overburden material and adversely affecting roads and unsoundly founded constructions. Soil creep and landslides are also common hazards in Dalhousie town.

4.1.3 Landslide studies by Geological Survey of India

Till date, GSI has accomplished landslide susceptibility mapping and detailed study of a number of complex landslides in different scales in the state of Himachal Pradesh. Some of these include macro-scale landslide susceptibility mapping of river basins such as Ravi, Beas, Sutlej Rivers susceptibility mapping along important roads such as Kalka-Shimla rail route, Narkanda-Rampur route, Kangra-Sihunta-Dalhousie route, etc.; susceptibility mapping of important towns and districts such as Shimla (Fig. 4.2).

In this compendium, the work of GSI on landslides in Himachal Pradesh is dealt according to the following sequence:

1. Macroscale landslide susceptibility mapping of river basins, district/town, road corridor.
2. Mesoscale landslide susceptibility mapping of town.
3. Microscale (site specific) landslide studies
4. Post-disaster study of landslides.

4.2 Macro-scale landslide susceptibility mapping

4.2.1 Landslide susceptibility mapping of Ravi River basin

The Ravi basin, with its historical and exotic scenic appeal, has ever remained an attraction for tourist and offers a vital passage to places of pilgrimage in Kinnar

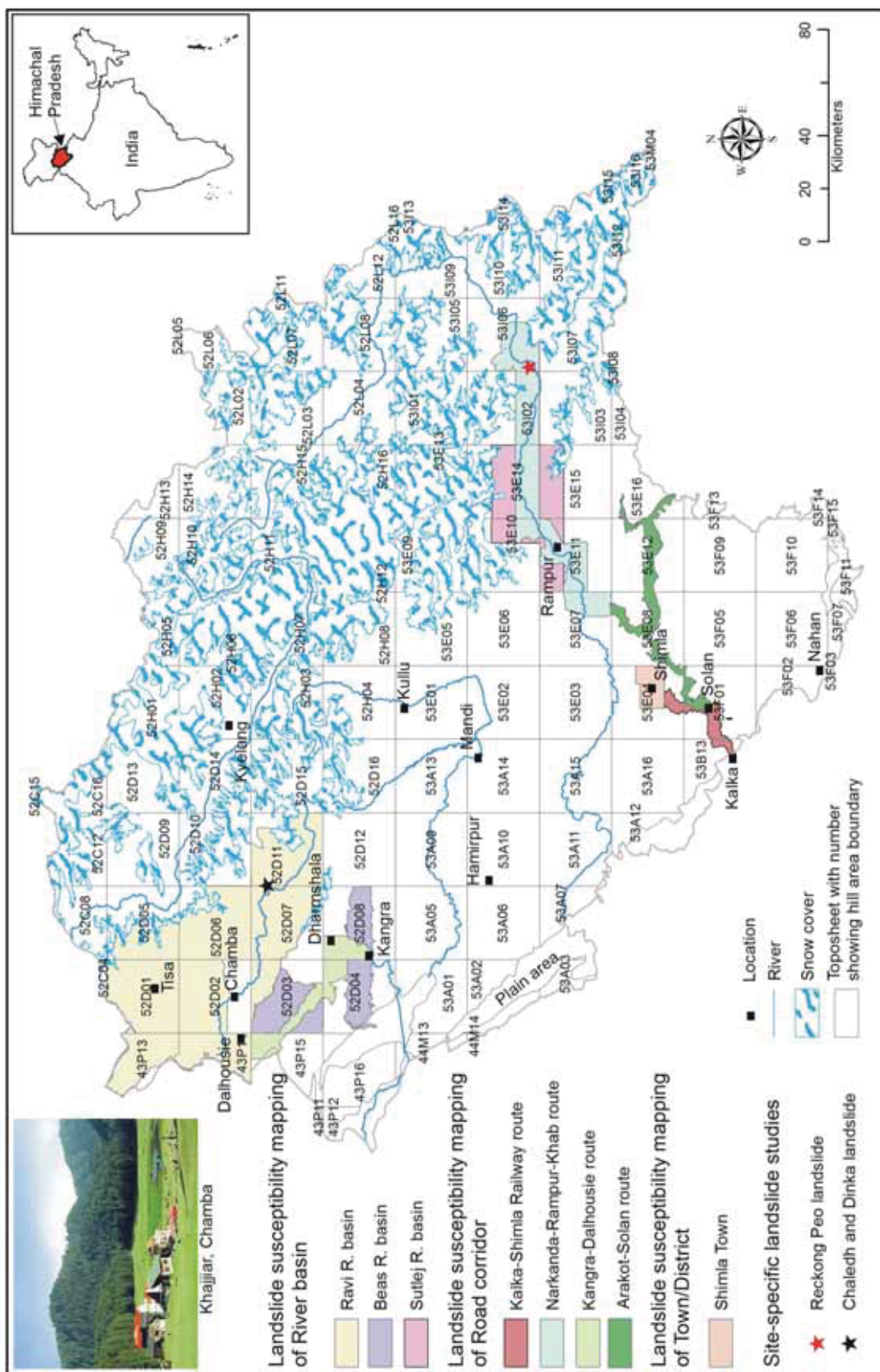


Fig. 4.2. Landslide studies carried out by GSI in Himachal Pradesh till 2013.

Kailash, Mani Mahesh and temple town Bharmaur. The basin, located in the western fringe of Himachal Pradesh, encompassing approximately 4500 km² area, attains importance as it accommodates places of tourist importance prominent among them being Bharmaur, Chamba and Dalhousie. Besides, some hydroelectric projects, under various stages of development, are also located in the basin. The communication networks in the area are frequently disrupted every year due to activation of a number of landslides as also the schedule of construction of hydel projects and other developmental activities.

The entire Ravi River basin is bounded within the Survey of India toposheets: 43P/13, 43P/14, 52D/1, 52D/2, 52D/3, 52D/5, 52D/6, 52D/7, 52D/10, 52D/11, 52D/14, 52D/15 and 52D/16 and is flanked in the north by the Chandrabhaga valley and in the south by Beas valley. GSI has carried out landslide susceptibility mapping for 3,710 km² area of the Ravi valley, covering parts of toposheets: 43P/13, 43P/14, 52D/1, 52D/2, 52D/3, 52D/5, 52D/6, 52D/7, and 52D/11. The work was carried out on scale 1:50,000 between 1993 and 1994, and 2002 and 2006 under five field season programmes (Chandra and Bhatnagar, 1997; Sharma et al., 2009; Kumar et al., 2009).

Geologically, the region exposes a wide assemblage of rock formations ranging in age from late Proterozoic to Recent. The Ravi basin exposes rocks belonging to Vaikrita Group, Kulu Group, Haimanta Group and Siwalik Group. The overburden materials consist of Quaternary fluvial sediments along with slope wash and scree materials. The Shasu Formation of Vaikrita Group comprising phyllite, schist, garnetiferous biotite schist, micaceous quartzite and gneiss with sporadic limestone bands, is conformably overlain by Chamba Formation. The Chamba Formation comprises a thick sequence of dark grey slate, phyllite with subordinate bands of metagreywacke and occupies most part of the basin. It is overlain by Manjir Formation of Haimanta Group, which constitutes the uppermost part of the lower sequence in this region and comprises chiefly lenticular, thick bedded diamictite with subordinate sandstone and intercalated argillites. The Manjir Formation is overlain by Katarigali Formation that consists of dark grey and carbonaceous pyritiferous slate containing black phosphate nodules, siliceous crystalline limestone, carbonaceous phyllite and phyllitic quartzite.

The upper sequence is represented by Salooni Formation which comprises grey and purple thinly bedded slate, calcareous sandstone, and arenaceous shaly limestone. It is overlain by Kalhel Formation which includes mainly crystalline dolomitic limestone of variegated colour, interbedded with grey coloured quartzite. The Dalhousie granite forms the crest-line of the Dhauladhar range and acts as water divide of Ravi and Beas rivers. It is emplaced within the Morang Formation of the Vaikrita Group showing concordant relationship. Dalhousie granite is predominantly medium grained with subordinate fine and coarse-grained varieties. The glaciated drift deposits, relict moraines and valley fill deposits such as river terraces, debris cones and fans are the prominent Quaternary deposits in the area.

The entire stratigraphic sequence is regionally folded into a major syncline referred to as "Chamba syncline" with NW-SE trending axial plane. Sympathetic faults crossing the Bagota *nala* have also been observed. The area has undergone polyphase deformation and forms a part of SW limb of a regional Chamba synclinorium. The rocks are regionally folded into the south-verging. The core of this syncline is represented by Kalhel limestone of Lower Triassic age. The general trend of rocks in the area is NW-SE with beds dipping low to moderate in NE direction besides vertical at places.

Physiographically, the area presents pronounced relief with high ridges and deep gorges. The valleys are 'V' shaped in the upper reaches; while in the lower reaches these are 'U' shaped. It is deeply dissected Himalayan terrain, close to the major watershed between River Ravi and River Beas with prominent Dhauladhar ridge in the south trending NNW-SSE. The southern part of the area involves part of northern slopes belonging to Dalhousie granite of Dhauladhar range, which acts as the water divide between River Ravi and River Beas. The upper reaches show good glacial features i.e., U-shaped valleys, cirques, moraines and glacial lakes (Mani-Mahesh Tal). The altitude generally varies from 1640 m at Banun in the west to 5274 m at Kuju ka *Tal* in the east on the Dhauladhar range. The conspicuous peaks in the area are Khidala Galu (5112 m), Sokdil *Galli* (4792 m) and Chobu pass (5114 m). The major drainages of the area are River Ravi, Changu *nala*, Bagota *nala* and Budhil *nala* besides several small streams of glacial origin in the northern as

well as in the southern part.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer Section 2.1.2, Chapter 2). Based on field traverses and study of satellite imageries, a total 405 landslide incidences have been recorded, out of which a detail inventory of 287 prominent landslides has been prepared. The inventory gives information on the location, type and dimension of landslide, nature of material involved, causative factors and its remedial measures. Annexure-I provides an inventory of some of the major landslides.

In toposheet 52D/11, the Holi slide is a major slide near Holi village which is the result of rock falls from the right bank of Ravi River. This slide blocked the flow of the Ravi River for two days and created an artificial lake. When the river made its own way, it shifted the river course in the left bank direction. The shifting of river course disturbed the toe portion of debris and overburdened mass of the left bank and caused major land subsidence and sinking of the road and village land. This slide is a good example of wedge failure, rockfalls and debris flow. In toposheet 52D/1, a rockfall zone occurs around Madhuwar, where rocks of Manjir Formation are exposed. This zone is prone to debris mobilisation during rainy season. Another rockfall zone occurs near Kalias, on left bank of Baira *nala* where scattered quartzites, phyllite/slates of Chamba Formation are exposed. In this toposheet, Sukrial *nala* slide zone, is a major slide situated on the left bank of Bira *nala*. The slide is developed in glacial drift deposit occurring over fissile slates/phyllites of Chamba Formation. The slide initiated due to deep erosive action of low order stream on steeper slope. Since this slide zone affects the road section, it is felt that a bridge over Baira *nala* may be constructed so that the hazard of the slide be avoided.

Plate 4.1 shows the landslide susceptibility map of Ravi River basin, covering 3,710 km² area. The area has been divided into 6639 slope facets. more than 80% of the area falls under low susceptible class, whereas high susceptible slopes constitute less than 4% area. In toposheets: 52D/5 and 52D/6, high susceptible zones are demarcated mainly in area near Bara village in Bagota *nala* section, Kiri-Laga area and near Gan village. The moderate susceptible zones are generally located in Bhadiara area, Laga area, Nakal-

Panglod *nala* section, rock fall zone in Khajaid *gad* and Chahed *nala* section. In addition, some sporadic high and moderate zones have also been demarcated. In toposheets: 43P/13 and 43P/14, high susceptible zones largely occur along communication routes which indicate greater influence of anthropogenic activities. In toposheet: 52D/11, most of the high susceptible zones are restricted in the valley portion where the toe portion of slope is disturbed by the river undercutting or by the man-made activities i.e., road cutting or by some engineering projects. Rock failures as well as debris or overburden slides are highest in Katarigali Formation followed by Manjir Formation. The back slopes are more vulnerable for the rock slide due to steepness of the slope and formation of a wedge plunging towards valley and planar failure, whereas the dip slopes are prone for the debris slide. In toposheets: 52D/3 and 52D/7, the high susceptible zones in the area are restricted to the river valley where the hill slope is disturbed which largely occur along Chamba-Bharmaur road, where there is greater influence of anthropogenic activities or river undercutting.

4.2.2 Landslide susceptibility mapping of Beas River basin

The Beas River is one of the major rivers of the Indus basin. It originates in the upper Himalayas from Beas Kund near Rohtang Pass in Himachal Pradesh and flows in the east-west direction in Himachal Pradesh till it emerges in the plains near village Talwara in Hoshiarpur district of the Punjab state. The total length of its course upto Beas Dam at Pong is about 230 km. The catchment area of Beas River is about 12,560 km² out of which only 777 km² is under permanent snow. The rest of the catchment area contributes water on account of rainfall especially from the high rainfall zone of Dharamsala, Palampur and Kangra. The river is a tributary of river Ravi.

The entire Beas River basin is bounded within the Survey of India toposheets: 43P/12, 43P/15, 43P/16, 52D/3, 52D/4, 52D/7, 52D/8, 52D/12, 52D/16, 52H/3, 52H/4, 53E/1, 53E/2, 53A/5, 53A/6, 53A/9, 53A/10, 53A/13 and 53A/14 and is flanked in the north by the Ravi valley and in the south by Sutlej valley. GSI has carried out landslide susceptibility mapping for 820 km² area of the Beas valley, covering parts of toposheets: 52D/3, 52D/4 and 52D/8. The work was carried out on scale 1:50,000 between 1992 and 1994 under

two field season programmes (Chandra and Bhatnagar, 1994).

Geologically, the region forms a part of Lower Himalaya and comprises the rocks belonging to crystallines of Vaikrita Group, Metasedimentaries of Shali Group (schists, phyllites, slates, shales and dolomites), Volcanics of Mandi Darla Formation, Dhauladhar granite sandstones and clay shales (red facies) of the Dagshais (Dharamsalas) of lower Tertiary age and sedimentaries of Siwalik Group (Mid Miocene-Pleistocene) consisting of sandstone, clay shale and boulder bed overlain by recent deposits. There is a transition from the foothills of the Siwalik range to the lesser Himalaya. Along this transition zone, parallel to the foothills lies the Kangra Valley filled with Quaternary sediments which exhibit the Pleistocene glacial morphology and contain huge thickness of lacustrine deposits.

The youngest tectonic event in the area is represented by Main Boundary Fault which brings Siwalik rocks in contact with Mandi Darla Volcanics. Shali thrust also demarcates the boundary contact between Shali Group and Siwalik Group. It has been observed that the rocks by the sides of Main Boundary fault are crushed and fractured giving rise to rock poor in strength.

Physiographically, the area in toposheets 52D/4 and 52D/8, lies in the foothill region of the NW Himalaya and represents diversified relief with mountains of moderate height not rising more than 2000 m from the mean sea level and valleys of moderate depths, gentle to steep slopes, escarpments and cliff faces. The region around Kangra town, though of low relief, exhibits highly dissected topography. In toposheet: 52D/3, the area is represented by deeply dissected topography with a relief difference of more than 3000 m. The maximum elevation 3626 m near village Bhuar Jot occurs at major water divide with elevation above 3000 m between Ravi and Beas river basins. Structurally controlled strike ridges trending NW-SE in general alternating with longitudinal valleys control the drainage system in the area. Some of the strike ridges are transformed into knife-edge ridges due to severe erosional activity. The overall drainage pattern is sub-parallel to trellis having medium-drainage density. The general flow direction being southerly to south-westerly further downstream it becomes westerly. Steep to very steep gradient have developed locally

in the areas.

The landslide susceptibility map was prepared by adopting 'Probabilistic approach' (refer section 2.1.2, Chapter 2). In order to demarcate landslide susceptible zones, the obtained probability values are grouped as-

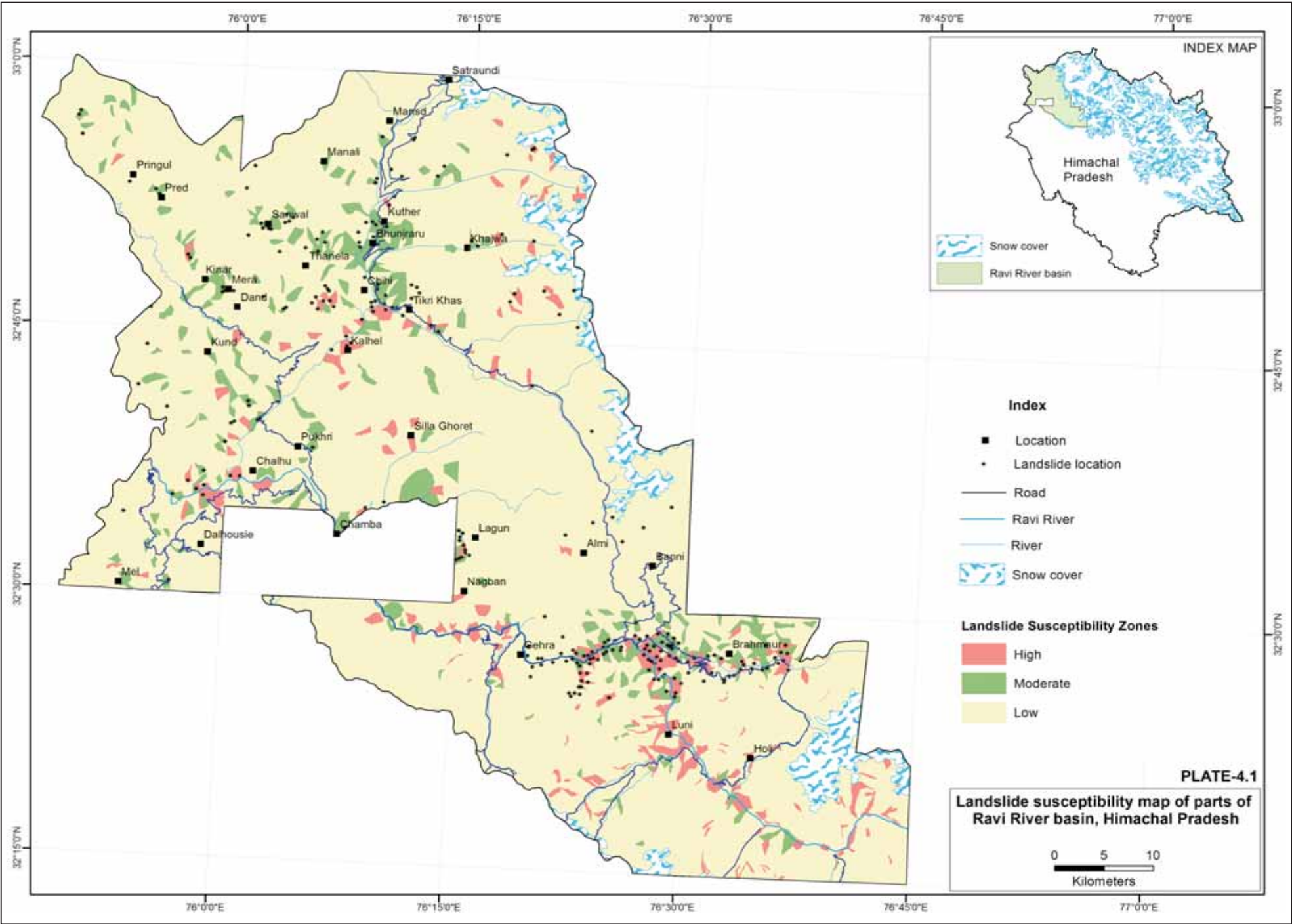
- i. Probability > 60% - Very High susceptible zone
- ii. Probability 41%-60% - High susceptible zone
- iii. Probability 21%-40% - Moderate susceptible zone
- iv. Probability < 21% - Low susceptible zone

Based on field traverses, a total of 136 landslide incidences have been recorded, and a detailed inventory of all landslides has been prepared. The inventory gives information on the location, type and dimension of landslide, nature of material involved, causative factors and its remedial measures. Out of 136 landslides, four landslides occur in crystallines, 35 in metasedimentaries, 5 in Dharamsalas, and 92 in Siwaliks.

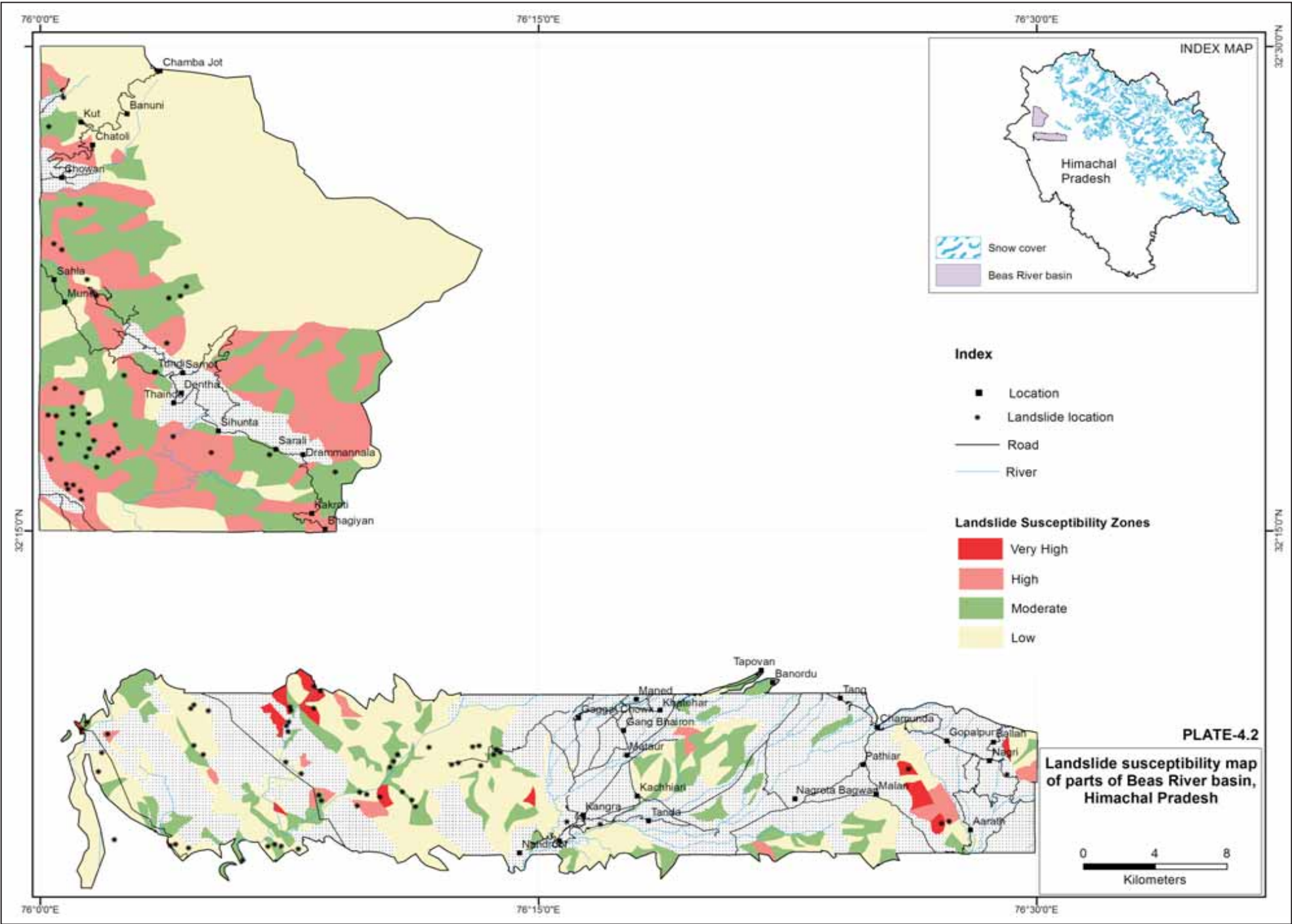
Plate 4.2 shows the landslide susceptibility map of Beas River basin, covering 820 km² area. The area has been divided into 825 slope facets. The very high susceptible slopes constitute only 1% area and are spatially located on north and south Sihunta and east of Sahla. About 13% area is characterised by high susceptible class, followed by 17% moderate and rest as low susceptible class. The low susceptible class also includes about 31% area covered by the terrace. The area in and around Kangra, Gopalpur, Dentha, etc., have wide terrace formation.

4.2.3 Landslide susceptibility mapping of Sutlej River basin

The Sutlej River rises as Langchen Khabab in the lakes of Mansarovar and Rakastal in the Tibetan Plateau from the southern slopes of Mount Kailash at an elevation of about 4,570 m above mean sea level (msl) and forms one of the main tributaries of Indus River. It travels about 322 km in the Tibetan province of Nari-Khorsam forming a plateau by successive deposits of boulders, gravel, clay and mud. Sutlej enters into the Indian Territory near Khab, a narrow cut into massive rock structure. The flow of Sutlej, arising mainly from snow and glaciers, has cut a valley about 914 m deep through these deposits. Hereafter, the river flows through Himachal Pradesh and Punjab states of India. After flowing



Landslide susceptibility map of parts of Ravi River basin, Himachal Pradesh



Landslide susceptibility map of parts of Beas River basin, Himachal Pradesh

in northwesterly direction, it changes direction towards south-west and covers another 322 km up to Bhakra gorge (Bhakra/Govind Sagar) (www.nih.ernet.in). The lower catchment largely drains directly into the reservoir and the higher slopes drain through tributaries. The important tributaries of the Sutlej River are the Soel khad, Alseed khad, Ali khad, Gamrola khad, Ghambhar khad, Seer khad, Sukhar khad, Sarhali khad and Lunkar khad.

The total geographical area of Sutlej River basin up to Bhakra dam is about 56,980 km² of which about 37,153 km² lies in Tibet. The remaining about 19,827 km² area lies in the Indian Territory. The Indian part of the Sutlej basin is elongated in shape. The shape and location of this basin is such that a major part of the basin area lies in the greater Himalayas where heavy snowfall is experienced during winters. The elevation of the catchment varies widely from about 500 m to 7,000 m above msl, although only a very small area exists above 6,000 m. The mean elevation of the basin is about 3,600 m. The gradient is very steep near its source and gradually reduces downstream.

GSI has carried out landslide susceptibility mapping for 1,040 km² area of the Sutlej valley, covering parts of toposheets: 53E/10, 53E/11, 53E/14 and 53E/15. The area forms part of Kinnaur, Kullu and Shimla districts of Himachal Pradesh. The work was carried out on scale 1:50,000 between 1981 and 1982 under one field season programme (Gupta, 1982).

Geologically, the area exposes granite and gneisses of Jeori–Wangtu complex; quartzites of Rampur Formation and rocks of Jutogh Group being represented by green basic schist and greenish phyllites with thin quartzite bands of Banjar Formation; carbonaceous phyllite and schist with quartzite and limestone bands of Khamrada Formation; rocks of Ghar Formation, which has a conformable contact with underlying Khamrada Formation and gradational contact with overlying Maldi gneiss and Kulu Formation. The overburden materials in the area consist of moraines, fluvioglacial and fluvial deposits, rock debris scree, soils etc. The glacio-fluvial deposits, mostly forming high banks along major tributaries are characterized by subangular to subrounded boulders. The fluvial deposit occurs as channel and floodplain deposits, terraces and fans. The channel and floodplain deposits are rounded heterogeneous boulders and

pebbles with gravels and sands containing mica flakes. This material is totally unconsolidated.

Geomorphologically, the mapped area forms parts of Greater and Lesser Himalayas. In this part, Sutlej River is the main drainage channel and in its youth stage, flows through a chain of high hills acquiring a sinuous course. The altitudes of the area vary greatly between 920 m at Sutlej riverbed near Rampur to 5240 m at Hansbeshan top. Ridges on the right bank of Sutlej River have NW-SE trend, whereas on its left bank these are almost N-S aligned. Some ridges in the western part of the area such as Sikari *Dhar* have more or less east-west trend. The higher peaks of around 5000 m elevation remain snow covered round the year, whereas winter snowfall is recorded above 1500 m. The landforms are mainly of glacial origin as many cirques and hanging valleys have been picked up from aerial photographs in higher reaches. The study of widely spread moraines in the area confirms that apart from trunk glacier, a score of tributary glaciers were also active in the recent past. The valley profiles of river Sutlej and its tributaries are, therefore, typically U' shaped, at least at the higher levels. However, a few streams like Kurpan *gad* show the modified shape of valley. Because of active fluvial regime in recent times, land forms like alluvial fans and terraces, change in stream courses. The landslide susceptibility map was and signatures of fossil valleys are also seen at many places. The remnants of old bed of Sutlej River are seen near Natpa, Khaneri and Rampur. The drainage pattern of the area at the right side of Sutlej River is dendritic, whereas left of Sutlej River, it is sub-dendritic and sub-parallel.

The landslide susceptibility map was prepared by adopting 'unique condition unit approach' (refer section 2.1.1, Chapter 2). Based on field traverses and interpretation of aerial photographs, landslides were mapped. All types of landslides are present in the Sutlej valley, including debris slides, rock slides and falls, creep, etc. The occurrence of rockslides is common along the highway and in the vicinity of the areas of other developmental activities, such as east of Kandru *khad* where developmental works for Sanjay Vidyut Pariyojna are in progress; the sheared gneiss and pegmatite rock exposed near 1890 bench east of Kandru *Khad* (the debris cone on left of Kandru *khad* is about 100 m wide at the base and is 60 m high); between Garsun and Chhota

Kamba where highly jointed and weathered porphyroblastic gneiss is resulting in rock slide and rockfall (after heavy rain and snowfalls of 14th and 15th May 1982 the slide reactivated); about 100 m downstream of Manglad *Khad* bridge (on the left side) sliding of gneissose schist boulders etc.

Plate 4.3 shows the landslide susceptibility map of Sutlej River basin, covering 1,040 km² area. The high instability class covers 43% area, whereas the medium instability covers 20% and remaining 37% by low instability class. The zone of high instability occurs along Sutlej river, Barauni *khad* and Sechi *khad*. The zone of high instability in average extends up to 1500 m to 2000 m higher than the river/stream bed level. However, the zones of high instability have been noticed extending further higher level stretching laterally in the valley configurations. The zone of medium instability in the area covered has no markable pattern of occurrence. It extends laterally with the valley configuration of Ganwi *khad* and above the zone of high instability east of Rampur. The zone of low instability has been marked in higher parts of slopes. The slopes are rocky and at places soil/ overburden covered. They have luxurious forest growth. The rills and gullies are shallow and joint controlled. Their progress is mainly due to block-by-block removal of rock along joints. There are, therefore, particularly no slides due to lateral or the erosion by the flowing water. In very steep parts, however, there are few rock falls. In these parts of slopes river terrace and other floodplain deposits have been categorized under this zone.

About 63% of the total area falls in zones of high and medium instability. The areas falling in these zones are mostly in lower parts of slopes close to valley floors. There are many denser patches of inhabitations in these parts of slopes. In addition, many developmental activities are going on in these parts. These activities apart from putting extra loads on the slopes on completion, involve a lot of cutting of slopes during their execution, thereby further endangering the stability of slopes. In such stretches, therefore, it becomes necessary to examine and study these slopes very carefully from the planning stage to minimize the problems and wasteful expenditure.

4.2.4 Landslide susceptibility mapping of Kinnaur district

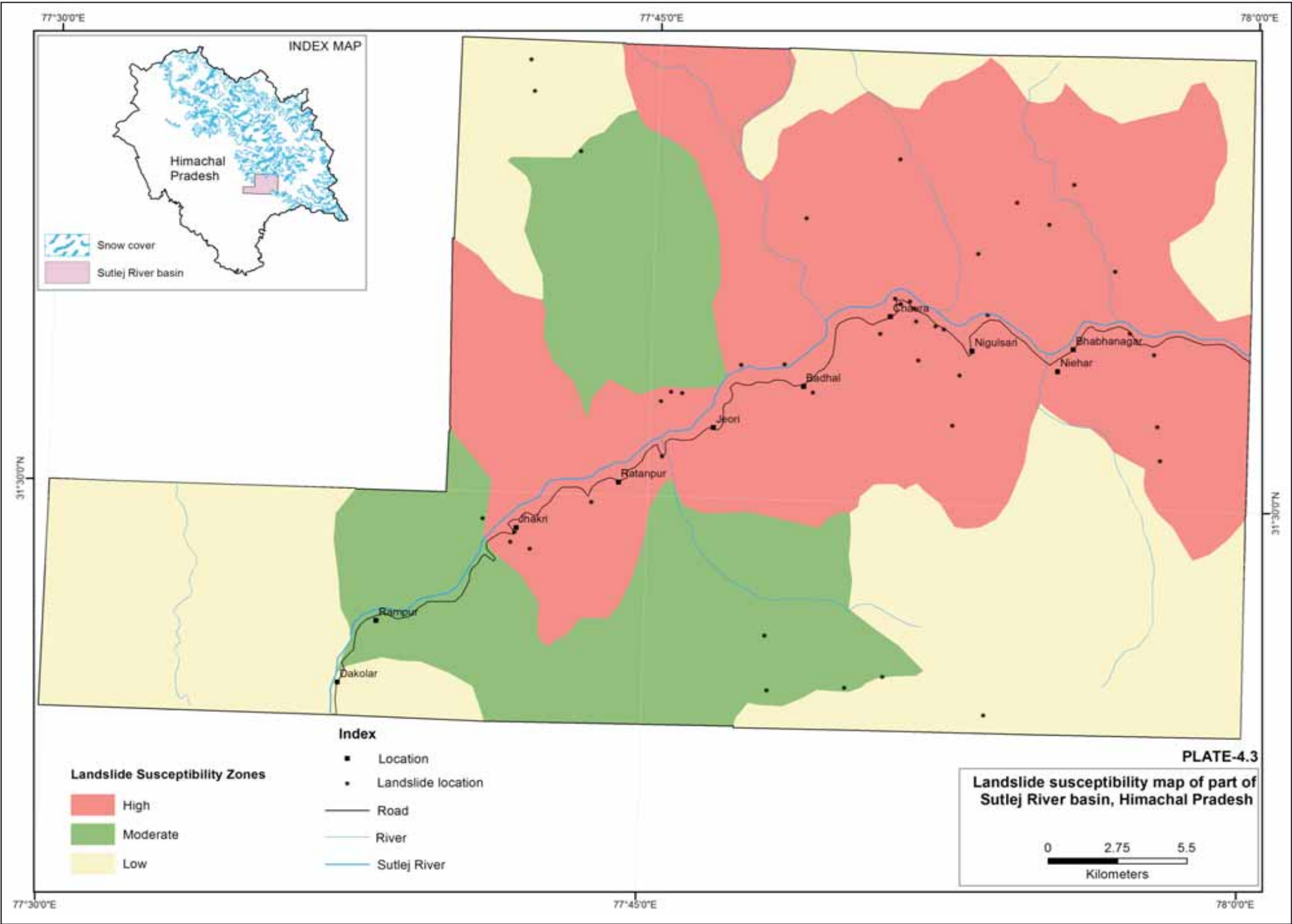
The district of Kinnaur is one of the most landslide prone

area in the state of Himachal Pradesh. The necessity of regional assessment of landslide zonation was felt, in view of the frequent occurrences of landslides in the valley disrupting the normal communication particularly during rains and causing danger to the human settlements and cultivated land. Landslide zonation has been done of around 860 km² area of the Sutlej valley in Kinnaur district, covering toposheets: 53I/2 and 53I/6. The work on landslide susceptibility mapping was carried out during field season programme of 1980 and 1981 (Gupta, 1982).

There is only one, all-weather road and a few fair weather roads. The all-weather road NH-22 is aligned, through lower parts of the slopes close to river Sutlej. A lot of construction work is going on at Rekong Peo to house new headquarters of Kinnaur district. The area being covered by this new township is of morainic material and is free from any landslide incidence. Large scale and rapid development activities are going on west of Wangar *gad* where Sanjay Vidyut Pariyojana is under construction. This scheme envisages utilisation of Wangar water to generate 120 MW of power in and underground power house near Wangtu. The construction activities are involving large scale cutting of slopes to accommodate approach roads and making of underground cavities for housing various civil structures of the project. The slopes both in rock and overburden have become unstable due to these activities.

Regionally the area is having very complicated geological setup, represented by a host of different lithological units. The area exposes rocks of Wangtu Gneiss and Granite (Porphyroblastic gneiss and porphyritic and non-porphyritic granite), Rampur Formation (white and light brown vitreous quartzite), Chails (Garnet phyllites with quartzite bands), Jutogh Formation (garnet mica schist and gneiss with quartzite bands along with carbonaceous and calcareous phyllite. with thin limestone bands), Maldi Gneiss (psammitic gneiss with banded quartzite and bands of schist), Mehbar Gneiss (Kyanite-bearing gneiss with bands of schist and quartzite), Rakchham Granite (Porphyritic and biotite granite with aplite and pegmatitic veins), Hilap Formation (Interbedded phyllite and quartzite with tuffs, cherts and dolomite in the middle part) and Pleistocene and Recent sediments.

The landslides in this stretch of Sutlej valley have been observed in all types of slope forming materials. Most



Landslide susceptibility map of part of Sutlej River basin, Himachal Pradesh

common are debris slides in unconsolidated overburden materials lying on slope in upper reach. Rocks are affected by rock falls and rock slides. Creep has been noticed at many places in overburden material. Debris slides are most common in the area. Between Morang and Akpa, a number of debris slides are seen in the overburden material above road level. The zone of fine morainic material consisting chiefly of silt with very few boulders, accumulated in a 2 km stretch along the river just downstream of Akpa, remains as a problematic reach (since the construction of a new road in 1962) because of frequent signs of slides. This material occurs in minor quantities on left bank and does not show frequent occurrence of slides. Near Pawari stabilised slides on left and active ones on right of the river are seen in glacial material and rock debris. All along the Sutlej River in between Karchum and Tapri there are many debris slides occurring on both sides of the river. Occurrences of slides in overburden materials are seen along tributary streams also.

There are not many active rockfalls in the area. About 3 km downstream of Shongtong near km stone 360 active rock fall occurs about 150 m above the river bed. The fallen rock material has been brought down by a *nala* along with the slush and deposited in the river bed. Along the stretch between km stones 361 and 362, rock falls occur frequently above old H.T. road level. Minor rockfalls have been observed on the right side of Sutlej River between Cheling and Tapri. Rock slides are much less in number in the area under study; the stretch between Betarang and Kilba and between Choling and Tapri rock slides are observed in the valley slope left of Sutlej River. Near Baru (Bercha) the slides have taken place in coarse porphyroblastic gneiss. East of Kundru khad two rock slides have been observed about 500 m above Sutlej River bed.

Apart from debris slide, rock fall and rock slide creep movement have also been noticed near Ribba, Purbani, Pawari, Kilba between Dumti *khad* and Sitling *Khad* and near village Jani.

The landslide zonation map was primarily prepared based on available aerial photographs (1:70,000 scale) due to adverse climatic condition in the terrain of high relief variations. Geomorphology, geology, slope forming material, land use and landslide incidences of the study area were mainly studied with the aid of aerial photo interpretation. The lithounits of geological formations have

been further simplified for the purpose of landslide zonation map in slope forming material maps. Overall the maps have been prepared to identify the process and conditions that promote instability. Once the role of these factors in promoting slope failures by interacting with each other is established a semi-qualitative classification can be made. Thus the degree of potential landslide hazard in an area can be estimated depending on the number of failure inducing factors present and their severity. For example, at one particular place "A" in a particular set of conditions the area is having landslide occurrence, under similar condition, no existing landslides is seen at some other places "S". A careful examination of these two places would reveal the important factor which is causing all the failures at "A". This factor could be disturbance in slope by road cutting, toe erosion by river or removal of vegetation. Therefore "A" will be classified as a zone of high landslide incidence and "S" as a zone of high landslide susceptibility. The mere induction of the factor responsible for causing landslide of "A" would turn "S" also into a zone of high landslide incidence.

It is on the above lines that a zonation has been attempted in the present work. In the first instance, over slope forming material map the landslide incidences were transferred. On the basis of this the materials having recorded occurrences of landslides were known. Then the slope map was superimposed over this map. This helped in demarcating preliminary map units of relative slope stability. If the area covered by existing landslides in a particular set of slope forming characteristics is more than 10%, the area has been marked as a zone of high landslide incidence. While defining such zone on this basis, the surficial drainage conditions have also been taken into consideration. Characteristically similar zone with no existing landslide has been classified as zone of high susceptibility. Here any interference (like road cutting) in the existing equilibrium might result in a series of slides. Likewise, the zone of medium incidences and zone of low incidences have respectively 2% to 10% and less than 2% part covered by landslides and correspondingly the zones of medium and low landslide susceptibility have been demarcated.

Based on above consideration, zones of high, medium and low susceptibility to sliding have also been demarcated where incidence is very low or almost nil (Plate 4.4). This way, zones of high, medium and low susceptibility to

landslides have been differentiated. The percentage of area covered by different zones is as under:

- I. Zone of high incidence -2.7%
- ii. Zone of high susceptibility -7.0%
- iii. Zone of medium incidence -18.6%
- iv. Zone of medium susceptibility -5.0%
- v. Zone of low incidence and susceptibility -66.7%

4.2.5 Landslide susceptibility mapping of Shimla Town

Situated in the North-West Himalaya, Shimla township spread over a conspicuous crescent-shaped ridge, has been witnessing a spurt of developmental activities ever since its inception. The hill slopes are under enormous stress and occasionally become critical owing to erosional degradation and slope cuts. With the objective to classify the slopes around town in respect of landslide susceptibility, macrozonation of the area has been carried out covering 110 km² on scale 1: 25,000 in parts of topsheet 53E/4 NW, NE, SW and SE. The area covered includes the part section of NH-22, Kasumpti, Khalini, Chhakkar in the south of the ridge; and Masobra, Dudhli, Annadale and Summer hill, north of the main ridge of Shimla. The work was carried out during field season programme of 2005 and 2006 (Sharma, 2007).

Geologically, the area is occupied by the rocks of Jutogh Group, Undifferentiated Jaunsar Group, Blaini Formation and Shimla Group. The larger part of the town area is occupied by phyllite, garnetiferous phyllite, quartzite and chloritic phyllite. The geological formations are regionally folded into WNW-ESE trending synform. The important tectonic feature of significance is Jutogh Thrust that separates underlying younger rocks with that of Jutogh Group of rocks. The town lies in sub-Himalayan zone which is earthquake prone. The effects of Kangra earthquake (1905) and Kinnaur earthquake (1975) have been recorded from the town and the area around.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer Section 2.1.4, Chapter 2). A detailed inventory of 21 landslides has been prepared. The area, in general, is devoid of major landslide activity, however, some surficial, shallow landslides, subsidence and creep have been observed all along. Though

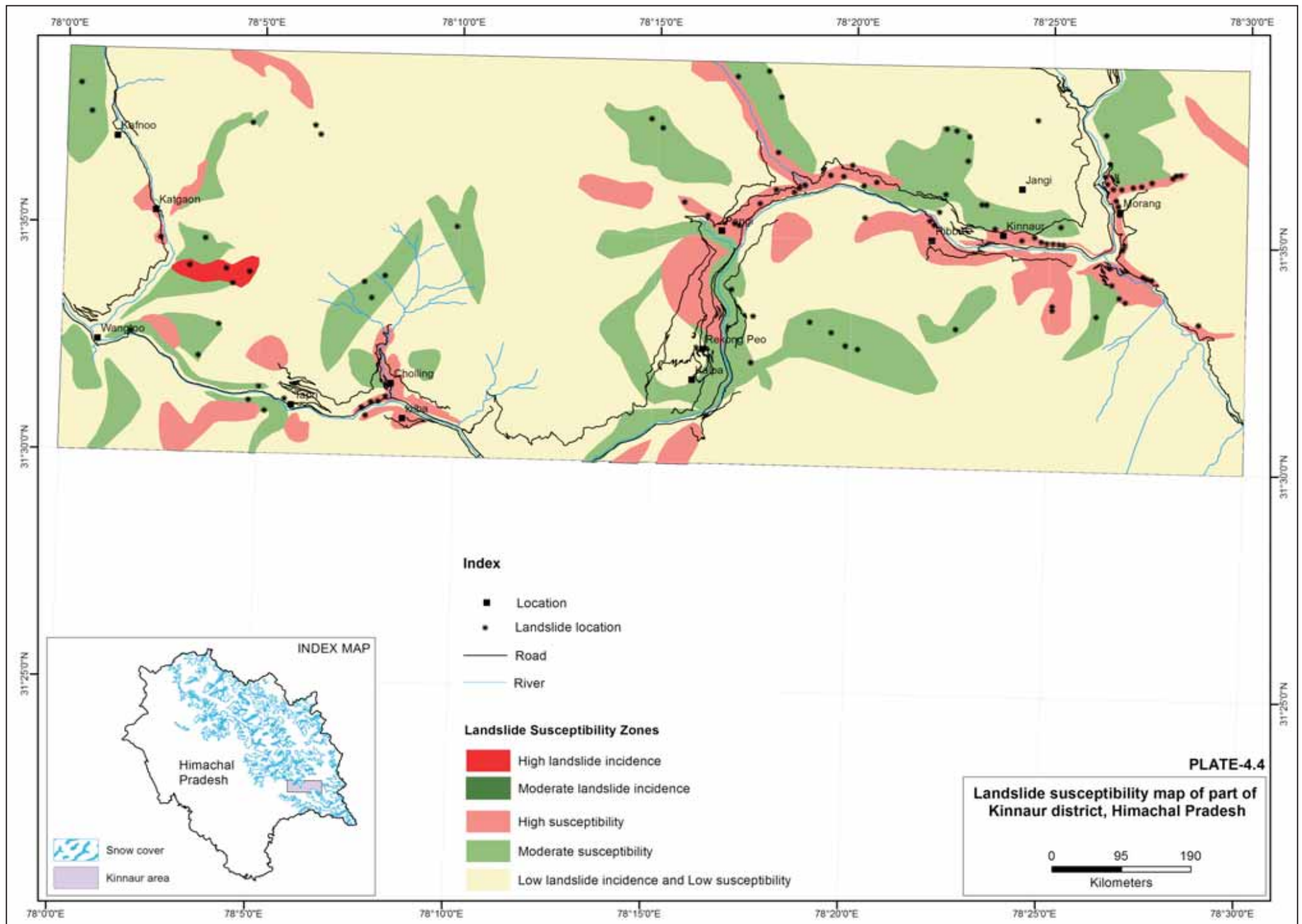
the slides are mostly surficial, yet the process of mass-wasting has affected vehicular traffic and inflicted damages to roads and buildings. Most of the slides are of debris types activated either by slope cuts, demographic pressure or by stream erosion. Zones of sinking/subsidence have been recorded in Kalibari area, Annadale road, Vikas Nagar area, Kaithul and Fingask sector consequent to rains of August 2006. The town has been frequently affected by landslides with shallow slips and subsidence generally occurring within overburden material. The problems of landslides and subsidence related to intensity of rainfall have been a major concern of Municipal authorities of Shimla, though no slide of mega dimension has so far affected the town.

Based on Modified BIS approach, the study area was grouped into four classes of varying landslide susceptibility (Fig. 4.3). The 110 km² area was divided into 593 slope facets, out of which 374 slope facets falls in Shimla Group, 200 in Jutogh Group, 6 in Jaunsar Group and remaining 13 in Blaini Formation. The zonation map reveals that very high and high susceptible zones are concentrated in south and north slopes of the ridge between Sanjauli and Dhalli, between Khalini and Kasumpti, close to Tuttigandi, south of Jutogh and some pockets in north of Shimla ridge. Large part of the area has been classified into very low to low category, where TEHD values are below 8.4. Moderate susceptible zones which are in a critical condition of slope stability are also evenly distributed in the area. The anthropogenic activities and accelerated erosion may have an aggregative effect towards the instability in the area.

The distribution of facets into different classes of landslide vulnerability reveals that approx. 77% of the area falls under low susceptible zone, 14% into moderate susceptible category, 6% falls in very low susceptible zone and remaining approx. 3% constitutes most vulnerable high to very high susceptible zones.

4.2.6 Landslide susceptibility mapping along Narkanda-Rampur-Khab road corridor

The Narkanda-Rampur-Khab section of National Highway (NH-22) is one of the busiest road corridors which is thronged by tourists including foreigners. This road is also known for landslide hazard, which often disrupt the traffic by blocking the road. The road passes through parts of Shimla and Kinnaur districts of Himachal Pradesh and covers



Landslide susceptibility map of part of Kinnaur district, Himachal Pradesh

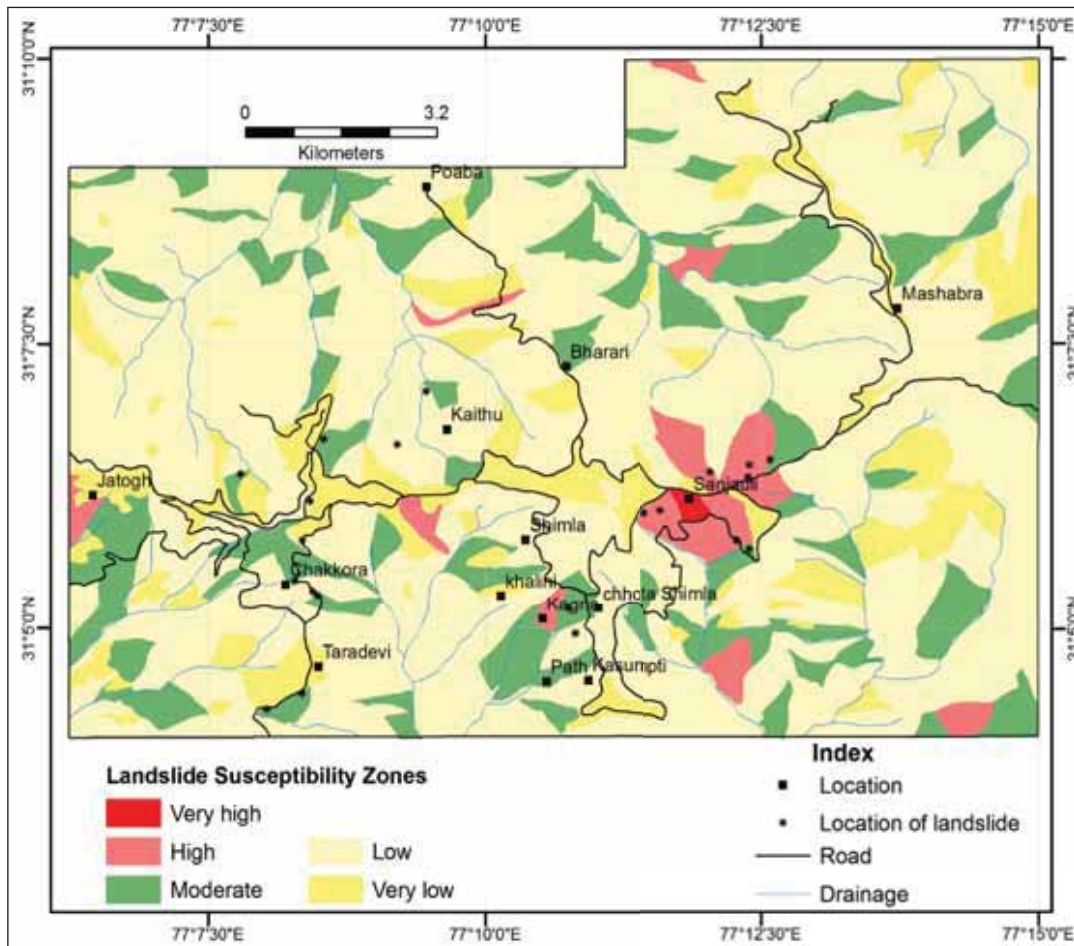


Fig. 4.3 Landslide susceptibility map of Shimla area.

toposheets: 53E/7, 53E/10, 53E/11, 53E/14, 53I/2, 53I/3 and 53I/6. The landslide susceptibility mapping was carried out on scale 1:50,000, covering 400 km² area (200 km) during field season programme of 2010 and 2012 (Kumar, 2012).

Geologically, the study area along Narkanda-Kumarsain-Nerath is mainly composed of schist with quartzite band of Khokhan Formation; streaky and banded gneiss of Gahr Formation and carb-slate, phyllite, quartzite and limestone of Khamrada Formation belonging to Kulu Group. The main rock types exposed around Nogli-Rampur-Khanera-Jakhri section are schist, phyllite and quartzite of Banjar Formation and pale white to green quartzite with phyllite interband of Manikaran Formation belonging to Rampur Group lying over Bandel-Jeori-Wangtu Granitoid Complex. Around Jeori-Nachar-Wangtu section the main rock types exposed are granitoid, gneiss and migmatized sediments of Proterozoic age belonging to Jeori-Wangtu

Granitoid Complex, which forms the basement for Rampur Group. Around Kalpa-Akpa section the main rock types exposed are sillimanite-kyanite bearing schist and gneiss, garnetiferous biotite schist, migmatite, micaceous quartzite and calc-silicate of Kharo Formation, belonging to Vaikrita Group. Along the section, the Chango-Akpa (Kaurik) and Roura *gad* faults have affected most of the rock units. The prominent Quaternary deposits in small patches are glaciated drift deposits, relict moraines and valley-fill deposits such as river terraces, debris cones and fans. The matrix-supported gravels in these terraces consist of angular to sub-angular clasts ranging in size from pebble to boulder embedded in a matrix of silty mud and sand.

The Kulu Thrust marks the base of the rocks of the Kulu Group; below it lies the rocks of Rampur Group folded into a complex antiform. Vaikrita Thrust observed near Shongtong bridge demarcates the tectonic contact between high-grade

and low-grade metamorphic rocks.

Physiographically, most of the area is covered by Great Himalayan and Zaskar ranges characterised by rugged topography marked by high mountains with narrow and deep valleys and gorges. The topography of the area represents a pronounced high relief with elevations varying between 900 m and 2800 m. Narkanda is situated at a height of 2708 m above msl and Rampur at 924 m. The area is mainly drained by the Sutlej River with its main tributaries Bhera *Khad*, Nogli *Gad*, Kut *Khad*, Chatinda *Khad*, Tikkada *gad*, Sorang *gad*, Soldan *Khad*, Salaring *Khad*, Panchot *Khad*, Wangar *gad*, Melam *Khad*, etc. These tributaries are perennial and fed by snow and rainfall. The general drainage pattern in the area is dendritic.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer Section 2.1.4, Chapter 2). A total of 53 landslide incidences has been mapped along Narkanda-Rampur-Khab section of NH-22, covering 400 km² area. Table 4.1 gives brief details of 10 major landslides. Major landslide incidences occur along Rampur-Wangtu-Akpa section. The main landslides are near Narkanda, Rampur, Kingal, Jakhri, Jeori, Nirsu, Gora, Chaura, Nigulsari, Wangtu, Powari, Pangi and Khadra. Annexure-I provides an inventory of some of the major landslides.

Figure 4.4 shows the landslide susceptibility map of Narkanda-Rampur-Khab route, covering 400 km² area. The entire route has been differentiated into 453 slope facets and based on TEHD values these are grouped in high, moderate and low susceptible zones. About 4%, 22%, 73% and 1% of the total facets are in high, moderate, low and very low susceptible categories respectively. In terms of rock type vulnerability, the gneiss, quartzite, limestone, migmatites and granitoids of Type-I category are more prone to high hazard category than schist, phyllite and slate of Type –III category. The high susceptible zones occur mainly along Rampur-Wangtu-Akpa section. This zone is mainly due to the presence of deep rill/gully erosion and road cutting disturbing hill slope stability.

In the high susceptible zones, restrictions on developmental work and discouraging the construction work on affected slopes may be seriously considered especially near Rampur, Gora, Wangtu, Powari, Pangi and Akpa areas.

Special attention is to be drawn for immediate measures along Kalpa-Akpa section as the headquarters of Kinnaur district, i.e. Reckong Peo which along this section is highly destabilised and the whole area is slowly subsiding causing major concern to the administration.

4.2.7 Landslide susceptibility mapping along Kangra-Dharmshala-Sihunta-Dalhousie road corridor

Landslides along communication routes in Himachal Himalaya are very common and often disrupt the life of people by blocking the road. Landslide incidences along Kangra- Dharmshala-Sihunta-Dalhousie communication route have affected the movement of tourists and pilgrims visiting places of mythological, archaeological and tourist importance, such as Kangra Fort, Masrur Fort, Jwala Devi, Dharmshala, Banikhet and Dalhousie. The road passes through parts of Gurdaspur, Kangra and Chamba districts of Himachal Pradesh and covers toposheets: 43P/14, 43P/15, 52D/3, 52D/4 and 52D/8. The landslide hazard zonation work was carried out on scale 1:50,000, covering 350 km² area (175 km) during field season programme of 2009 and 2010 (Kumar, 2011)

Geologically, the area exposes a wide assemblage of rock formations ranging in age from Early Proterozoic to Recent. The northern part mainly belongs to Vaikrita Group of rocks, including schists, gneiss, migmatite and Dalhousie granite. The Dalhousie granite forms the crest-line of the Dhauladhar range and acts as water divide of Ravi and Beas rivers. It is emplaced within the Morang Formation of the Vaikrita Group showing concordant relationship. The southern part of the area mainly encounters Lower Siwalik, Middle Siwalik, Upper Siwalik and Quaternary deposits. The prominent Quaternary deposits in the area are glaciated drift deposits, relict moraines and valley-fill deposits such as river terraces, debris cones and fans. The matrix-supported gravels in these terraces consist of angular to sub-angular clasts ranging in size from pebble to boulder embedded in matrix of silty mud and sand. The entire stratigraphic sequence is regionally folded into a major syncline referred to as "Chamba syncline" with NW-SE trending axial plane. The area has undergone polyphase deformation and forms a part of SW limb of a regional Chamba synclinorium. The general trend of rocks in the area is NW-SE with beds

Table 4.1. Inventory of major landslides along Narkanda-Rampur-Khab section.

Map Ref.	Dimension Width (at toe) (m)	Height (m)	Type of slide	Causative factors Remedial measures
1	50	60	Debris slide	Caused due to toe erosion by river. Retaining wall was suggested.
2	500	60	Rock cum debris slide	Caused due to road widening and toe-cutting by river. Smoothening of slope profile with retaining structure at the base and proper drainage lining were suggested.
3	70	70	Debris slide	Caused due to toe erosion by <i>nala</i> . Proper drainage and retaining wall were suggested.
4	60	50	Debris slide	Toe erosion by river and gully erosion by <i>nala</i> . Toe support by providing retaining structure was suggested.
5	50	50	Debris slide	Toe erosion by river. Toe support by providing retaining structure was suggested.
6	70	100	Debris slide	Road widening. Toe support by providing retaining structure was suggested.
7	150	150	Rockfall	Toe cutting by river and <i>nala</i> erosion. Toe support by providing retaining structure and proper drainage were suggested.
8	80	80	Debris slide	Toe cutting by river and road widening. Toe support by providing retaining structure was suggested.
9	150	150	Rock cum debris slide	<i>Nala</i> erosion. Toe support by providing retaining structure and proper drainage were suggested.
10	60	60	Debris slide	<i>Nala</i> erosion. Proper drainage and retaining structure were suggested.

Map Ref. is the slide number given in Fig. 4.4.

dipping low to moderate in northeast direction besides vertical at places.

The topography of area, presents pronounced relief with high ridges and deep gorges with elevations varying between 500 m and 1800 m. The area has rugged topography as it falls in the Lesser Himalayan ranges which trend NW-SE to E-W. The prominent NW-SE trending Dhauladhar range is marked by high and steep cliffs of granite, most of which are snow covered. The area to the north of the Dhauladhar range is more rugged and hilly, while south of it is less rugged and is more or less a plain valley filled with Quaternary sediments and alluvium. The southern part of the area is drained by the Banganga River with its southerly flowing tributaries Manuni *Khad*, Bahl *Khad*, Gai *Khad*, Chambi *Khad*, Khauli *Khad*, Brahl *Khad*, Bhed *Khad* etc. These tributaries flow on the southern slope of lofty Dhauladhar ranges. The northern part is drained by Ravi River. The general drainage pattern is dendritic.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (refer Section 2.1.4,

Chapter 2). A total of 15 landslide incidences has been mapped along Kangra-Dharmshala-Sihunta-Dalhousie road. Most of the landslides occur along the Sihunta-Lahru-Bakloh-Banikhet, possibly due to gully/rill erosion, poor strength of rock, structural discontinuities and presence of sparse vegetation. The main landslides are located at Balganga, Hatli, Sihunta (Fig. 4.5a), Bradhhman, Kakira (Fig. 4.5b), Lahru, Thalel, Bakloh (Fig. 4.5c) and Banikhet (Fig. 4.5d). Annexure-I provides an inventory of some of the major landslides.

Fig. 4.6 shows the landslide susceptibility map of Kangra-Dharmshala-Sihunta-Dalhousie route, covering 350 km² area. The entire route has been differentiated into 336 slope facets. Based on TEHD values these are grouped in High, Moderate and Low susceptible zones. Majority of the facets (66%) are confined to different types of sandstone, clay and boulder conglomerate of Dharmshala Formation and Siwalik Group and remaining facets (34%) are confined to quartzites of Sundernagar Group. About 2% area falls in high susceptibility and 9% falls in moderate susceptibility

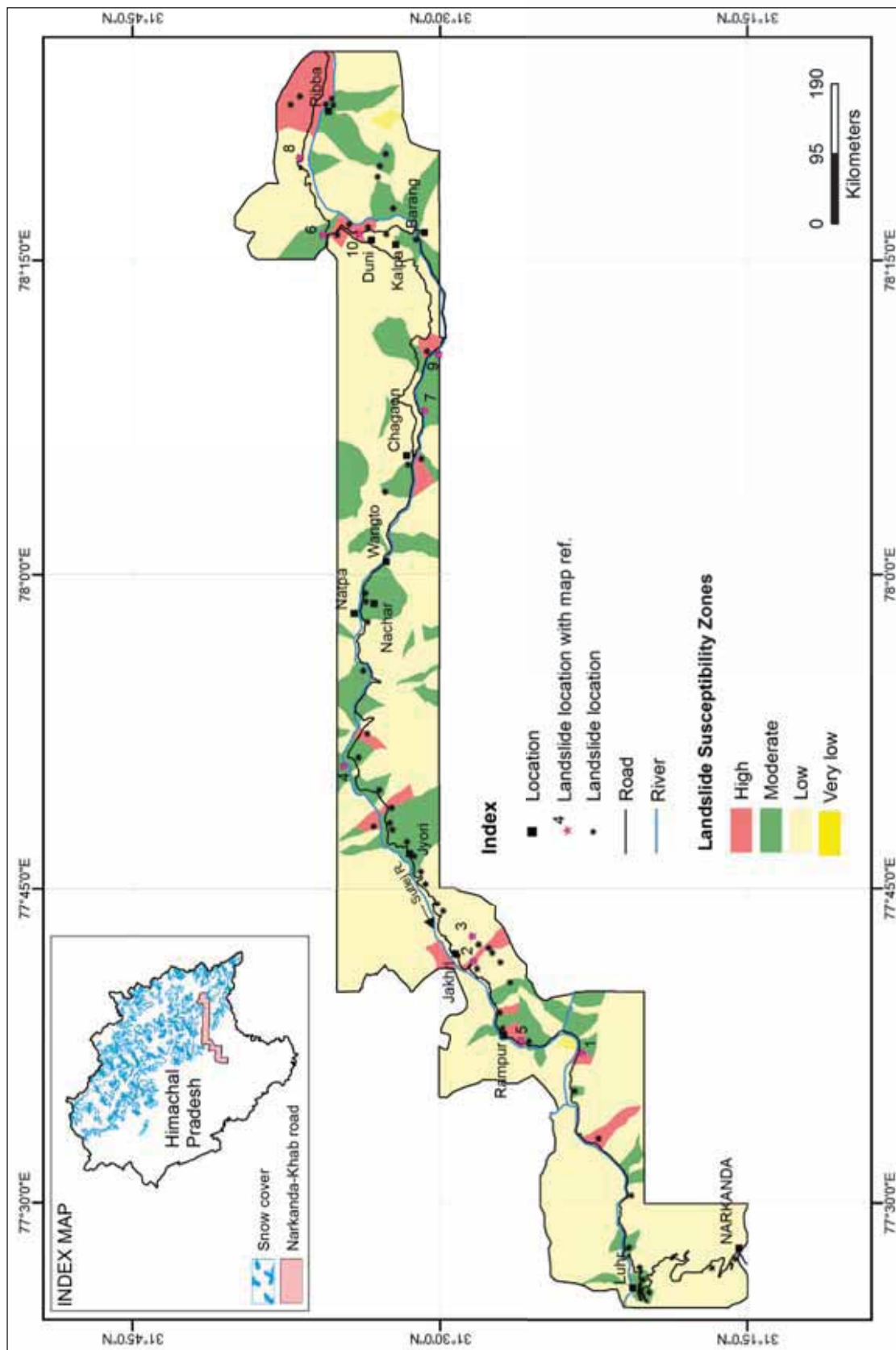


Fig. 4.4. Landslide susceptibility map along Narkanda-Rampur-Khab section of NH-22, Himachal Pradesh.



Fig. 4.5. Major landslide along Kangra- Dharmshala-Sihunta-Dalhousie road: (a) debris slide near Sihunta, (b) debris slide zone at 6 km Kakira, (c) rock fall zone near Bakloh junction and (d) wedge failure before Banikhet bridge.

class. Low susceptibility class covers about 89% area. The area is devoid of very high and very low susceptibility class. The high susceptibility zones occur mainly along Sihunta-Lahru-Kakira-Bakloh-Banikhet section. This zone is mainly due to deep rill/gully erosion disturbing hill slope stability. Near Dhurasappar, this high hazard zone is developed due to road cutting. In the high hazard zones, restrictions on developmental work and discouraging the construction work on distressed slopes may be seriously considered especially near Lahru, Kakira and Dharmshala areas.

4.2.8 Landslide susceptibility mapping along Kalka-Shimla narrow gauge railway route corridor

The hilly mountainous region of Himachal Himalaya is linked with the rest of the country not only by winding roads and high passes, but also by the 96 km world heritage railway

route connecting Kalka and Shimla. On this narrow gauge the first toy train of the country is being operated since 1904. The average gradient of this railway starting from Kalka at an elevation of 656 m, is 1 in 33, attaining a height of 2075 m at its last halt, i.e. Shimla. The train passes through 889 bridges both small and large ones. Bridge No. 226, the longest one, is 97.4 m long and Bridge No. 541 which is 23 m above the *nala* bed near village Kanoh is the highest bridge. There are, in all, 102 tunnels all along the route, the longest being Barog tunnel measuring 1143.6 m in length.

The route passes through parts of Haryana and Himachal Pradesh and covers toposheets: 53E/4/SE, 53E/4/SW, 53F/1/NW, 53F/1/NE and 53 B/13. The work on landslide susceptibility mapping for Kalka-Shimla route was carried out on scale 1:25,000, covering 192 km² area (96 km) during field season programme of 2002 and 2003 (Gupta, 2009).

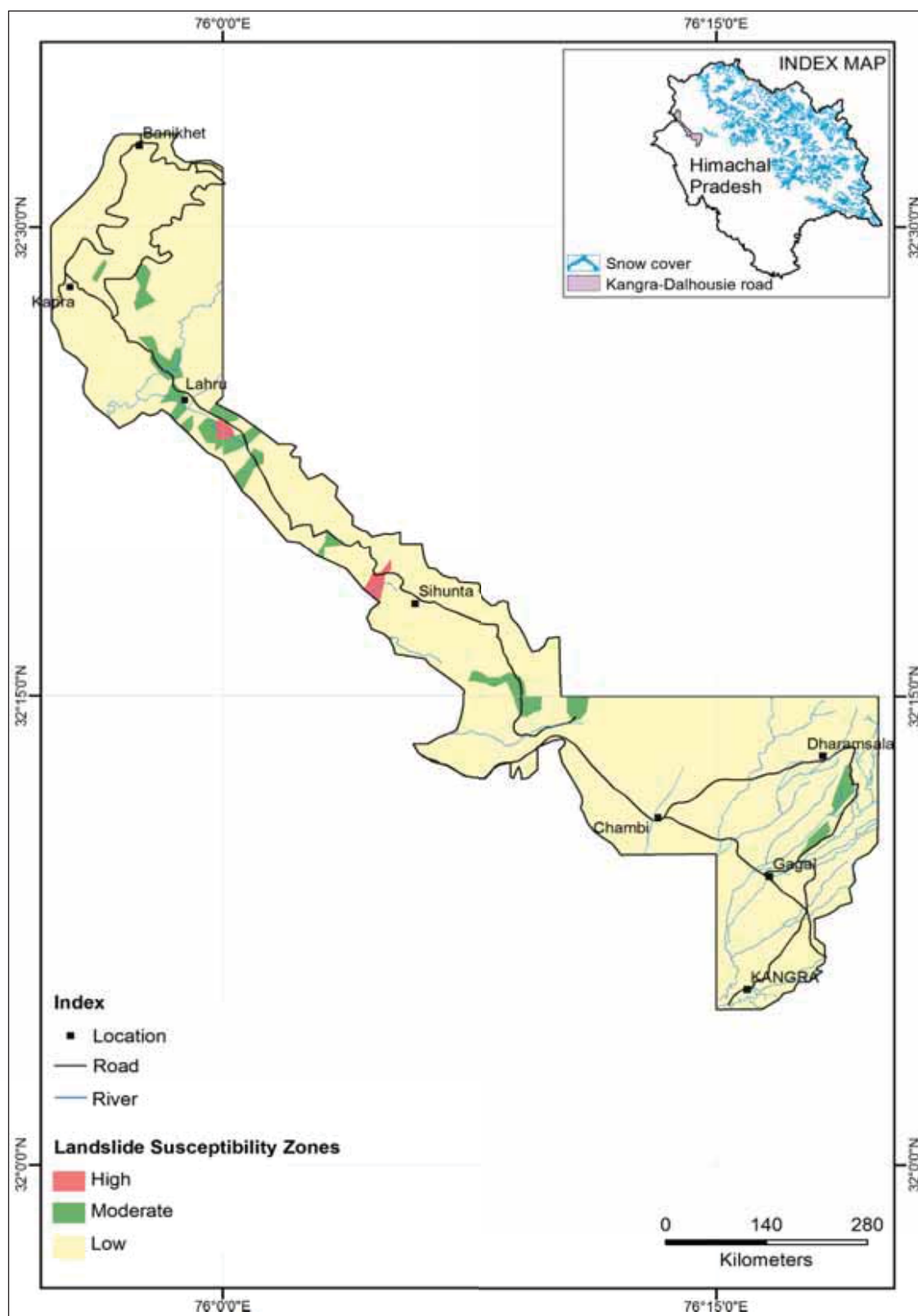


Fig. 4.6. Landslide susceptibility map along Kangra- Dharmshala-Sihunta-Dalhousie road corridor, Himachal Pradesh.

Starting from Kalka towards east and northeast, structurally the contact of Siwalik and lower Tertiary sediments (Subathu, Dagshai and Kasauli), close to Parwanoo is marked by the Bilaspur Thrust (MBT-2). The red facies of Dagshai Formation occurs near Datiyar. These rock formations occupy the core of the Garkhal Syncline, flanked by green facies -Subathu Formation. Repeated occurrence is also marked in the form of the Sonwara anticline further east. Thickly bedded sequences of green and purple rock units of Dagshai and Kasauli formations are exposed in the Dharmpur and Kumarhatti area also. The Barog *nala* marks a thrust contact between Infra Krol and Kasauli Formations. The Krol and Infra Krol rocks form a wide open synform at Solan, called the Pachmunda syncline the core of which is occupied by the thickly bedded quartzite and flaggy limestone, Middle Krol pink shale and Upper Krol limestone and massive but incipiently bedded dolomite. East of Solan these rock formations are repeated in the form of open anticline and a syncline just south of Kandaghat, where the dolomitic sequence exhibits deep weathering, cavity formation and brecciation. The adjacent phyllite and shaly rock units are highly carbonised indicating effects of intensive alteration, fracturing and metasomatism. Between Kandaghat and south of Kaithlighat rocks of Simla and Jaunsar groups comprising limestone and slates, phyllite and schistose quartzite and phyllite, are exposed along the road section, respectively. Further east up to Shimla, granite gneiss, thickly bedded greenish grey quartzite, carbonaceous phyllite, limestone with schistose bands belonging to Jutogh Group are exposed.

Kalka is the major township, located on a wide piedmont zone formed by a number of streams and rivers debouching at the break in slope at the foothills, and is also the railway station of the narrow gauge railway. It is situated at an elevation of 656 m. Kaushallia Nadi lies to the southeast of the town. Towards east of Kalka, the topography rises abruptly in the form of hills incised by deep valleys with both dry and perennial *nalas* that form a sub-dendritic to trellis type of drainage pattern. The winding train route follows some of the prominent drainages and water divides in the area. Kasauli and Garkhal (El 1910 m highest point) lie on one such divide located north of Kalka. The drainage pattern, between Dharmpur and Barog trends in NW-SE direction and indicates structural control of the rock

formations. At Barog (El 1878 m), a wide ridge marks a change into a rolling topography of the area, as the drainage pattern becomes sub-dendritic towards east, due to the presence of open folding in the rocks of Krol Group. The prominent river that flows near southeast of Solan and Kandaghat is the Asian river. The train route follows the right bank of the river. The ground elevations rise progressively towards north of Kandaghat, as the train route negotiates a circuitous path around Kiarighat (El 1973 m), Kaithlighat (El 1919 m), around Taradevi Hill, Prospect Hill (El 2175 m) and Summer Hill to reach Shimla (El 2075 m).

The landslide susceptibility map was prepared by adopting 'BIS method (refer section 2.1.3, Chapter 2). A total of 65 landslide incidences has been mapped along Kalka-Shimla route. About 9% of failures occurred in quartzite, 10% failures in highly weathered shale, 5.3% failures in fresh shale (i.e., phyllite and slate of Simla Group), 6.5% in limestone and 6.2% in schist. Slope failures were more in highly weathered shale. Major failure in granite gneiss was not recorded in the area studied.

Fig. 4.7 shows the landslide susceptibility map of Kalka-Shimla route, covering 350 km² area. The entire route has been differentiated into 670 slope facets and based on failure probability values these are grouped in Very high, High, Moderate, Low and Very Low susceptible zones. A total 9 facets (1.3% of total slope facets) fall in Very Low susceptible Zone whereas 288 facets (42.3%) in Low susceptible Zone, 245 facets (36.1%) in Moderate, 119 facets (17.5%) in High, and the rest 19 facets (2.8%) in Very High susceptible Zone.

The slopes along the railway track from Kumarhatti to Barog have recently become vulnerable due to the cutting of a bye-pass road leading to Solan. Since the railway track lies below the level of the bye-pass, rock falls and slides may endanger the safety of the heritage train route. It has been noticed during the field investigation that recent indiscriminate human activities in the form of cutting of slopes for buildings and widening of existing roads and excavations for new roads and bye-pass are being carried out. It is recommended that these activities need to be curtailed/stopped so as to keep the track safe from initiation of any slide, as well as getting damaged from falling boulders, from higher levels.

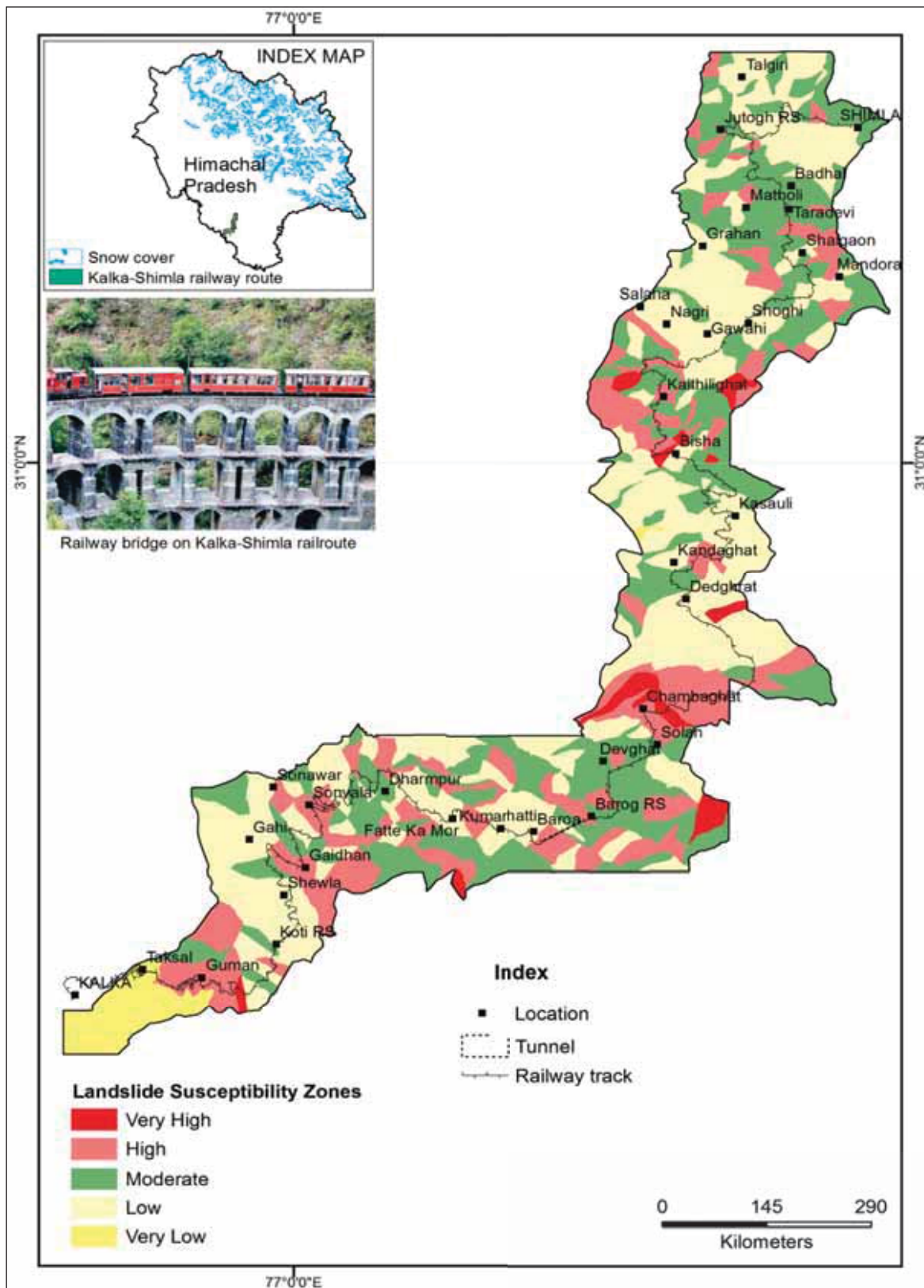


Fig. 4.7. Landslide susceptibility map along Kalka-Shimla railway route.

4.2.9 Landslide susceptibility mapping along Arakot-Rohru-Narkanda-Theog-Chail-Solan road corridor

The Arakot-Rohru-Theog-Narkanda-Chail-Solan section of road is known for landslide hazard, which often disrupts the traffic by blocking the road. This route also connects the National Highway (NH-22). Important hill stations like Chail, Theog and Narkanda also lie on this route which highlights the tourist attraction not only in summers but also for the winter sports. The road passes through parts of Shimla and Solan districts of Himachal Pradesh and covers toposheets: 53E/4, 53E/8, 53E/12, 53E/16 and 53F/1.

The landslide susceptibility mapping was carried out on scale 1:50,000, covering 350 km² area (175 km) during field season programme of 2008 and 2009 (Sharma, 2010).

Geologically, the road from Arakot to Solan exposes rocks of Jutogh, Jaunsar, Simla and Baliana Group and Krol group of rocks. Jutogh, Giri, and Krol thrusts are the main tectonic features in the area. Jutogh Group is represented by carbonaceous phyllite, quartzite, chlorite and sericite phyllite, garnetiferous schist, slate in Rohru–Arakot section. The general trend of these rocks is N50°W-S50°E with 40° dip in northeast direction. The Jutogh Group of rocks occurs in two detached belts, i.e. as a pear-shaped klippe in Shimla area and the northern extension of main Chur belt in Sutlej and Pabbar valleys. The rocks of this group are classified into ten formations and are broadly grouped into three assemblages based on identical lithological characters and degree of metamorphism. The three assemblages consist of carbonaceous phyllite, slate, schist, quartzite, limestone, shale, dolomite, gneiss, amphibolite with garnet, kyanite and staurolite mapped into different formations followed by quartzite and schist assemblages and garnet schist, graphite schist, amphibolite, psammitic gneiss and marble assemblage, all mapped into different formations. The Khainchwa-Pabbar granite of Tertiary age is found intruded within the Jutogh Group. Jaunsar Group is exposed in Shimla area and in Pabbar valley. This group has its lower contact thrust with Shimla Group while its upper contact is thrust with Jutogh Group. This undifferentiated group is represented by quartzite, phyllite, slate, conglomerate, greywacke, limestone, dolomite and metavolcanics and is intruded by Kharsali Granite. Shimla Group of rocks are

represented by four formations viz. Basantpur Formation comprising limestone, shale, quartzite and conglomerate; Kunihar Formation consisting of shale, siltstone and limestone; Chhaosa Formation made up of shale, siltstone, quartzite and greywacke; and Sanjauli Formation represented by shale, siltstone, greywacke, quartzite, sandstone conglomerate and slate. This group is succeeded by Blaini Formation of Baliana Group along a thrust contact and comprises shale, slate, pebbly sandstone and mudstone. This is overlain by Infra Krol Formation which is characterised by fragile carbonaceous shale and slate. Pyritiferous, carbonaceous slates, variegated slate, shale, marl and limestone/dolomite belonging to Krol Group are well exposed in Solan section of the route.

Thick Quaternary to Recent deposits in the form of pebble/cobble/boulder sediments occur along the valleys of Giri and Pabbar rivers are represented by point bar and valley fill deposits i.e., old fluvial terraces indicating widespread regime development of fluvial process.

Physiographically, the area is part of the Lesser Himalayan range and exhibits highly dissected and rugged topography controlled by long ridges, deep and narrow valleys covered by sparse to dense forest with shrubs, bushes and mixed jungle trees. The region is drained by two major southerly flowing drainage system viz., Pabbar and Giri rivers. The main drainage is represented by Giri River and its major tributaries such as Bagar Ka Nal Nadi, Bedar Khad, Dhabror Khad, Asan River and Pabar River flowing from NE to SW with tributaries such as Dogra khad, Biskalti *nala*, Salanti *Gad*. The river Pabbar forms deep, narrow gorge and shows meandering at a number of places. Numerous small drainages cut through the mountainous terrain to join the various stream and tributaries to give rise to an overall dendritic to sub-dendritic pattern. The high ridges in the area are represented by long ridges running on both the banks of the rivers. Prominent among them are Shankhan dhar, Badro dhar, and Guldeh dhar. The route at Arakot has an elevation 1498 m, Rohru 1575 m, Jubbal 1710 m, Theog 2400 m and Narkanda 2750 m.

The landslide susceptibility map was prepared by adopting 'Modified BIS approach' (Refer section 2.1.4, Chapter 2). A total of 18 landslide incidences has been mapped along Arakot-Rohru-Theog-Narkanda-Chail-Solan

route. Table 4.2 gives brief details of 13 major landslides. Annexure-I provides an inventory of some of the major landslides.

Fig. 4.8 shows the landslide susceptibility map of Arakot-Rohru-Theog-Narkanda-Chail-Solan, covering 350 km² area. The entire route has been differentiated into 327 slope facets and based on TEHD values these are grouped in Very High, High, Moderate, Low and Very Low susceptible zones. About 2%, 8%, 15%, 64% and 11% of the total facets are classified into very high, high, moderate, low and very low susceptible categories, respectively.

The main causative factor attributed to landslides is the rainfall. In addition, over-saturation of highly weathered material, toe cutting by Pabbar and Giri rivers and high energy water flowing *nalas* and lateral cutting by local drainage coming down the hills have induced different types of slides and rock falls along the route. At places, the dipping strata parallel to sub-parallel with slope direction towards road/valley side is also a major contributing factor in sliding of the rock mass. It has been noticed that encroachment upon the forest land for agriculture purposes on hill slopes has further accelerated the slides and soil erosion.

4.3 Micro-scale landslide studies

4.3.1 Chaledh and Dinka landslides, Brahmour, Chamba district

The Chaledh and Dinka slide zone covering 0.38 km² area was geologically mapped on scale 1:2,000 using theodolite (Fig. 4.9) with an aim to evaluate the nature and causes of the landslides and its effects on the proposed Budhil *nala* hydroelectric project (Chandra and Bhatnagar, 1997). The Chaledh slide is a complex slide developed due to combination of several failed slopes. It extends about 800 m in length and 500 m in width. The crown is located at 2480 m above msl whereas toe is at 1726 m. Many isolated and independent failed slopes of overburden and weathered rock also occur below the toe of combined slide upto the Budhil *nala* and Chaledh *nala* confluence having an elevation of 1560 m above msl. The debris covered part of Chaledh slide shows seven number of break in slopes of which six are above the Kharamukh-Brahmour road and one below the road (EL 1972 m) which represent different slip circle geometrics (Fig. 4.10). The Dinka slide occurs about 300 m

NW of Chaledh slide. It has a length of 350 m and width of 150 m. The crown is at EL 1960 m and toe extends upto Budhil *nala*. A large part of the Dinka slide and entire slope face below Kharamukh-Brahmour road have been covered by retaining walls by state PWD in order to protect the road.

The rock types exposed at Chaledh and Dinka slide area are predominantly medium to fine grained quartzites to quartzitic sandstones with thin bands of phyllites of Katarigali Formation under a thin cover of overburden soil.

The geo-mathematical modelling of the slide suggests that the slope failure along the rocky scars are planar failures along the master joints, whereas debris failures are along the slip circles with very shallow centres and smaller radius of curvatures. The cause is attributed to combination of many factors, viz., structural, rock types, topography, groundwater and climate. The quartzitic rock mass has been weakened along structural elements leading to sheared and closely jointed rock mass. These have been further weakened by the frost action and be easily eroded away by moving snow/ice and surface runoff or toppling. This has developed steep slopes favourable for wedge failures and continued toe erosion by human activity has resulted into present form of Chaledh and Dinka slides.

4.3.2 Reckong Peo subsidence zone, Kinnaur district

In the first week of October 2010, a large number of widespread cracks with subsidence developed in slopes at several places in Reckong Peo Township, Kinnaur district, Himachal Pradesh. These have affected the houses, roads, government and private buildings etc. Preliminary investigation of the affected site was taken up from 28 November to 4 December 2010 to ascertain the probable causes of this incidence and to suggest immediate preventive measures (Kumar et al., 2012).

Geologically, the area exposes muscovite sillimanite schist, augen gneiss and migmatites of the Kharo Formation belonging to the Vaikrita Group overlain by thick fluvioglacial deposits. The fluvioglacial deposits comprise poorly sorted composed of angular to sub-angular boulders, cobbles and pebbles of gneiss, schist embedded in a semi-consolidated sandy to silty, at places clayey, matrix. Rock is exposed on the southern side of distress reach and it is weathered high-grade schist which is folded on mesoscopic

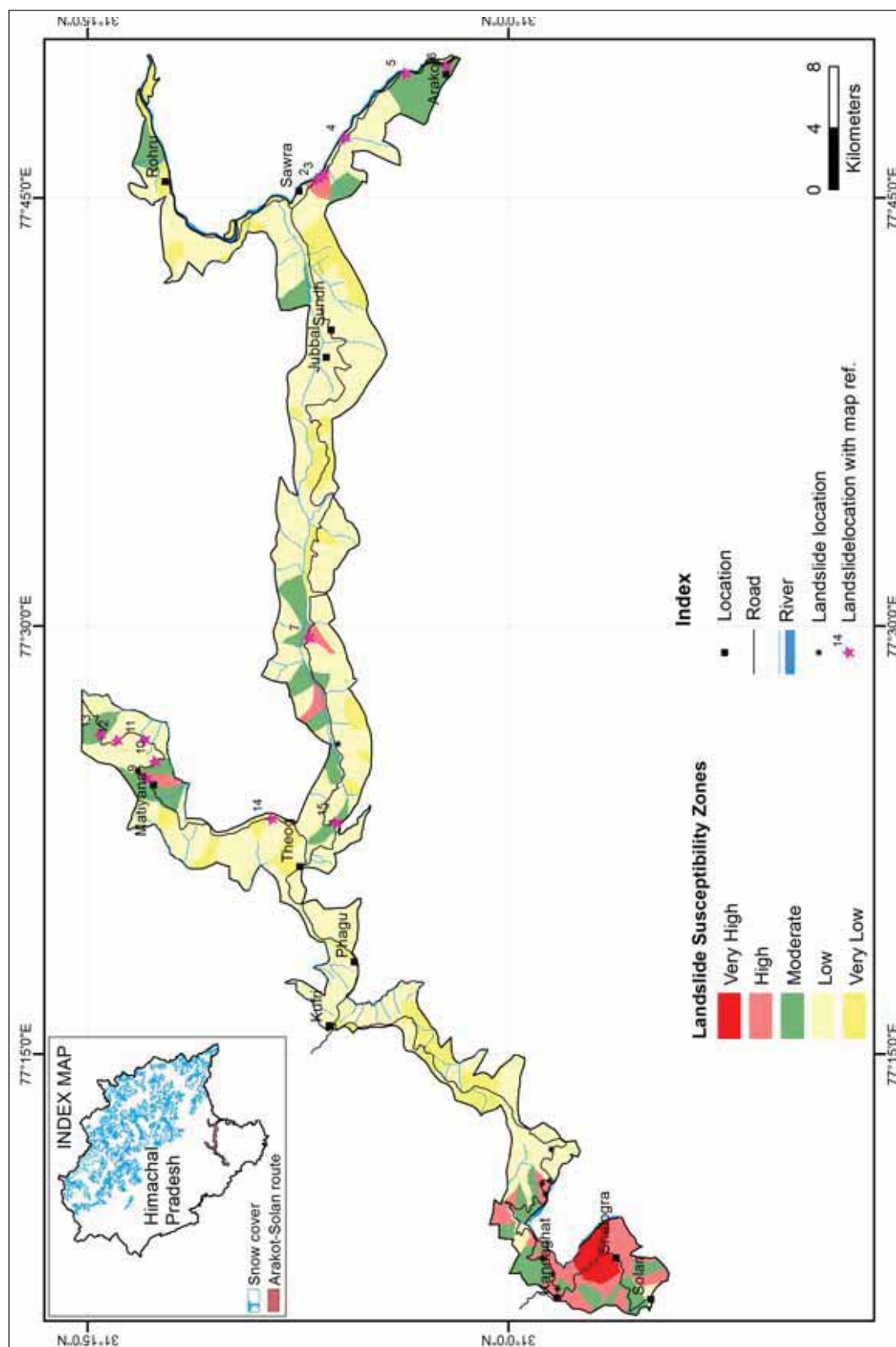


Fig. 4.8. Landslide susceptibility map along Arakot-Rohru-Narkanda-Theog-Chail-Solan road corridor.

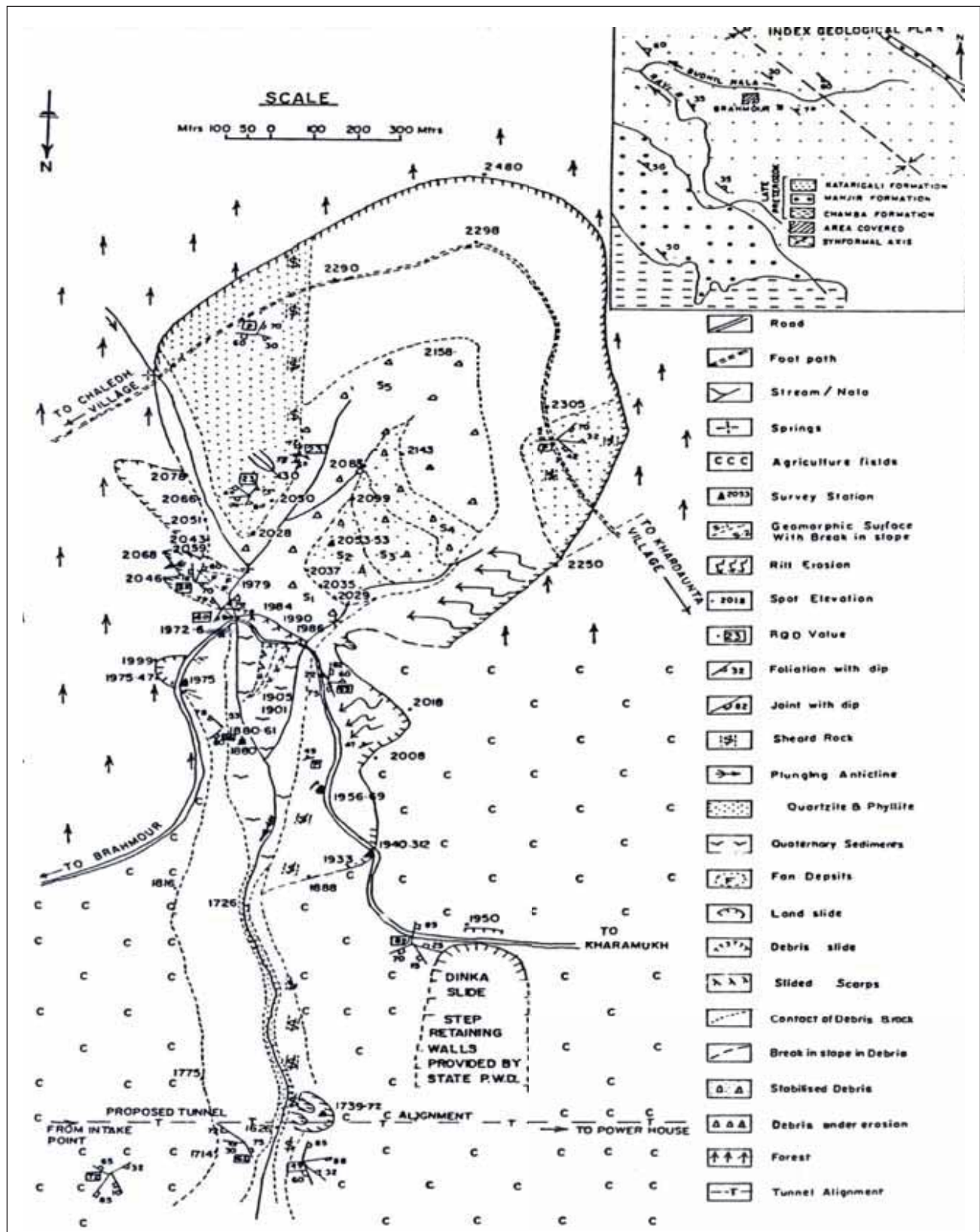


Fig. 4.9. Detailed geological and topographical plan of Chaledh and Dinka landslides.

Table 4.2. Inventory of major landslides along Arakot-Rohru-Narkanda-Theog-Chail-Solan section.

Map Ref.	Dimension Length (m)	Height (m)	Type of slide	Causative factors and temporary remedial measures
2	60	40	Rock slide (Planar)	Poor lithology and road cut caused the slide. Benches at critical heights and retaining structure, drainage improvement were suggested.
3	50	80	Rock cum debris slide	<i>Nala</i> erosion, rockfall on steep slope. Toe support by retaining structure, drainage improvement work were suggested.
4	30	20	Debris slide	<i>Nala</i> erosion. <i>Nala</i> training work with boulder crate support was suggested.
2	60	40	Rock slide (Planar)	Poor lithology, and road cut. Benches at critical heights and retaining structure, drainage improvement were suggested.
5	15	10	Debris slide	Poor lithology, and road cut. Benches at critical heights and retaining structure, drainage improvement were suggested.
6	8	5	Debris slide	Toe erosion. Benching of slope and toe support were suggested.
7	10	12	Debris slide	Gully erosion undercut by flowing conditions. Slope benching with drainage improvement work were suggested.
9	75	15	Debris slide	Toe erosion of <i>nala</i> and deep gully erosion. Drainage improvement, toe support, and benching of slopes were suggested.
10	150	80	Rock slide/ Rock fall	High relief steep slopes. Slope dressing and rock bolts were suggested.
11	70	20	Debris slide,	Toe erosion of <i>nala</i> and deep gully erosion. Drainage improvement, toe support, and benching of slopes were suggested.
12	100	15	Debris slide	Erosion action of <i>nala</i> , flow condition during rainy months. High strength toe wall support, drainage improvement works were suggested.
13	40	30	Rock slide	Road cut. Toe support wall was suggested.
14	200	120	Rock slide	Road cut extending the slide; fields at risk. Toe support with adequate drainage improvement work were suggested.
15	70	30	Debris slide	Toe erosion by <i>nala</i> . Bolder crate wall to check toe erosion was suggested.

Map Ref. is the slide number given in Fig. 4.8.

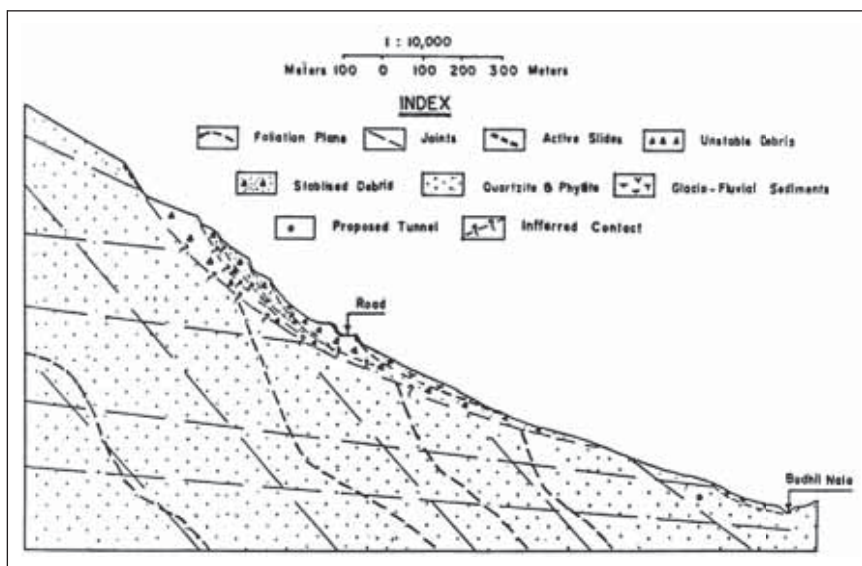


Fig. 4.10. Geological cross section at Chaledh slide (from crown to toe).

scale. The trend of foliation recorded is N40°-80°E to S40°-80°W with 20°-35° dip in northwestern direction.

Cracks with opening varying from 4mm to 30 mm in the Govt. degree college building, Reckong Peo were first observed on 4th October 2010. These cracks were subsequently observed to be extended in the ITBP ground during examination by the local administration. Also, cracks were observed in the Irrigation and Public Health building, Girls Hostel, sewage treatment plant. The cracks got widened up to 18 cm in college ground. The maximum width of the crack at ITBP ground was 15 cm with settlement of ~6 cm.

The detail map reveals that the affected/distress zone is about 650 m in width and 350 m in length (Fig. 4.11). The widespread discontinuous cracks have been observed upto 400 m length. These cracks are slightly arcuate. Circular failure surfaces are clearly visible as crown (vertical head scarp) at ITBP ground with subsidence upto 0.6 m. Ground cracks are manifested in step-like manner. The mass movement at toe is manifested by buckling of concrete wall of sewerage plant located about 300 m from the crown (head scarp) (Fig. 4.12). Arcuate tension cracks up to 40 cm wide and >1 m deep have been observed in the crown portion of the slide at ITBP ground. Settlement/subsidence of 10 cm to 60 cm have been recorded along the cracks. These cracks extend from ITBP ground in the northern direction down to Department of Industry complex and area further below.

For irrigating the apple orchards and other crops in the Reckong Peo area water channels/Kuhals are being used. It has been observed that an unlined channel exists just above the crown of the current distress zone. It is apprehended that this unlined channel contributed significantly to the surcharge of the fluvio-glacial material to a large extent in the absence of rain.

The following recommendations were made to mitigate the hazard: (i) irrigation water should flow through lined drains, (ii) damaged lined drains and sewerage lines in the distress reach should be repaired immediately so that no seepage of water occurs, (iii) for monitoring of the subsidence it was advised to construct concrete pillars at various locations, (iv) four core boreholes are proposed in the distress zone (Fig. 4.11) in order to study the depth of rock, failure surface, water level, etc., (v) in Reckong Peo

Township, all the settlement on the distressed ground should be shifted to rocky and unsaturated foundation with gentle slopes away from the unstable slope and all the ground cracks to be packed with impervious soil.

4.4 Post-disaster landslide studies

4.4.1 1st and 2nd April 1963 event along Kiratpur Bilaspur road

On 1st and 2nd April 1963, a major landslide had occurred on the newly-constructed Kiratpur-Bilaspur road. The slide damaged the road section, which subsided to 33 m below. The landslide, measuring 200 m width along the road, is located about 41 km from Kiratpur on the Kiratpur-Bilaspur road in toposheet: 53A/15 (Lat. 31°15'20"N: Long. 76°46'20"E). The affected area is on the right side of the Gambhar Khad, a tributary of the Sutlej River. The study was carried out with an aim to geotechnically assess the landslide and to ascertain its cause and probable relation with Bhakra reservoir (Prasad, 1963).

The geological map of toposheet 53A/15 shows that in the vicinity of the slide area, a thrust fault occurs between the Upper Siwalik rocks and the overlying Lower Siwalik rocks (Gambhar thrust). In the field, it is observed that the Gambhar thrust forms the base of the landslide. The rocks above the thrust mostly consist of bands of purple claystone and siltstone with minor layers of silty sandstone, all in a highly fragmentary and incipiently sheared state, and traversed by numerous, minor faults. The rocks strike N20°E-S20°W and dip 43° towards S70°E. Seepage of water was noticed near the Bilaspur end of the slide area and about 6m above the road level.

The cause of the slide is attributed to the presence of highly sheared and fragmentary rocks. During rainfall, the free flow of the groundwater was probably checked on account of the crushed nature of the material in the fault zone forming the base of the landslide. Further, steep cutting of the hillside for laying the 6 m wide road has induced slumping in the sheared rock mass. There are chances of a further deterioration of the slide by collapse of the rock mass from still higher level because the lateral support has been removed by the present slide.

The possibility of saturation of the area by the Bhakra reservoir prior to the formation of the landslide was ruled out

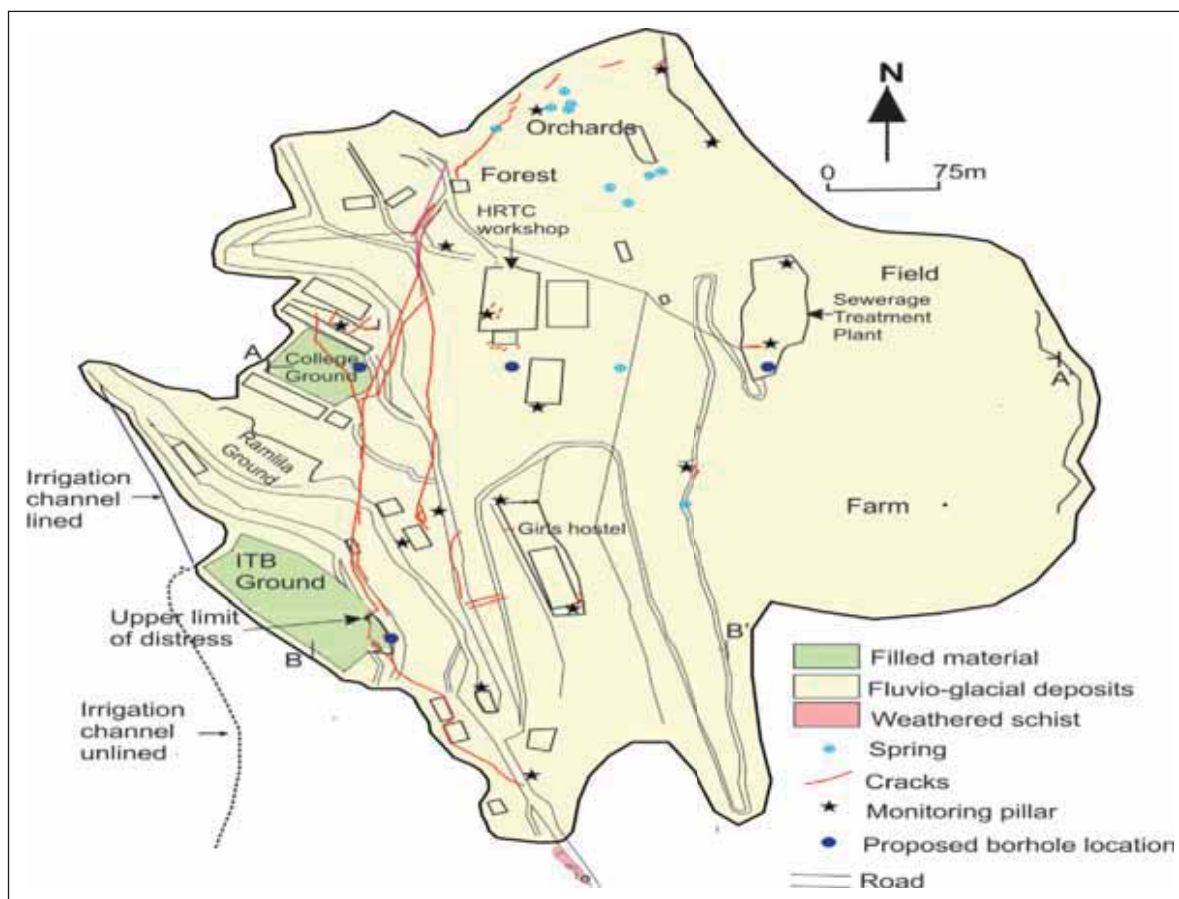


Fig. 4.11. Geological map of the subsidence zone at Reckong Peo (elevation data not available in original report).

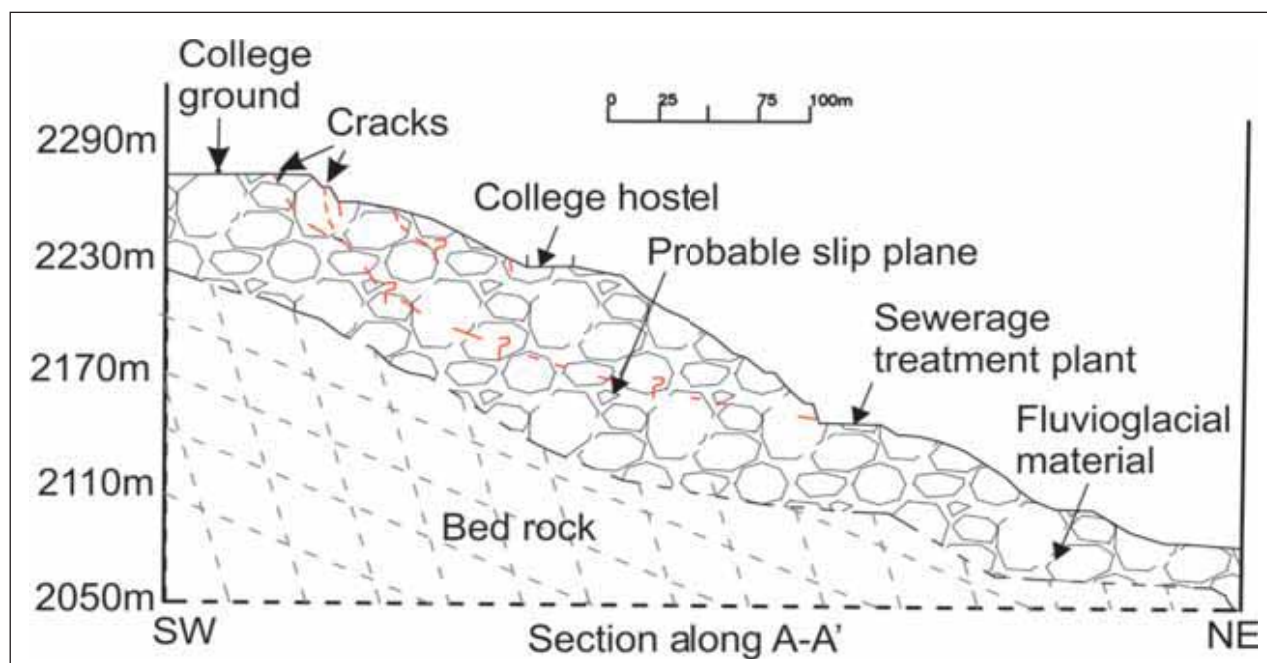


Fig. 4.12. Geological cross section along A-A' at Reckong Peo landslide zone (for section refer Fig. 4.11).

as the slide is located 4 km away from the prevailing reservoir level. For stabilisation of the landslide, the following remedial measures have been suggested on a trial basis: (i) benching of the slopes to 4:1, (ii) provision of surface and sub-surface drainage system, (iii) construction of restraining structures near the toe of the slide. In addition guniting or bitumen spraying on the slopes and berms at the final excavation levels may restrict the entry of rainwater and, thereby, promote the overall stability of the slide area. Alternatively, re-aligning the road to bypass the slide area, as indicated by the P.W.D., has been suggested.

4.4.2 July/August 2007 event in Mandi, Kullu and Lahaul-Spiti districts

The fragile geomorphic condition of Himachal Himalayas has witnessed reactivation of several landslides along with triggering of several other new slides subsequent to heavy downpour in Mandi, Kullu, Lahaul and Spiti during the months of July and August 2007. A total of eight slides were studied (Kaistha and Sajin Kumar, 2007), out of which three are located along NH-21, two along the subsidiary link roads, two near the remote human settlement of Kashaut (Mandi) and Tarehan (Kullu) and one adjacent to the surface powerhouse of Parbati Stage –II Hydroelectric Project in Sainj Valley (Kullu). Some of these include:

1. **Bhuwana landslide:** It is located along National Highway No. 21 in Mandi at Lat. 31°26'55"N-Long. 76°51'05"E. It is a debris slide (200 m wide and 50 m high), which includes slope debris and pulverized and weathered shale of Dagshai Formation. Subsequent to heavy rainfall on 14th August 2007 a thick overburden mass and pulverized and weathered rock mass got locally charged with rainwater leading to reduction in its shear strength and caused the slope instability. For the slope stabilization and protection of road, the well-designed breast wall and retaining wall are to be founded on rock with deeper foundation with provisions of weep holes.
2. **Spangani landslide:** It is located nearly 500 m upslope of the village Spangani, near Bihali, along left bank of Sainj River on NH-21 at Lat. 31°45'38"N-Long. 77°15'35"E; toposheet: 53E/5. The run-out zone is channelised along a local *nala* and comprises mainly debris slurry affecting nearly 200 m stretch of the road.

The slide, reported since one decade, is activated during every monsoon. The area exposes highly sheared and fractured transition zone comprising phyllite and limestone of Bhallan Formation of Rampur Group of rocks. A deep and wide lined channel construction for smooth passage to the debris slurry could be an effective measure.

3. **Gulaba landslide:** It is located at Manali 23.3 km milestone on NH-21 at Lat. 32°19'04"N- Long. 77°12'09"E; toposheet: 52H/4 in Kullu district. It is a chronic debris slide that reactivates after every rainy season. It has developed along a major slope depression with several convergent slope streams leading to Kothi *Nala*. The zone has an approx. length of 500 m with its crown near Manali 23.3 KM milestone and is nearly 300 m wide. The affected zone exhibits wide-spread development of tension cracks beyond the crown and subsidence zones including nearly 900 m of road stretch along the flanks. The d/s areas near Kothi have been reported devastated on several occasions due to huge debris flow. The diversion of ingressing slope water, well designed retaining walls and toe support along the *nala* banks, filling of tension cracks and use of geonets on barren slope could be effective in slope stabilization. Provisions of sufficient passage to debris flow in d/s part may be effective in keeping road communication through.

4.4.3 August 2007 event in Shimla and Kinnaur districts

During August 2007, heavy rain and cloudburst resulted in several landslides in Shimla and Kinnaur districts in Himachal Pradesh. The slides have caused enormous damage to life and property. Field inspection of 16 slides was carried out between 21st August and 1st September 2007 (Kaistha, 2007). Some of these include:

1. **Railway Station slide:** A landslide occurred on the 13 August 2007 night which damaged the Koti railway station and railway track. The heavy rain washed away nearly 50 m of the earth below tracks and created a nearly 5 m depression. The track was virtually hanging in this stretch. The movement of huge boulders bent the railway line at places. This incident resulted in damage

to a cabin, a toilet and partial damage to 2-3 quarters.

2. **Matiyana slides:** Overburden material slid over hut on 13th August 2007 at 11 pm killing four labourers in Nag village near Matiyana.
3. **Ghanwi landslide:** on 14th August 2007 at 06:00 PM debris flows occurred at Bhavi village. The cascading heavy downflow of water caused failure of Kapni and Khatrina *nala* embankments carrying the debris dominated by boulders and slush. The Bhavi village is situated between the Kapni and Khatrina *nala* just upstream of their confluence with the Ghanvi *Khad*. Initially, the water rose in the Kapni *khad* and local people were unaware of the sudden flow of debris and slush in the Khatrina *nala* (Fig. 4.13) which suddenly carried huge boulders ramming into the buildings and damaging nearly 14 of them including reported death of 52 persons. The Ghanvi – Phancha road which also passed through the two *nalas* suffered badly.
4. **Khrogla Nala slide:** In Kinnaur district a cloud burst occurred near the water divide of the Kharogla *nala* (a tributary of Baspa River) and Tangling *Khad* (a tributary of Sutlej River) on 11th August 2007 at 07:00 PM. It affected 700-800 m length, 300-350 m wide area adjoining the road. The cloud burst event generated heavy influx of granite boulders dominated debris flow admixed with subordinate cobble, pebble and sand. It washed away 200 bighas of land along with 1200 apple trees as per DC office records. Apart from this, 4 houses, a primary school building, a 27.45 m long Bailey bridge on Kharogla *nala*, part of the Kinner camp were reported to be damaged.
5. **Raldhang slide:** Occurred near Skibba village, in Kinnaur district. There is a transverse glacial debris ridge extending right upto the National Highway-22. The recent cloud burst event which caused flash floods in the Kharogla, Tangling *nalas* also received flood



Figure 4.13. The post-disaster scenario of the Bhavi village showing deeply incised Khatrina *nala* with thick debris dumped at its mouth after wiping out significant part of village.

water on this side of the ridge during the 11 August 2007 event at 07:00 PM triggering the slide. The slide is 400 m long, 600 m wide and nearly 150 m in height. It is formed of granitic boulders, cobbles, pebbles and sand. It shows the development of badland topography and has affected the barren land downstream of the Skibba village including a stretch of the NH-22. Though a part of the slide portion along the road seems to be stabilized due to the dense growth of vegetation but higher slopes formed of less cohesive sandy glacial debris are barren and liable to generate more slope instability in future too. The steel rock traps on the hillside of road in addition to a series of check dams along the *nala* course with proper subsurface road drainage is required in this part.

4.4.4 16th August 2008 event in Sirmaur and Shimla districts

On 16th August 2008, several landslides occurred due to rainfall in parts of Sirmaur and Shimla districts. Geological assessment of five landslides was carried out along Paonta–Shilai, Solan–Sainj and Chhaila–Theog road (Kumar, 2008). The area exposes rocks of Krol Formation, Infra Krol Formation and Simla Group.

On Sataun–Kamrau road two landslides have occurred at 1.5 km from Kamrau (toposheet: 53F/10) and one at 6.5 km from Kamrau (Lat. 30°35'18.9"N; Long. 77°39'28.9"E; toposheet: 53F/10). The 1.5 km slide is debris slide (50 m wide, 40 m high and 75 m run-out) and 6.5 km slide is also debris slide (90 m wide, 50 m high and 7 m run-out). These slides got reactivated on 16 August 2008 after moderate to heavy rainfall and blocked Kamrau–Sataun road. The slides started during the road widening, as per the information from local people, as the slope cut was not proper and a negative slope was formed due to local undercutting in the slide affected area. Due to the negative slope cut in the weathered to highly weathered poor rock mass, the slide started during the rains and got enlarged during the current spell of monsoon.

On Solan–Sainj road a debris slide occurred at 2 km from Sainj at Lat. 31°04'22.6"N; Long. 77°22'56.7"E; toposheet: 53E/8 in District Shimla. This is an old slide that got reactivated on 16th August 2008 after moderate to heavy

rainfall. The slide is 150 m wide and is 50 m high with run-out of 80 m. Grey to dark grey shales and quartzite belonging to Simla Group are exposed in the slide area.

On Chhaila Theog road a debris slide occurred at 4 km from Chhaila at Lat. 31°03'55.5"N; Long. 77°22'14.6"E; toposheet: 53E/8 in District Shimla. The slide is 30 m wide and 20 m high with run-out of 40 m. Grey to dark grey shales and slates belonging to Simla Group are exposed in the slide area.

Other landslides examined were in overburden/weathered rock mass triggered due to rainfall. Remedial measures viz., wire mesh crates, shotcrete and rock bolting, etc., have been suggested.

4.4.5 Landslide near Rangrik village, Lahaul and Spiti district

On 2nd August 2009, the Times of India reported that “Volcanic-like activity triggers scare in Lahaul–Spiti” in the mountainous region near Rangrik village in the Spiti valley. Following the report, GSI investigated the area between 8th and 13th August 2009 (Kumar and Singh, 2009).

The area exposes dolomite with carbonaceous shale partings belonging to the Lilang Group along with overburden material. Lilang Group consists of a thick sequence of mainly carbonate-rich rocks of Mesozoic age. The area lies near the northeastern end of the Spiti fault. Spiti fault is a high-angle strike fault along which crest of Spiti anticline has fractured and is an active fault.

A landslide, measuring 300 m long, 200 m wide and 35 m deep, occurred on 28th July 2009 about 2 km SE of Rangrik village at Lat. 32°14'56"N; Long. 77°59'29"E; toposheet: 52L/3 in district Lahaul & Spiti. A loud noise along with dust cloud was noticed by some villagers coming from the top of the mountain, where landslide occurred. The hill slopes where slide occurred are covered by weathered to highly weathered dolomite with carbonaceous shale partings overlain by overburden material. The landslide occurred at the top of the hill slope at an altitude of ~4400 m. At the crown of the slide 80 m long and ~30 m deep vertical scar has been observed. At the base of the scar a patch of wet carbonaceous material was observed. Some local villagers observed, through binocular, gushing out of water from the same patch at the time of slide. The slide is pear shaped.

Tension cracks 0.5-1.5 m wide and more than 2 m deep have been noticed on the periphery of the slide nearby crown.

This slide appears to be a composite slide with rotational failure at the crown and planar failure at the toe of the slide. The slide is marked by vertical settlement of ~30 m at the crown resulting in formation of ~30 m high scarp, deep tension cracks on the periphery and a toe bulge of ~15 m high just above the toe.

The cause is attributed to natural factors such as weathered and disintegrated rock mass and built up of pore water pressure.

4.4.6 26th February/4th-5th March 2011 events along NH-21, Bilaspur, Mandi and Kullu districts

On 26th February, and between 4th and 5th March 2011, total eight landslides occurred along the National Highway (NH-21) between Chandigarh and Manali, in Bilaspur, Mandi and Kullu districts (Kumar, 2012a). Their brief description is given as under;

1. **Slide at Swarghat:** This is debris slide having dimensions as 10 m wide and 40 m high and mobilized due to heavy precipitation and road cutting. The rock exposed in the slide area is sandstone. The suggested remedial measure is to provide toe support by retaining structure in the form of berms and also trimming of slopes.
2. **Slide at 5 km before Kellar:** This is a debris slide which is 10 m wide and 70 m high. The rock exposed in the area is sandstone and shale, showing trend in NW-SE/30°SW. The slide is caused due to toe erosion of river. The suggested remedial measure is to provide retaining walls in the form of cribs.
3. **Slide near Mandi:** This is a rock cum debris slide mobilized due to road widening and heavy precipitation. The dimension is 10 m wide and 40 m high. The rock exposed in the area is schist and slate having foliation trend as N-S/30°E and joints as J1=N40°E/vertical and J2=E-W/50°S. The suggested remedial measure is to provide toe support by retaining structure in the form of breast wall.
4. **Slide at 9 km before Bhuntar:** This is a debris slide with dimensions as 5 m wide and 20 m high, caused due to toe erosion of river. The rock exposed in the slide area

is gneiss. The suggested remedial measure that can be applied is to provide retaining walls in the form of cribs.

5. **Slide at 3 km before Raisan:** This is a debris slide exposed in the glacio-fluvial terrace material having dimensions as 50 m wide and 100 m high. It is caused due to toe erosion of river and often mobilized during heavy rainfall period. The suggested remedial measure is to provide toe support by retaining structure in the form of wire mesh sausages at toe of the slide.
6. **Slide at 28 km before Kullu:** This is debris slide with dimensions as 7 m wide and 30 m high. The rock exposed in the slide area is biotite schist and gneiss. The slide is caused due to toe erosion by river. The suggested remedial measure is to provide toe support by retaining structure in the form of wire mesh.
7. **Slide at 6 km from Manali:** This is a debris slide exposed in the glacio-fluvial terrace material having dimensions as 50 m wide and 100 m high. It is caused due to toe erosion of river and often mobilized during heavy rainfall period. The suggested remedial measure is to provide toe support by retaining structure in the form of wire mesh.
8. **Subsidence at Shiv temple, Bran:** The foundation wall of Shiv temple broken down due to heavy precipitation and snowfall of 3rd-4th March, 2011. The foundation was built on the fluvio-glacial terrace material and area prone to subsidence. The suggested remedial measure is to build wall with deep foundation on hard rock.

4.4.7 9th July 2011 event at Rani nala, Marhi, Kullu district

As per media reports, due to incessant rainfall of 8-9 July 2011, a landslide triggered at Rani *nala* which blocked the NH-21. The slide is located at Marhi along NH-21 near Rohtang pass on Manali-Leh route in Kullu district (Kumar, 2012b).

The Rani *nala* landslide is a rock cum debris slide which got mobilized due to heavy precipitation/ snowfall and *nala* erosion. The rock exposed in the slide area is quartzite and chlorite schist showing foliation trend as N25°W-S25°E/25°S65°W. The slide is approx. 100 m wide and 150 m high. The geotechnical test of soil sample collected

from slide area shows that the soil is well graded with 97.33% of sand and 2.67% of clay and silt. The soil has low cohesion i.e., 0.04 kg/cm² and high internal friction angle i.e., 41°. Thus with increase of water content, the soil failed due to low cohesion.

It was recommended that for suggesting a long-term remedial measure, the Rani nala slide area needs to be surveyed in detail on 1:1000 scale and geophysical studies need to be done. As, short-term measures, filling and compaction by locally available material, construction of causeways/culverts and improvement of drainages are recommended. In fact, drains can control the movement of surface water, seepage and help in reduction of pore water pressure at depth.

4.4.8 6th-7th August 2011 event at Gumma and Hanogi temple, Mandi district

On 6th-7th August 2011, the continuous rainfall triggered two landslides (debris slides) in Mandi district: Gumma landslide (100 m wide and 100 m high) near Jogindernagar on Pathankot-Mandi National Highway (NH-20) and near Hanogi temple (60 m wide and 60 m high) on Mandi-Manali National Highway (NH-21). NH-20 and NH-21 have now been renamed as NH-154 and NH-155 respectively. The post-disaster geological assessment was carried out by

Kumar, (2012c).

The Gumma landslide (Fig. 4.14A) got mobilized due to heavy precipitation and blocked the traffic. As per media reports, the Jogindernagar-Mandi portion of national highway has been blocked for more than 12 hours due to heavy landslides near Gumma, the most vulnerable point where a fragile salt mountain is sinking and disrupting the smooth traffic movement after incessant rainfall (72 mm and 142.5 mm).

Geotechnical test of soil samples collected from these slide areas shows that the soil of Gumma is sandy in nature with 98.12% of sand and has low cohesion (0.09kg/cm²) and high internal friction angle (42°). Thus, with increase of moisture content, the slope failed owing to low cohesion. The soil near Hanogi temple is sandy in nature with 80.65% sand and silt and clay content is 19.35%. The soil has high cohesion 0.21 kg/cm² and internal friction angle is low i.e., 11°. The Natural Moisture Content (NMC) of Hanogi temple soil is 5.24 % and density is 1.41 gm/cc and is well graded with low clay and silt content.

Geologically, the Gumma slide area is occupied by rocks of grey sandstone, clay and shale of Upper Dharamsala/Kasauli Formation belonging to Subathu Group of Oligocene- Lower Miocene age and the slide near Hanogi

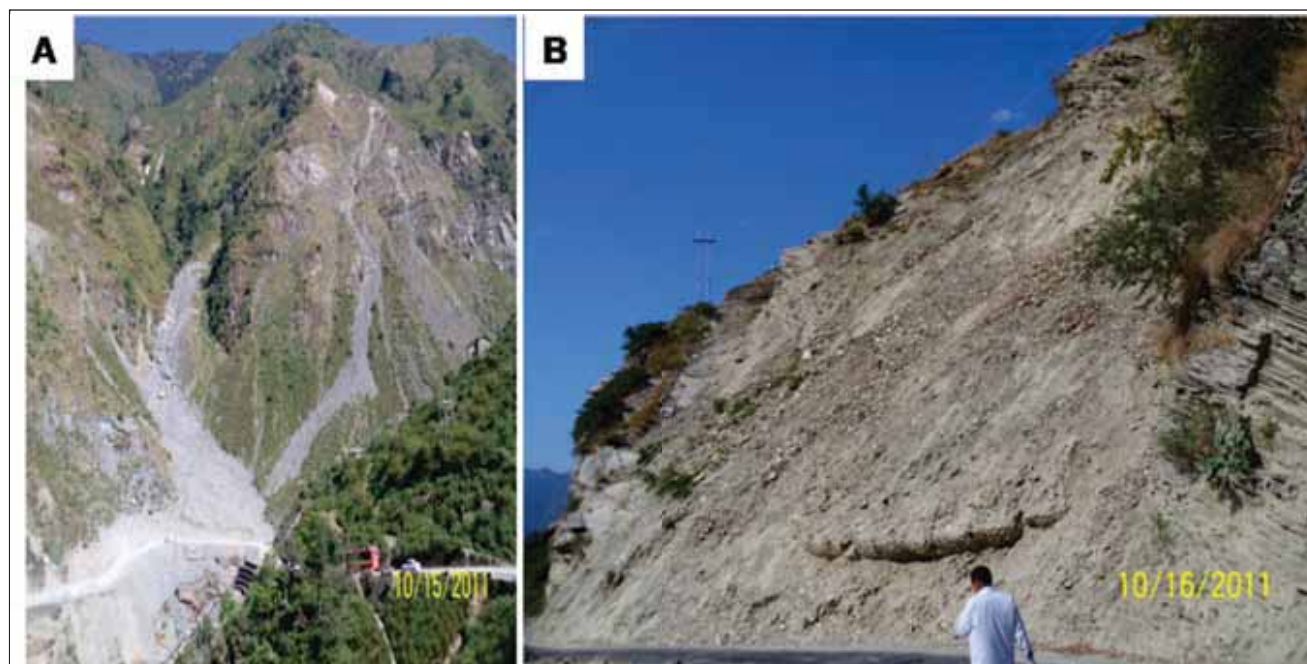


Fig. 4.14. Field photograph of Gumma landslide (A) and Hanogi temple landslide (B), Chamba district.

temple is a debris slide (Fig. 4.14B) in an area occupied by rocks of biotite schist, gneiss and migmatites of Sundru Formation of Vaikrita Group.

The recommended remedial measures include erection of retaining wall, bio-engineering techniques, reforestation of the areas occupied by degraded vegetation, proper land use measures and creation of awareness among local population be taken in advance in order to mitigate the hazard posed by these vulnerable slides to ensure safety of life and property.

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Chapter 5: Landslide studies in Jammu and Kashmir

5.1 Introduction

The state of Jammu & Kashmir is strategically located in the northwest corner of India. It shares its borders with China in the east, Pakistan in the west, Afghanistan and Russia in the north and plains of Punjab and Himachal in the south and southeast. The state covers 2,22,236 km² area, of which about 69,000 km² forms part of hilly terrain of the Himalayas, excluding the permafrost region (Fig. 5.1), wherein GSI has carried out/ is carrying out some landslide studies. All of the 22 districts of J&K fall under mountainous region, where landslides are one of the common and perennial natural hazards.

5.1.1 Geology and Geomorphology

Geologically, the state preserves almost a complete geological succession from Proterozoic to Holocene. Most of the rocks occurring in the Lesser and the Higher

Himalayan terrains are Proterozoic in age. The Early Proterozoic rocks comprise a complex suite of gneisses and schists with interstratified bands of marble and calc-silicate rocks and quartzite with igneous intrusive (GSI, 2012). These have been variously designated as Central Crystallines. The Middle Proterozoic rocks are represented by carbonates, calc-arenites, slate, flaggy limestone and stromatolitic limestone/dolomite whereas the Neoproterozoic rocks are mostly calcareous, arenaceous and graphitic carbonaceous shale. The Permian rocks are classified into Agglomeratic Slate, Nishatbagh Formation, Panjal Volcanics, Mamal and Zewan formations in ascending order. The Agglomeratic Slate Formation has a complex lithology of slate, quartzite, diamictite and pyroclastics with characteristic marine fauna indicating Late Carboniferous to Early Permian in age. In Kashmir basin, Panjal Volcanics (Lower Permian) overlies Agglomeratic Slate with or without the intervention of Nishatbagh

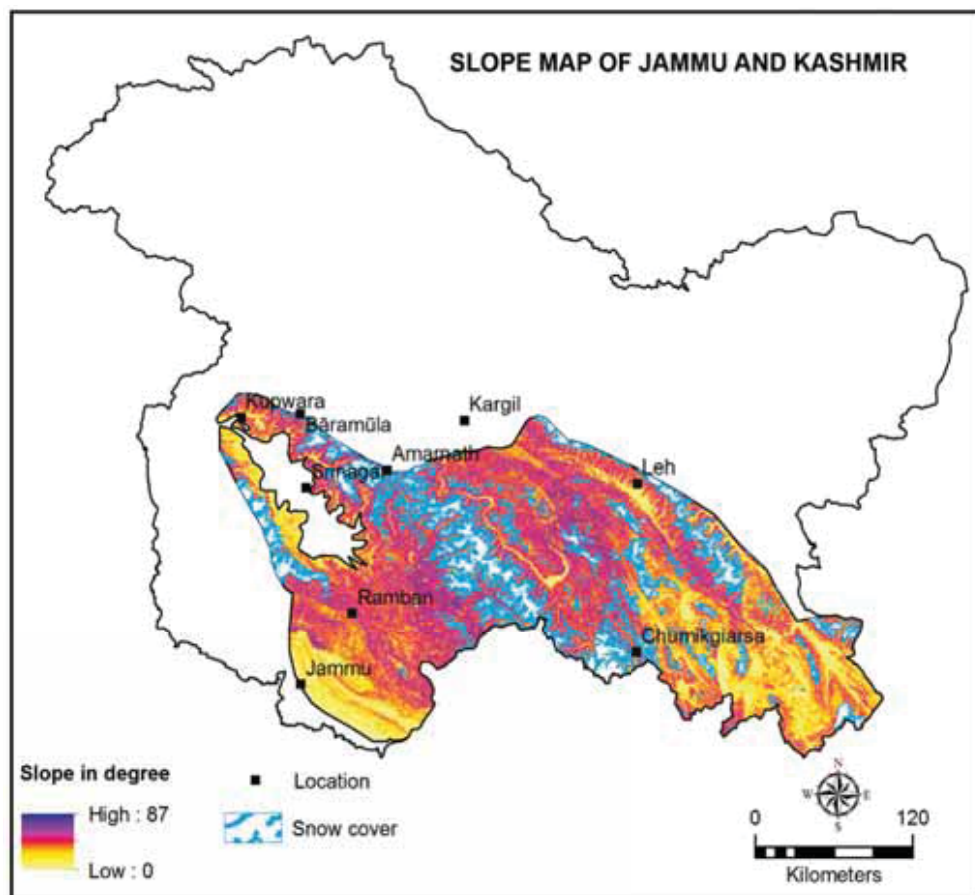


Fig. 5.1. Hill area boundary of parts of Jammu and Kashmir taken for landslide studies shown over the slope map prepared from Aster DEM.

Formation. These volcanic rocks, covering over 20% of the exposed hard rock areas in Kashmir valley, comprise lava flows of acid, intermediate and basic composition. In many parts of Kashmir, Panjal Volcanics are succeeded by Gondwana beds of Mamal Formation. The Zewan Formation (Upper Permian) comprises marine fossiliferous argillaceous rocks the basal part and calcareous with intercalations of shale at the upper part. Triassic-Jurassic rocks are represented by Lilang Group conformably overlying Kuling Group (Late Permian). The Cretaceous rocks are mainly confined to Indus Suture Zone and Cretaceous - Eocene rocks are exposed in Shyok-Nubra belt of Ladakh region in the Trans-Himalaya. In the Inner Tertiary belt of Jammu region, Jangalgali Formation (Cretaceous – Eocene) is unconformably overlain by Subathu Formation (Palaeocene-Eocene), which, in turn, is overlain by the Murree Group (Upper Eocene to Lower Miocene age). Quaternary deposits are present along the vast alluvial tracts, flood plains, river terraces, talus, scree, fan deposits of major rivers and their tributaries and fluvioglacial deposits in Jammu, Kashmir and Ladakh regions. These have been classified into Older Alluvium (Middle to Late Pleistocene) and Newer Alluvium (Holocene).

The Jammu & Kashmir is entirely a mountainous state, except for about five kilometres wide stretch of Terai zone south of Siwalik foothills and adjoining Indo-Gangetic alluvial plain. From south to north, the Jammu and Kashmir Himalaya has four distinct physiographic divisions. It starts with the Outer Himalayan Zone, between 600 m to 1200 m, being characterised by structural and denudational hills comprising WNW-ESE to NW-SE trending ridges separated by sub-latitudinal, flat-bottomed valleys called 'Duns'. This is followed by Lesser Himalayan Zone, between 3500 m to 5000 m, also is being characterised by structural and denudational hills but are incised by deeply cut valleys and precipitous gorges. The Pir Panjal and its northerly trending offshoot Saribal Range are part of this zone. The Pir Panjal Range exhibits steep escarpment towards the plains showing an anastomosing nature of hills and valleys, in contrast to a rather gentle slope towards Kashmir Valley in the north. Beyond 5000 m, the Higher Himalaya is characterised by mighty snowy peaks, steeper and more rugged terrain than Lesser Himalayan Zone. Nanga Parbat attaining an elevation

of 8126 m is located in this part of the Himalayas. Rising steeply like a wall from Lesser Himalaya, the whole of this zone with the exception of the deep ravines lies above the perpetual snow line. The Kashmir Valley about 140 km long and 40 km wide, is enclosed from the west and south by Pir Panjal whereas to the northeast by the Great Himalayas. Jhelum River along with its tributaries form the principal drainage of the Valley. It is a structural Basin covering an area of about 4865 km² representing an old lacustrine bed. The Ladakh region to the north and east of Kashmir Valley is known for its high altitude terrain and forms parts of Trans-Himalayan Zone. This zone is also characterized by WNW-ESE to NW-SE trending mountain ranges. Zaskar, Ladakh and Karakoram ranges are located in this zone.

5.1.2 Landslide hazard

Landslide is a common natural as well as a man-made hazard in Kashmir Himalaya, particularly during monsoon. It not only causes direct loss of life and property, but also indirect loss by blocking the transportation routes, particularly National Highways (NH-1A) and other arterial roads. In the recent past, due to extensive road construction and other developmental activities, the frequency of landslides has increased manifold in Jammu and Kashmir.

In 2005, GSI has published detailed inventory of 84 major landslides in Jammu and Kashmir (GSI, 2005). Majority of them recurrently affected the National Highway, both NH-1A and NH-1B. Between Jammu and Srinagar, along NH-1A, the most landslide prone zone lies within Batote and Banihal sector, and include important slides such as Nashri, Nera, Budwan, Khuni *nala* and Markakot. Khuni *nala* is the most notorious reactivated landslide, which occurs within granite gneiss of Salkhala Group. The sliding has taken place due to rock fall along steeply dipping joints. Landslides are also persistent hazard along NH-1B, between Batote and Kishtwar, along the left bank of Chenab River. Prominent slides along this road are Malhori, Chakwa *nala*, Raggi *nala*, Nagni and Khileni.

The Ladakh region of Jammu and Kashmir is also prone to landslide hazard. In 2010, prolonged rainfall followed by massive unprecedented cloudburst triggered numerous debris/mud flows and sand flows in and around Leh town, killing 182 people, damaging 607 houses, breaching all important roads leading to Leh area.

Till date, GSI has accomplished landslide hazard zonation mapping of Chenab River basin and post-disaster studies of a number of landslide events in the state of Jammu and Kashmir. In this compendium, GSI work on landslides in Jammu and Kashmir is incorporated according to the following sequence:

1. Macroscale landslide susceptibility mapping of river basins, district/town
2. Post-disaster study of landslides

5.2 Macro-scale landslide susceptibility mapping

5.2.1 Landslide susceptibility mapping of Chenab River basin

Chenab River forms in the upper Himalayas in the Lahaul and Spiti district of Himachal Pradesh, and flows through the Jammu region of Jammu and Kashmir into the plains of the Punjab in Pakistan. The Chenab River basin covers an area of about 18,000 km² in Jammu and Kashmir. A major part of the catchment is either snowbound or inaccessible. GSI has carried out landslide susceptibility mapping for 450 km² area of the Chenab valley, covering parts of toposheet: 43L/13. The area is located between Jammu and Katra towns in Jammu and Udhampur districts of Jammu and Kashmir. The mapping was carried out on scale 1:50,000 during 1992 and 1993 field season programme (Sharda, 1996).

Geologically, the area forms part of southernmost tectonic belt of Himalayas which is also known as Frontal Fold Belt. It is made up of essentially Tertiary and Quaternary sediments. The rocks exposed include dolomites belonging to Sirban Dolomites of Late Proterozoic age; alternate bands of sandstone and siltstone/shale of Upper Murree Formation, which is followed by arenaceous rocks of Lower Siwalik occurring confined to core of the regional Surinsar-Mastagarh anticline. Middle Siwalik is represented by Dhok Pathan Formation, consisting of arenaceous suite comprising mainly of sandstone. Upper Siwalik rocks are exposed in central portion of the area. The rock includes alternate bands of variegated shales, claystone and sandstone with bands and lenses of conglomerate. The overburden includes Recent deposits.

Geomorphologically, the area forms part of Himalayan Foot Hills characterised by hogback topography with a number of strike ridges and longitudinal valleys. The ridges

extend in NNW-SSE direction. The area has two prominent ridges: Gorta Dhak in the west with trend N-S to NNW-SSE direction and forming prominent water divide in the area, and Nandini Rakh in the east trending NNW-SSE direction. Famous Nandini Tunnel has been excavated through this ridge. Chenab river forms prominent draining agency on western slopes of this ridge and it cut across the ridge in the northern margin of the area. The drainage on the left bank of Chenab is straight to semi dendritic.

The landslide susceptibility zonation map was prepared by using a graphical method, which uses cumulative frequency curves for all the active slopes are drawn for their V/H values into classes of 0.1 increments. The middle 50% are kept in high susceptibility category and remaining 50% in moderate susceptibility category. For evolving the parameters required for zonation, the following thematic maps were prepared:

1. Slope Forming Material map-cum-Landslide Incidence map – This map was prepared on 1:50,000 scale, depicting distribution of landslides and rock/overburden, with relevant structural details.
2. Slope Morphometry map – This map was prepared on 1:50,000 scale, showing slope direction and inclination (V/H ratio) for individual facets.
3. Prepared Landslide susceptibility zonation map after analysis and integration of data collected from various thematic maps.

In order to demarcate landslide susceptibility zones, the overall percentage of active (failed) slopes in the area i.e., 7% is taken as a guide. The slope classes having percentage of active slopes >14% were categorised in high susceptibility category, those with active slopes from <3.5% in low category and those with active slopes from 3.5% to 14% were kept in moderate susceptibility category.

Based on field traverses and study of satellite imageries, a total 271 landslide incidences have been mapped. Most of the failures were recorded in bedrock. In total 45 landslides occur in Recent deposits, 87 in Upper Siwalik, 71 in Middle Siwalik and 68 landslides in Upper Murree and Lower Siwalik.

Plate 5.1 shows the landslide susceptibility map of

Chenab River basin, covering 450 km² +area. The area has been divided into 3,097 slope facets. About 33% slope facets occur within Middle Siwalik, 27% in Upper Siwalik, 23% in Sub-Recent deposits and 16% in Upper Murree and Lower Siwalik. Most of the slopes, 51% falls under low susceptibility class, whereas high susceptibility slopes constitute 6% slopes. The slopes in Lower Siwalik and Upper Murree formations are most susceptible to failure as compared to those in other formations in the area and the slopes located in Middle Siwalik terrain are least susceptible to failure probabilistically as compared to those in other formations.

5.3 Meso-scale landslide susceptibility mapping

5.3.1 Landslide susceptibility mapping of Vaishno Devi area, Udhampur district

Vaishno Devi Mandir is a very popular Hindu temple dedicated to the Hindu Goddess, located at the Trikuta Mountains in Udhampur district of Jammu and Kashmir. The temple complex is approachable through fair weather road from Jammu which is about 40 km from Katra, and further north by a 15 km all weather trek road. A 12 km route to Bhavan from Dharsah Jodi is a foot track.

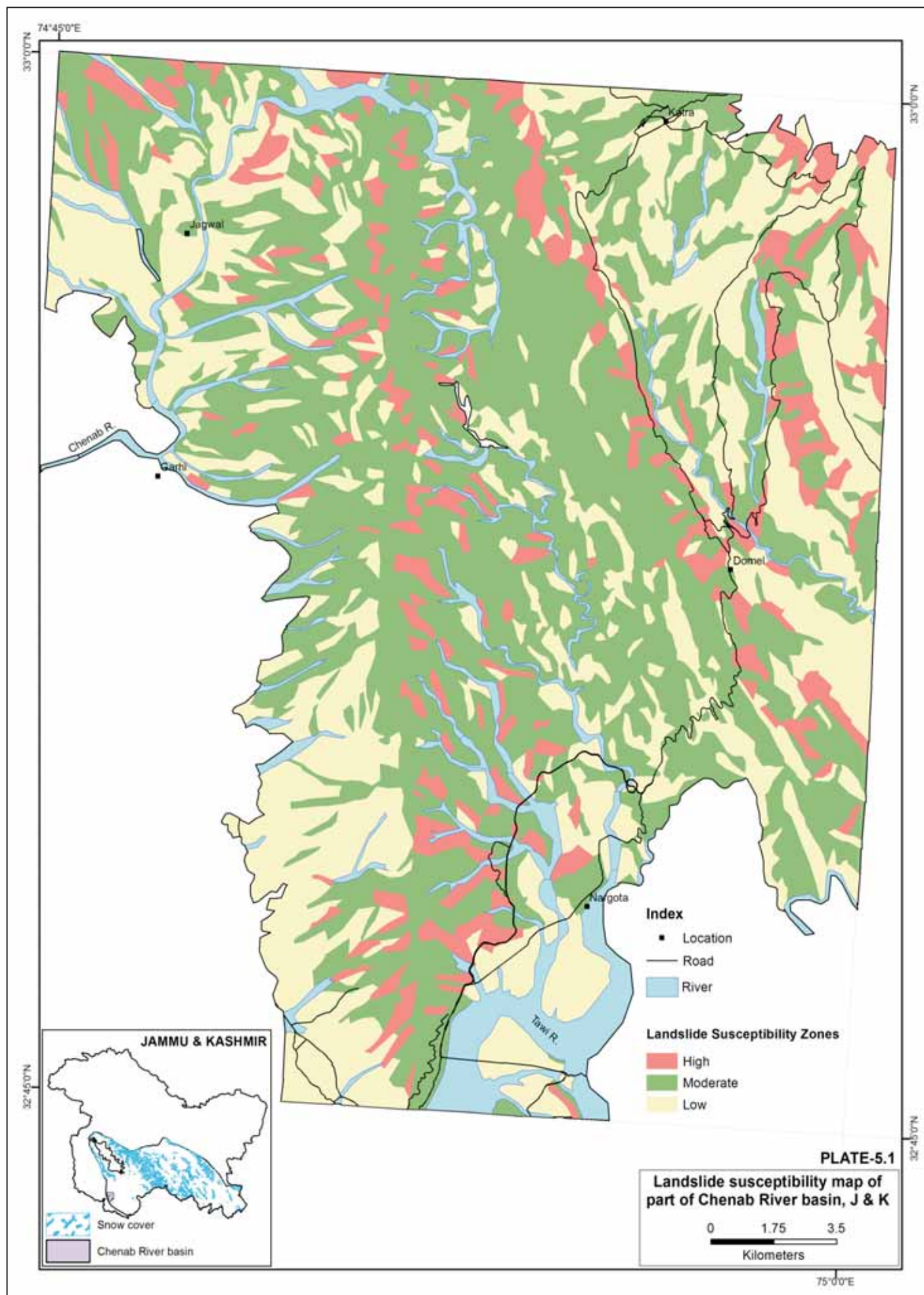
Landslides are frequent and annually recurring phenomenon along the Vaisnodevi area. Most often, they are triggered by rain on slopes which are modified by anthropogenic activities in the process of new track construction along the Bhawan route. Such slopes are steeply cut and left overhanging thereby making them more susceptible to future instability. With the objective to classify the slopes around town in respect of landslide susceptibility, mesozonation of the area has been carried out covering 20 km² on scale 1: 10,000 in parts of toposheets 43L/13/NE and 43 K/16/SW. The susceptibility studies were carried out during field season programme of 2006 and 2007 (Kumar, 2008).

Geologically, the area exposes rocks of Sirban Group, Mid Siwalik, Subathu, Murree and Older alluvium. Sirban Limestone Group (Meso-Proterozoic age) consists of dolomite, cherty dolomite, limestone and quartzite. The dominant carbonate sequence is characterized by columnar and branching stromatolites. The Middle Siwalik of Mio-

Pliocene age comprises sandstone, siltstone and shale. The sandstone encloses clay pellets. The Middle Siwalik occurs along Riasi Thrust in Katra area and is in direct contact with Sirban Group to its north. The Murree consists of pale yellow to pale purplish and greenish grey to pale grey, medium to coarse-grained, hard and compact, current-bedded sandstone with intercalations of chocolate brown to greenish grey shale, siltstone and clay conglomerate. Isolated patches of Quaternary sediments in form of older alluvium (Jammu Formation) are exposed along the major streams of the area. It consists of poorly sorted assemblage of sediments.

The topography of the study area is rugged and mountainous with varying altitudes ranging from 868 m (Balganga), 1048 m (Charan Paduka), 1482 m (Ardhkunwari), 2041 m (Sanjichat), 1900 m (Bhavan) to 2200 m (Bhairon). The Sirban limestone Group forms the high ridge trending WNW-ESE with steep slopes while the Younger Tertiary rocks occupy the lower topography with gentle slopes. The drainage is mainly governed by the Balganga and Pei Khad rivers. A number of freshwater springs is present in the area.

The landslide susceptibility map was prepared by adopting 'SMR based approach' (refer section 2.2.1, Chapter 2). A detailed inventory of 13 landslides has been prepared (Annexure I). Based on above method, the study area was grouped into three classes of varying landslide susceptibility class (Fig. 5.2). The 10 km² area was divided into 397 slope facets. Majority of the slope facets (78%) are confined to limestone/dolomite and stromatolitic limestone of Sirban Group, remaining are distributed as sandstone of Middle Siwalik Subgroup (6%), shale, siltstone and clay of Upper Murree Formation (6%) and older colluvial material of Jammu Formation (10%). The zonation map reveals that the area is devoid of Very High susceptible zones. The distribution of facets into different classes of landslide susceptible zones reveal that approx. 60% of the area fall under Low susceptible Zone, 36% into Moderate susceptible category and 4% fall in High susceptible Zone. The High susceptible zones in the area are restricted mainly to the new track from the Ardhkunwari to Bhawan which is largely due to disturbing the hill slope stability by cutting the slope for making new track just below the existing old track.



Landslide susceptibility map of part of chenab River basin, J & K

Based on the study, it was recommended that afforestation of barren hill slopes and provision for lined drains for waste water disposal should be carried out. Also filling up of subsidence cracks with sand mixed coal tar/cement may be carried out at 0/200 km stone from Ardhkunwari along the new track and at 9/700 km stone from Ardhkunwari along Sanjichat track route towards Bhawan. Subsurface drainage management may be carried out through horizontal/vertical drainage holes at 10.5 km stone from Bhawan, 3/250 and 4/200 km stone from Darshan Jodi. Protection measures against scouring and toe erosion along river course by boulder pitching and construction of wire crate walls and providing lined cascading chute drains for different *nala* courses may be undertaken.

5.4 Post-disaster landslide studies

5.4.1 Landslides along NH-1A and NH-1B, Srinagar-Jammu National Highway

Landslide is a major hazard along the Jammu-Srinagar National Highway (NH-1A). The highway road passes through the rugged topography forming steep scarps at places. Between Ramban and Banihal, the highway has been aligned within the Precambrian rocks of Ramban, Salkhala and Ramsu Formations comprising slates, phyllites, quartzites, granite-gneisses, gypsum and minor shoots of basic volcanics. The strata is highly folded and characterized by two major thrusts i.e., Panjal Thrust in the north of Chenab River and Murree Thrust in the south of Chenab River. These rock units are traversed by a number of joint sets and shear zones, which have resulted into blocky and pulverized nature of the rock masses.

A total 18 major landslides were studied between Ramban and Banihal along NH-1A during 2008 (Kumar 2007 and 2008). Some of these include; (i) Seri debris slide at 151.500 km (length: 250 m, height: 70-80 m). It first triggered in 1988 because of toe cutting by the river Chenab and reactivated in February 2005. In 2008 it was initiated due to bank erosion by torrent stream; (ii) Kala More Rock cum Debris slide at 154.100 km (length: 60 m, height: 80 m). It was triggered in February 2005 after heavy rainfall and snowfall. In 2008 the slide found to be stable (Fig. 5.3a); (iii) Fagla Rock cum Debris slide at 160 km (length: 60 m, height: 80 m). It was triggered 20 years back. A number of

major and minor cracks have been observed on and above the road. The slope wash material starts flowing after continuous rainfall; (iv) Panthal rock slide at km. 168.500 is a major and most vulnerable slide zone affecting 200 m length of NH-1A (Fig. 5.3b). The crown of the slide is extended upto 300 m high. The slide zone exposes granite-gneisses with thin bands of mica schist, phyllites and basic volcanic. The general orientation of the rock foliation is N55°W-S55°E and dipping 60° to 75° north easterly in to the hill. It has been observed that a number of overhangs, loose rock blocks and debris material are resting in the upslope portion of the slide zone which can cause shooting stone problem; (v) Slide at 161.025 km is a new slide developed in March 2005 due to *nala* erosion. The slide has affected 25 m length of the road. This slide has been developed through narrow 1st order *nala* draining through soft slates/phyllites of Ramban Formation which has vertical fall on the road; (vi) Rock cum debris slide at 162.500 km triggered on 7 December 2006 due to toe cutting of hill slope for road widening. The slide has affected the road for a length of 80 m and blocked traffic for many days. The slide exposes fresh and intact slate/phyllite and quartzite rocks.

For all these slides appropriate remedial options have been suggested. It was concluded that along NH-1A from Ramban to Banihal, the landslides could have been tackled/avoided at the time of the construction of this road. The suggested remedial measures will have considerable checks for some of the slides but the entire length of the road cannot be made free from hazard as most of the slides have retrograded to a height that is difficult to manage. Hence, small tunnels should be conducted to avoid most of the vulnerable area forever.

A total 49 major landslides lie along Jammu-Batote-Ramban and Tikri-Katra road sections along NH-1A, out of which detailed inventory of 32 landslides have been prepared during 2005 (Kumar and Kumar, 2005). Along Chanderkot-Ramban-Seri road section, which extends from 144 km to 157 km stone and comprises a sequence of autochthonous fold belt, 20 major slides have been recorded, out of which an inventory of 10 slides has been prepared. Seri, Ramban and Kehla maur are the major devastating slides in this section. Along Pira-Chanderkot road section, which extends 128 km to 143 km stone, 19 major slides have

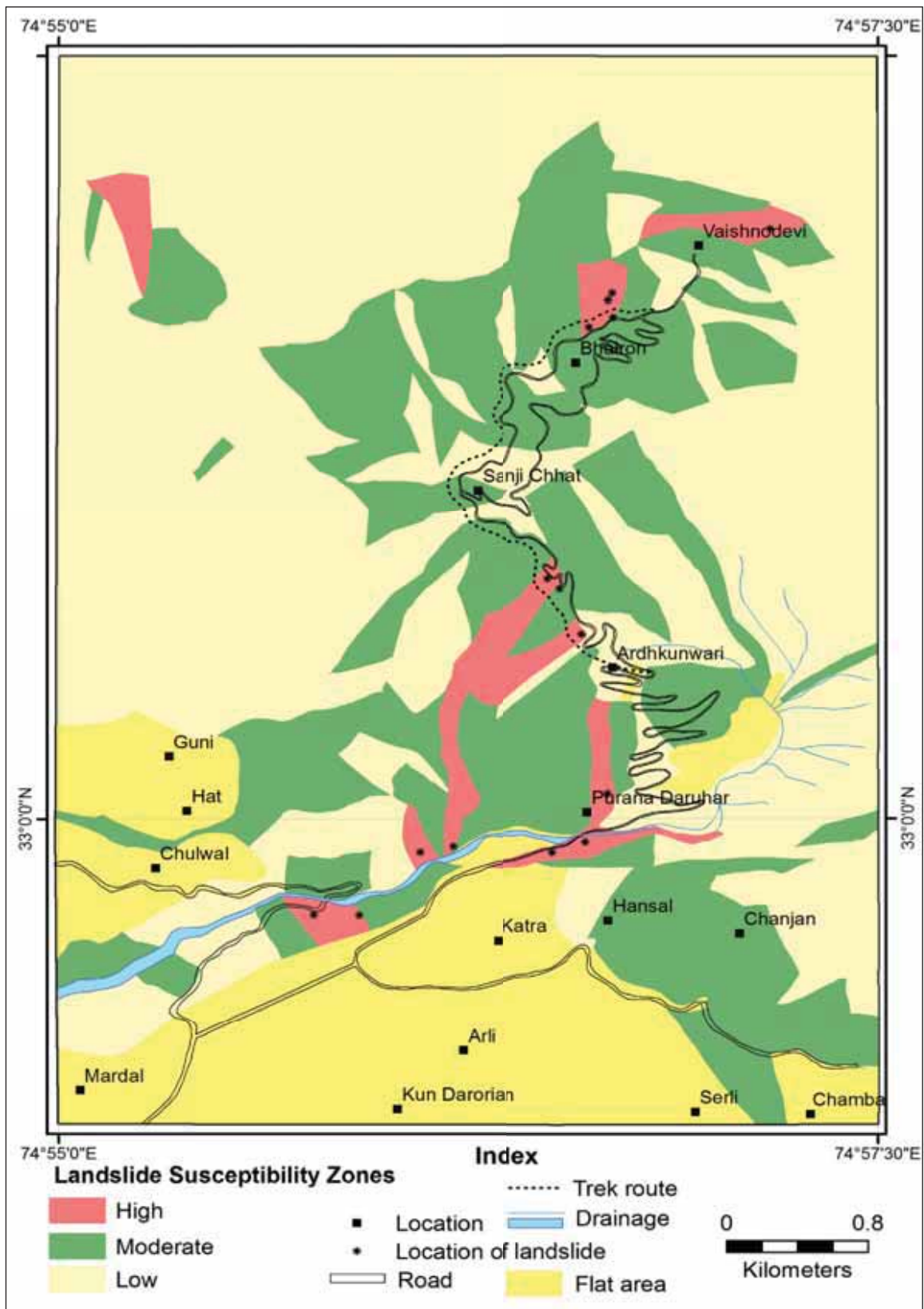


Fig. 5.2. Landslide susceptibility map of Vaishno Devi area.

been recorded, out of which an inventory of 10 slides has been prepared. This section contains the major Nashiri slide zone which is affecting more than one km of the road section. Along Patnitop-Kud-Chinenei-Dharamthal road section, 11 major slides have been recorded, out of which an inventory of 5 slides has been prepared. The major slide is at the sharp hairpin bend near the Patnitop pass. Along Dharamthal-Udhampur-Jhajjar Kotli road section, seven slides have been recorded, out of which an inventory of 5 slides has been prepared. Amongst these, three slides are debris slides within the Murree Group of rocks and two are overburden slides. Along Tikri-Katra road section, Sirban dolomites and quaternary sediments of Vaishno Devi Formation are exposed. There are only two problematic landslides recorded along the road. It was suggested that detailed investigations of slides like Seri, Ramban, Kehla maur, Pira, Nashiri and Patnitop is required for recommending suitable slope treatment measures for their mitigation.

A total 11 major landslides were studied between Batote and Banihal along NH-1A and eight landslides between Batote and Kishtwar along NH-1B during 1998 (Malbarna 1998). Some of these include; (i) Debris slide and flow at 128 km before Nachar *nala* bridge. The landslide developed on 31st December 1997 after rains and resulted in 30 m subsidence of 70 m length of the road. Construction of pucca drains and toe support at Nachar *nala* is recommended; (ii) Debris fall at 148.62 km on the right bank of Chenab River, near Ramban. It has affected 112 m section of the road and probably caused due to erosion by surface runoff affecting soft and weathered overburden mass resting on 50°-60° slope; (iii) Debris slide at 162 km developed in March 1998. The slide affected about 75 m of road length. The overburden composed of disintegrated slate and phyllite have failed during rains; (iv) Budwan Debris slide and flow at 166.85 km is an old slide initiated in 1980s. The initiation zone is located 300-500 m above the road. The disintegrated rock mass exposed at the Srinagar side have failed due to pore water pressure and resulted in debris flow. Other slides along NH-1B are Malori debris slide, Napli slide, slide between 49.030 to 49.234 km, slide between 49.650 to 49.750 km, slide between 49.802 to 49.936 km, Phagumarh slide, slide between RD 305 m and RD 603 m, Slide at 103.7 km. Other slides along NH-1A are Slide at 151.33, Slide at 160 km, Panthal slide at 168.50 km, Makarkote slide at 169.75 km,

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Slide at 170.360 km, Slide at 172 km, Slide at 177.10 km and Slide at 181.2 km.

A total 16 major landslides were studied between Batote and Banihal along NH-1A during 1961 (Raju, 1961). The road was blocked twice in 1961 i.e., during March and April. Some of these include; (i) Peerah debris slide between 183 km and 185km. It is about 91-122 m wide along the road and exposes highly brecciated and weathered phyllites, shale, limestone and quartzite of Dogra slates. It is caused due to undercutting of the toe by river Chenab; (ii) Kalapani rock slide at 177 km is 305 m wide along the road and is located in the Dogra slates. It is caused due to road widening, (iii) Bani *Nala* Debris slide at 165 km is about 91 m wide along the road and reported to have occurred before 1958. In 1958, check walls along contours had been constructed on the slopes at vertical intervals of 15 m and, presumably, due to the restraint offered by these structures, the area is reported to have not experienced slides since then.

Other slides along NH-1A are Nashri slide, Slide at Km 171, Slide at Km 173, Slide at 164 km, Phagla *nala* slide at 161 km, Badwan *nala* slide at 156 km, Khuni *nala* slide at 153 km, Makerkote Slide at 153 km, Slide at 151 km, Slide at 145 km, Slide at 140 km, Slide at 79 km and Slide at 72 km.

5.4.2 Landslides at Pari and Tangar, Doda district

Detailed geological mapping of the Pari landslide (scale 1:1000) and Tangar landslide (scale 1:2000) was carried out covering 0.80 km² area (Srivastava and Krishnamurthy, 1973). Both slides are located on the left bank of River Chenab and occur in the form of amphitheatres bounded by two small streams on the upstream and downstream sides, respectively. The entire slide area at both the sites are covered by landslide debris, which consists of rock fragment of sandstone embedded in soil matrix, and are probably the remnants of old landslide. The slide areas are bounded on three sides by rock outcrops, consisting of sandstone, claystone and purple shales of the Murree Group.

The old slide Pari is the result of rock failure due to undercutting of sandstone band along the synclinal axis by the river. This resulted in failing of the underlying incompetent shales and claystone bands. The extent of the slides is limited by the presence of stable sandstone bands due to repetition on the anticlinal axis at the upstream end

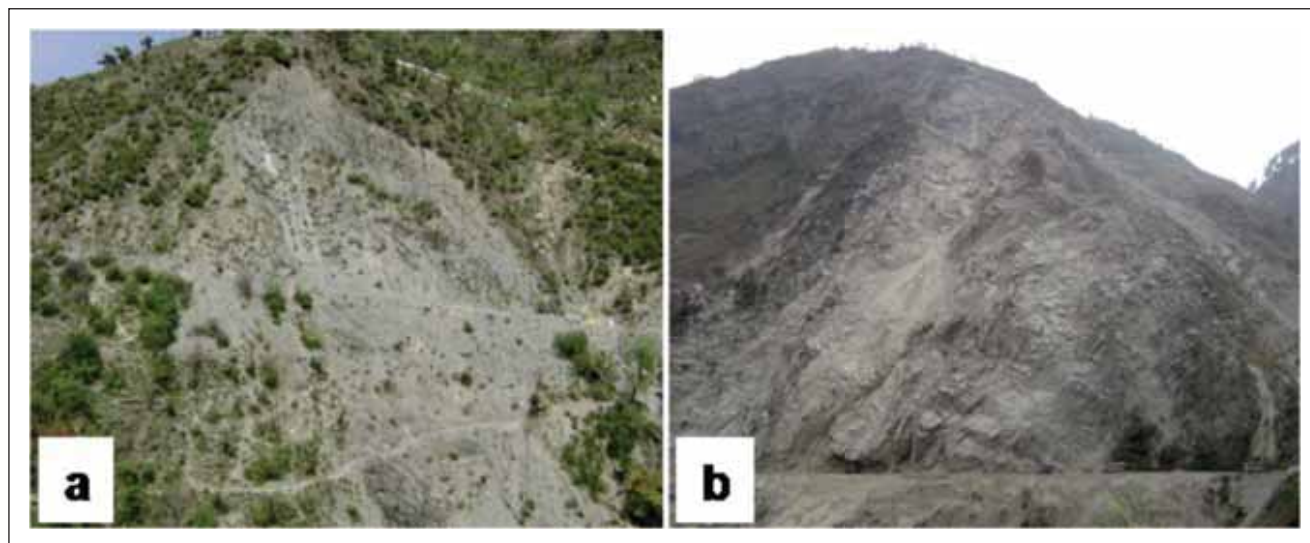


Fig. 5.3. Field photographs of slides as viewed in March 2008: (a) Rock cum debris slide at 154.100 Km and (b) Panthal rock slide at 168.500 km.

and the plunge of the syncline on the downstream end. The rock fall at Tangar is also due to the undercutting of sandstone bands (dipping into the hill) by river, thus creating an overhang that failed in due course. The slide debris pushed the river away from the sandstone band to its present course on the upstream end of the slide area. It is apparent that the subsequent erosion by the river and the cross streams has not yet been able to remove the entire slide debris material.

As regards the structural failure of the rocks which had been responsible for the major old slide the chances of activation in future become remote as the creation of the Sawalkot Dam reservoir will arrest further erosion of the riverbed. The slides involving overburden failures, located above the dead storage level of the reservoir will have some relevance since the material lying below the dead storage level will be merely changing place within dead storage level itself. For these slides, it was recommended that provision of small check dams made of wire sausages filled with loose stones at judiciously selected locations along the *nala* bed may be provided for preventing further erosions.

5.4.3 Nashri Landslide on Srinagar-Jammu National Highway

The Nashri landslide is located at milestone No. 119 on the Srinagar-Jammu National Highway, on the eastern slopes of the hill forming the left bank of the Nachar *nala* (Raju, 1961; Ashraf, 1965; Ashraf and Nag, 1966). It occurs in two

separate zones, the zones lying to the north is referred as Nashri Major Slide while that on the south is called Nashri Minor Slide. Along the National Highway, these two slide zones are 450 m apart, but at the head, they are only 240 m apart. The Nashri Major Slide extends from the Nachar *nala* bed (EL. 946 m) to EL. 1150 m. At the road level, it is about 300 m wide and branches off into two portions, one to the west with head of the slide located at EL. 1315 m and another to the northwest with crest of the slide at EL. 1261 m. The total area occupied by the Nashri Major Slide is about 0.1473 km². The crest of Nashri Minor Slide is 60 m higher (EL. 1375 m) and is 80 m wide at the road level and 8.5m wide near the bed level of the Nachar *nala*.

The rock unit affected by the slide are the Murree claystones-siltstones with a few bands of sandstones and debris of clay with boulders of sandstone (Fig. 5.4). The slide is a mud flow type. The clay, derived from the weathering of the Murree claystones and siltstones, is hard and tough when dry, and is stable on slopes as steep as 1:1; but when wet it becomes highly plastic and mobile as mud and its angle of repose becomes very low.

For treatment of the slide it was recommended that: (i) proper surface side drainage should be made, (ii) trimming of the surface of the flowing clay on 2:5:1 slope with 3 m wide horizontal berms after every vertical lift of 8 m and longitudinal drains, (iii) breast walls of dry masonry at toe of the trimmed slopes along with graded filter at the back of the wall, (iv) toe protection by means of retaining wall, (v)

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grouting and anchoring of the sandstone bands above the head of the slide, (vi) sealing off all cracks, (vii) afforestation, etc.

The author also recommended that if the mitigation measures are found costlier to execute, then tunnel alignment, as suggested in the report, may be considered after detailed study.

5.4.4 30th December 2008 event at km 11.550 at Bhawan, Vaishno Devi, Reasi district

The approach road from Katra to Holy Cave (Bhawan) of Mata Vaishno Devi Holy Shrine passes through rugged topography forming steep scarps at a number of places. A number of accidents and casualties on account of loose rock falling has been reported from time to time all along the tracks. At 11.550 km near Bhawan, a rock fall occurred on 30th August 2008 at 11:00 hrs, thereby resulting in one death and seriously injuring six others. The geological assessment of the landslide site was carried out by Kumar (2009a).

This rock fall occurred due to wedge failure and sliding/detachment has taken place in the heavily inhabited area and foot track for the pilgrims at the foot of the hill slope approaching to the Holy Shrine of Shri Mata Vaishnodevi and Bhairon Baba Temple. The hill slope at the slide area is steep ($>60^\circ$) and shows, at places, development of negative slopes. The exposed rocks are dolomitic limestone and cherty dolomite. These rock units are traversed by a number of joint sets. The source area lies in the inaccessible escarpment slope. The distance between the zone of detachment and the zone of accumulation is more than 400m. The presence of bedding shear zone has facilitated the failure of the rock mass.

It was recommended that the overhanging rocks at the upslope area need to be removed. Also, since the detachment zone is in an inaccessible area and to make pilgrimage safe from any landslide hazard, it was suggested to use mitigation options such as provision of boulder gathering trenches at the break in slope of the hillsides; rock trapper between the slope/run out zone; boulder barriers to catch the falling rocks.

5.4.5 6th February 2009 event on NH-1B near Assar, Doda district

On 6th February 2009, intense rainfall triggered a debris slide
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at 21 km near Assar Town (Lat. $33^\circ 07' 43.7''$ N; Long. $74^\circ 24' 14.2''$ E; toposheet: 34O/8). The slide resulted in a major accident in which one person died; besides two trucks, one ambulance and a Tata sumo got buried under the debris. About 200 m road length was completely washed off with 150 m crown height from the reservoir level. The geological assessment of the landslide site was carried out by Kumar (2009b).

The slope forming material comprises of boulders and pebbles of phyllites imbedded in the sandy-silty matrix. Rocks exposed in the vicinity of the landslide area belong to the Ramban Formation and are represented by grey phyllites with thin quartz veins. The general trend of the rock mass is $N40^\circ$ to 45° W – $S40^\circ$ to 45° E dipping 15° to 20° north easterly. Because of the occurrence of two major tectonic features i.e., Murree Thrust and Panjal Thrust in the close vicinity of slide zone, the rocks in this area have undergone intense deformation with the development of a number of joints and shear planes. Due to intense rainfall and over saturation, the unconsolidated mass resting over a steep slope (about 70°) slid. Minor transverse cracks developed in the agricultural fields located above the crown. The trench excavated for laying cable wires along the side of the road also contributed to sliding. During rainfall, the material got saturated and the free flow of water entered into the trench formed a number of sinkholes all along the roadside; thus facilitating the movement.

After preliminary study of the slide at 21 km, it was recommended to bypass the slide zone through alternate road from the adjoining/upslope area. Another option is to bypass this zone through a traffic tunnel by taking the road further inside the slope.

5.4.6 5th-6th August 2010 event at Leh, Ladakh

On the night of 5th and 6th August 2010, between 00:00 hrs and 00:30 hrs, intensive rainfall followed by massive cloudburst (240 mm within a few hours) in high altitude terrain of Leh (3505 m), triggered numerous debris flows, mudflows (earth spreads) and sand flows in toposheets: 52F/8 and 53F/12 (Fig. 5.5). These widespread, composite flows in the over saturated slope-forming materials caused 182 deaths including 3 foreign tourists, damaged 607 houses, breached all major communication networks to Leh town besides inflicting an unaccountable loss of livestock and agriculture fields. The disaster caused severe damage to

the settlements in parts of Leh town, Sabu village, Choklamsar, Leh airport area, Nimu, Ney and Bazgo area around the town. The geological assessment of the landslide sites was carried out by Sharma *et al.* (2010).

The Leh region represents a broad U shaped glacial valley of Indus river sandwiched between the lofty high ranges of Ladakh in the north and Zaskar in the south. Huge piedmont fans, river terraces, recent flood plains with prominent point bars, lateral bars and Aeolian deposits are the major geomorphic units of the terrain. Lacustrine deposits, indicating neotectonic activity, at places, have been observed near Sputik, Phyang and Nimu localities. Geologically, the affected region is occupied by Ladakh Granitoids and Quaternary sediments of glacial, fluvioglacial, lacustrine, alluvial and Aeolian origins. Widespread occurrence of varied, unconsolidated Quaternary drift deposits perched over gentle to fairly steep slopes are susceptible to mass movement under conditions of heavy saturation.

Unprecedented rainfall during 4-6 August 2010 caused excessive mass movement of drift deposits and over spilling

of the banks of the streams. In Leh area, the damage was confined in the catchments of Shaksaling *nala*, flowing from an elevation 3800 m to 3410 m. The debris flow mobilized and damaged the settlements, Bus Stand building, BSNL buildings, Hospital Complex, Radio Station, etc. in its 3 km run-out distance. The Sabu *nala* section, located about 11 km east of Leh, was affected the most by the cloudburst. The prolonged and heavy rainfall that reportedly lasted for 30 minutes raised the water level by about 10-15 feet and triggered the movement in slope debris. Water charged with debris, wooden logs and huge blocks of granite choked the course of the *nala* at bridge points near villages Zong, Myek and Ayu Sabu. The village settlements, forest and agricultural fields were damaged on account of over spilling of water mixed with debris and boulders, which flowed out with an appalling velocity, resulting death of 11 persons in Sabu village. When the debris blockades at bridge points breached due to further on-gush, the debris flow spread out in the downstream commands. This phase, lasting for about 30-45 minutes, was, in fact, the major cause of devastation to Choklamsar village, ITBP Camp, Leh-Manali route, New Choklamsar market, etc. It is reported that bodies of 48

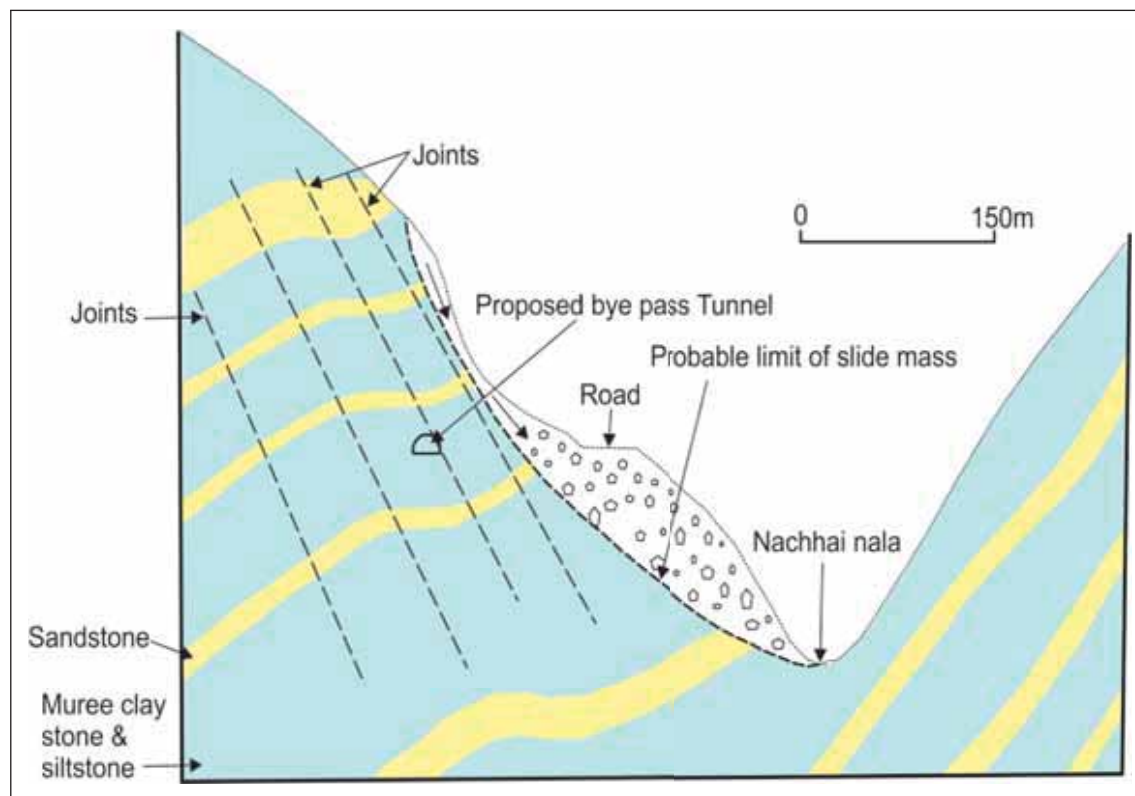


Fig. 5.4. Geological sketch section of the main Nashri slide.

people were recovered from the debris from these areas. A pile of debris upto 4 m high was observed at Leh–Manali road near New Choklamsar village. The debris further moved and spread along the road before falling into Indus River. Typical accumulation lobes of finer fraction of debris material were observed at tail end of the flow. The total runout distance of the debris flow from the epicenter of the cloudburst in the Sabu *nala* to the tip of the debris flow was of the order of 10 km. The maximum lateral spread of debris flow has been observed to be about 2 km. The morphological dimension of the debris flow and lateral spread belies the current figures of deaths and damages in the area.

As a prelude to the devastating cloudburst of 5th-6th August 2010 another cloudburst event of 4th-5th August 2010 also triggered a number of debris flows in the valley of Nimu *nala*, Umlah *nala* and Phyang *nala*. The widespread debris flow in these areas resulted in 11 deaths. Some unconfirmed casualties have been reported from Phyang area also. The natural depressions on both sides of *nala* and low-lying dry streams, where sprawl of settlements have grown, were in general, the worst affected sites of devastation; the higher elevation of slopes were the least affected locations.

5.4.7 19th July 2011 event at Pani Nala, Kishtwar district

On 19th July 2011, at 04:30 hrs, a massive landslide (rock

fall) occurred at Chamoti village near Pani *nala* (Lat. 33°09'12"N; Long. 75°47'52"E); cutting across the National Highway road (NH-1B). The slide, located near Thatri in Kishtwar district on the banks of Chenab River, resulted in three casualties. The geological assessment of the landslide sites was carried out (Kumar, 2012).

Geologically, the slide area is occupied by glacio-fluvial material overlying the mica schist belonging to Salkhala Group. The general dip of foliation of the schist varies between 40° and 45° in the southeasterly direction. Geomorphologically, the area is represented by moderate to high mountains and deep valleys - representing a young mountain system. Most of the inter-montane valleys are 'V' shaped with deeply dissected profiles. River terraces also form a prominent part of the geomorphological landscape. The major river of the area is the Chenab and its tributaries namely Kuli *gad* and Kal *nai*.

The landslide is a rock fall type measuring 20 m in width and 75 m in height from toe. It got triggered due to heavy precipitation and toe erosion of river. The main cause is attributed to adverse structural orientation forming wedge intersection.

It was suggested that proper retaining walls and drainage network to be designed to protect the slide area.

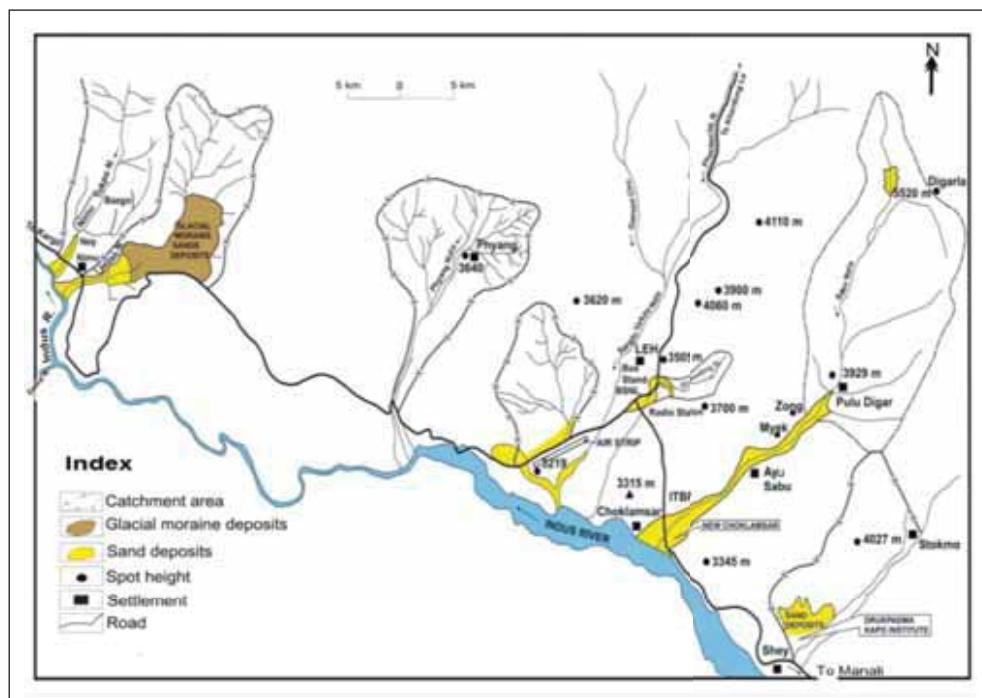


Fig. 5.5. Areas affected by cloudburst of 5th and 6th August, 2010 Leh, Ladakh.

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Annexure-I

INVENTORY OF MAJOR LANDSLIDES IN NW HIMALAYAS

(In addition to the published data in GSI's Special Publication no-71 entitled 'Inventory of Landslides of NW Himalayas')

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
<i>Area: Along Nandprayag – Badrinath road, Uttarakhand</i>							
1	30°34'05" 79°33'15" 53N/10	300	40-60	Overburden	Debris slide	Removal of toe due to road widening contains 4 slides of varying slope.	Toe support by providing retaining structure and drains on ground.
2	30°33'52" 79°34'03" 53N/10	160	60	Overburden	Rock cum debris slide	Valley facing joint forming critical slip plane, aggravated due to removal of toe due to road widening.	Scaling to remove rock overhangs and retaining structure at the base.
3	30°33'50" 79°34'32" 53N/10	100	80-120	Gneiss	Rock slide (wedge failure)	Failure along two sets of joints and their intersection, rocks highly distressed, aggravated due to road cut.	Adequate rock scaling and smoothing of slope profile with retaining structure at the base.
4	30°33'57" 79°34'45" 53N/10	50	40-50	Gneiss and overburden	Rock cum debris slide	Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris.	Slope flattening and benching, boulder pitched wall and wire crate at the road level.
5	30°34'15" 79°34'45" 53N/10 (Near Baldora)	300	100	Gneiss	Rock fall and Debris slide	Failure of distressed rock mass along smooth valley facing joint, aggravated due to road widening, contains 2 slides.	Slope scaling and removal of detached rocks, shotcrete and toe wall and ditch to facilitate debris accumulation. Slope flattening and benching, providing boulder pitched toe wall.
6	30°37'33" 79°33'19" 53N/10	40-50	60-80	Gneiss overburden	Rock cum debris slide	Failure in overburden mass resting on dip slopes. Removal of toe due to road widening contains 2 slides.	Toe support by providing retaining structure.
7	30°38'53" 79°31'22" 53N/10	100-150	120	Overburden	Debris slide	Toe erosion/ undercutting by Nala initiated sliding, overburden lying on steep slope, water seepage along joint plane facilitate sliding.	Provision of accumulation ditch at the toe to arrest the slide debris.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
8	30°39'03" 79°31'19" 53N/10 (Near Lam-bagar Chatti)	350	80-100	Overburden mostly morainic material	Debris slide	Toe undercutting by river, freezing and thawing action of snow and melt water resulting gully erosion of morainic mass and road widening further aggravated the slide, contains 2 slides of similar nature.	Dressing/ easing of overburden slope profile near the head, benching, boulder pitched wall with wire crate at critical spots besides providing geo-jute cover all along the slide surface and retaining wall with wide bench at toe to facilitate debris accumulation.
9	30°40'40" 79°31'46" 53N/10	60	40	Morainic material and gneiss	Debris slide	Removal of toe due to road widening.	Toe support by providing retaining structure.
10	30°33'17" 53N/10	60	120	Biotite gneiss mixed with overburden	Rock fall cum debris slide	Failure along two sets of joints and their intersection, rocks highly distressed, modification of slope resulted in debris slide at lower level due to road cut.	Slope scaling and removal of detached rock mass, shotcrete, toe wall and ditch to facilitate debris accumulation.
11	30°31'47" 79°30'47" 53N/10	50	40	Overburden	Debris slide	Removal of toe due to road widening.	Toe support by providing retaining structure.
12	30°31'22" 79°30'02" 53N/10 (Near Helang)	150	100	Quartzite	Rock fall	Failure along two sets of joints and their intersection, rocks highly shattered, aggravated due to road widening and resulted in the detachment of rock mass, contains 3 slides.	Scaling to remove rock overhangs, spot bolting of rock mass and shotcrete using wire mesh.
13	30°30'30" 79°29'30" 53N/6	200	20	Overburden	Debris slide	Overburden lying on steep slope. Toe erosion/undercutting by <i>nala</i> .	Retaining wall with provision for adequate slope draining.
14	30°29'16" 79°28'46" 53N/7 (Near Patal Ganga)	300	100	Slate/ phyllite	Rock fall	Rocks having closely spaced joints and are highly distressed, removal of toe of steep slopes >65° resulted in wedge failure along slopes, contains 4 slides.	Scaling to remove rock overhangs, spot bolting of rock mass and shotcrete using wire mesh, high strength toe wall with wide bench over it to facilitate debris accumulation.
15	30°29'35" 79°28'08" 53N/7	100	150	Overburden	Debris slide	Overburden lying on steep slope. Toe erosion/under-cutting by <i>nala</i> and located near Belakuchi.	Easing of overburden slope profile. Providing benches and retaining wall, with properly designed weep holes.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
16	30°29'35" 79°28'08" 53N/7	50	40	Quartzite	Rock fall	Failure along two sets of joints and their intersection, rocks highly shattered, aggravated due to road widening and resulted in the detachment of rockmass.	Scaling to remove rock overhangs and shotcrete.
17	30°28'29" 79°27'42" 53N/7	400	40-60	Quartzite	Rock fall cum debris slide	Removal of toe due to road widening, contains 4 slides.	Toe support by providing retaining structure.
18	30°27'18" 79°25'56" 53N/7	50	80	Overburden	Debris slide	Overburden lying on steep slope. Toe erosion/ undercutting by <i>Nala</i> .	Easing of overburden slope profile. Providing benches and retaining wall, with properly designed weep holes.
19	30°17'14" 79°09'07" 53N/3	40-50	40	Basic rock	Rock slide (wedge failure)	Failure along two sets of joints and their intersection, water seepage along joint plane, aggravated by road widening activity.	Back dressing of crown, rock bolting of vulnerable joints, retaining wall with provision for adequate slope draining.
20	30°17'16" 79°15'32" 53N/7	50	60-70	River terrace material	Debris slide	Removal of toe due to road widening activity, located near Jaikandi.	Toe support by providing retaining wall at the road level.
Area: Along Nandprayag – Badrinath road, Uttarakhand							
21	30°46'15" 78°08'47" 53J/1	80	50	Overburden mostly soil	Creep	Deep incision along <i>Nala</i> causing toe erosion.	-
22	30°47'53" 78°08'53" 53J/1	25	35	-	Rock slide	Toe erosion by river causing failure along steep joints.	-
23	30°47'35" 78°09'17" 53J/1	25	55	River terrace material	Debris slide	Subsidence in road.	-
24	30°47'17" 78°09'26" 53J/1	15	20	Massive quartzite overlain by debris	Debris slide	Failure of mass on steep slopes affected by road excavation.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
25	30°47'48" 78°10'51" 53J/1	25	15	Igneous rock	Rock slide	Failure along open joints due to distressing.	-
26	30°48'40" 78°14'36" 53J/1	20	20	Debris	Creep	Subsidence of ground and tilting of trees.	-
27	30°48'58" 78°13'32" 53J/1	30	35	Debris of Phyllite in sandy matrix	Debris slide	Bank erosion and flow of debris during high <i>Nala</i> discharge.	-
28	30°49'23" 78°13'48" 53J/1	100	60	River terrace material	Debris slide	Toe erosion by Yamuna River during floods.	-
29	30°49'00" 78°14'34" 53J/1	20	20	Igneous rock	Rock fall	Detachment of rock along relief joints.	-
30	30°46'45" 78°07'46" 53J/1	200	40	Debris	Creep	Due to water saturation, movement resulting in wall bulging, ground cracks, subsidence and level splitting of road.	-
31	30°47'00" 78°08'16" 53J/1	45	35	Debris	Debris slide	Water saturation effect in debris and bank erosion.	-
32	30°47'52" 78°09'15" 53J/1	80	100	River terrace material	Debris slide	Toe erosion by Yamuna; gully erosion and further head ward erosion.	-
33	30°48'07" 78°10'36" 53J/1	45	55	Phyllite, quartzite	Rock slide (wedge failure)	-	-
34	30°48'25" 78°10'05" 53J/1	40	45	Debris overlying slates	Rock cum Debris slide	<i>Nala</i> erosion induced debris slide and rock failure along dip slopes.	-
35	30°50'44" 78°12'30" 53J/1	40	45	Debris overlying slates	Debris slide	Failure along steep interface of rock and overburden.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
36	30°52'15" 78°11'25" 53J/1	100	80	Debris	Creep	Creep zone affecting cultivated land and road. Subsidence reportedly more in rainy season.	-
37	30°51'35" 78°12'18" 53J/	50	75	Slates	Rock slide	Rock slide on the dip slopes due to steepening of beds (>40°).	-
38	30°51'24" 78°12'35" 53J/1	70	100	Debris with phyllite clasts	Debris slide	Nala erosion inducing slide.	-
39	30°47'20" 78°07'24" 53J/1	100	40	River terrace material	Debris slide	Extensive bank erosion at the confluence of Kamola gad with Yamuna.	-
40	30°47'37" 78°07'18" 53J/1	150	50	Quartzite, cherty limestone	Rock fall and Wedge failure	Wedge failure along 65°/230°. Highly distressed rock occurring as dead mass.	-
41	30°52'35" 78°05'36" 53J/1	20	20	White quartzite	Rock slide	Failure along joints parallel to slopes.	-
42	30°52'35" 78°05'57" 53J/1	30	15	Prophyritic granite	Rock slide	Removal of toe due to road cutting.	-
43	30°52'21" 78°05'52" 53J/1	15	20	Soil from weathering of granite	Debris slide	Probable impact of flowing water.	-
44	30°52'30" 78°06'18" 53J/1	70	35	Rock debris (gneiss)	Debris slide	-	-
45	30°52'42" 78°07'17" 53J/1	40	50	Rock debris (gneiss)	Debris slide	Critical equilibrium of slope could be disturbed due to rain.	-
46	30°52'04" 78°06'35" 53J/1	50	20	Soil debris	Debris slide	Toe erosion by Nala on its left bank.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
47	30°52'24" 78°06'02" 53J/1	10	15	Soil debris	Debris slide	Toe erosion by <i>Nala</i> .	-
48	30°53'02" 78°05'20" 53J/1	30	20	Assorted debris overlying gneiss	Debris slide	Failure due to gully erosion by a seasonal <i>Nala</i> .	-
49	30°55'47" 78°06'06" 53J/1	30	20	Soil debris	Debris slide	Toe erosion by <i>Nala</i> inducing slide and subsidence of road.	-
50	30°55'12" 78°06'15" 53J/1	40	45	Quartzite	Rock slide	Planar failure along valley facing open joints.	-
51	30°54'15" 78°06'34" 53J/1	100	15	Quartzite boulder silt/clay matrix	Debris slide	Isolated spots of failure in a zone of width 100 m.	-
52	30°53'40" 78°06'12" 53J/1	100	30	Layered silty clay	Debris slide	Toe erosion by <i>Nala</i> .	-
53	30°52'58" 78°04'03" 53J/1	20	15	Assorted slope debris	Debris slide	Slope disturbance due to road cutting.	-
54	30°53'09" 78°02'05" 53J/1	10	20	Clasts of phyllite and limestone in a calc matrix	Debris slide	-	Slide partially retained by providing retaining structures.
55	30°53'10" 78°01'53" 53J/1	200	130	Blocks of phyllite and limestone embedded	Debris slide	Toe erosion by <i>Male gad</i> has resulted in slide, subsidence, ground fissures and complete damage to road.	-
56	30°49'30" 78°13'37" 53J/1	25	20	Fragment of weathered basic rocks	Debris slide	Failure along road cut.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
57	30°49'38" 78°13'58" 53J/1	30	20	Phyllite and quartzite overlain by volcanics	Rock slide	Failure due to detachment along open joints.	-
58	30°50'31" 78°14'00" 53J/1	35	25	Phyllite	Rock slide	Planar failure in crumpled phyllites on the dip slopes.	-
59	30°50'50" 78°14'30" 53J/1	55	35	Epidiorite	Planar and wedge failure	Failure along open joints obliquely inclined towards free face.	-
60	30°52'09" 78°14'00" 53J/1	35	35	Massive basic rock	Wedge failure	Failure due to wedge formed by two joints. Foliation plane acts as detachment surface.	-
61	30°52'30" 78°14'00" 53J/1	40	30	Debris consisting of phyllite/schist	Debris slide	Weak rock generating debris over the dip slope.	-
62	30°52'11" 78°14'27" 53J/1	40	35	Slate	Planar failure	Slide induced due to undercutting on the dip slope.	-
63	30°52'58" 78°14'29" 53J/1	80	40	Terrace material	Debris slide	Bank erosion in Badiyar <i>gad</i> .	-
64	30°53'26" 78°14'23" 53J/1	70	20	Rock debris (quartzite)	Debris slide	-	-
65	30°54'04" 78°14'16" 53J/1	60	30	Boulders/pebbles in sandy matrix	Debris slide	-	Toe partially supported to prevent bank erosion.
66	30°55'27" 78°14'30" 53J/1	1000	450	Chlorite schist, epidiorite	Rock slide (wedge failure)	Slide material I is brought down by <i>Nala</i> causing accumulation and resulting into a huge rock debris fan, partially damming the river course.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
67	30°54'02" 78°13'50" 53J/1	250	80	Quartzite boulders/debris	Debris slide	Toe cutting by Badiyar <i>gad</i> , inducing slope movement resulting in complete damage to road.	-
68	30°51'08" 78°13'50" 53J/1	40	20	-	Debris slide	An old slide reactivated in the road cut section.	-
69	30°51'56" 78°13'06" 53J/1	60	50	Phyllite	Rock slide	Toe cutting by the <i>Nala</i> causing creep and slide of rocks.	-
70	30°51'55" 78°12'47" 53J/1	150	60	Phyllite	Rock slump	Rock slumping is along the dip slopes.	-
71	30°45'20" 77°52'17" 53E/13	50	30	Rock blocks in sheared rock matrix	Debris slide	Due to saturation in the toe portion.	-
72	30°45'25" 78°03'42" 53J/1	25	25	Thinly bedded limestone	Planar rock failure	Day lightment of bedding along the free face.	-
73	30°45'56" 78°02'49" 53J/1	35	60	Overburden mainly soil	Debris slide	Toe cutting by the <i>Nala</i> causing series of debris slides.	-
74	30°45'06" 78°05'12" 53J/1	35	30	Overburden of pieces of greywacke	Debris slide	Toe cutting along the road.	-
Area: Upper Yamuna basin (around Yamuna Chatti and Yamunotri), Uttarakhand							
75	30°58'35" 78°28'45" 53J/5	500	250	Overburden	Rock cum debris slide	Located west of Kharsali. Caused due to toe erosion by Unata <i>gad</i> .	Retaining wall at toe.
76	30°52'10" 78°15'42" 53J/5	1000	200	Massive quartzite	Rock fall	Located north of Masalgaon. Dislodgement due to structural discontinuity.	Increase the density of forest to check the movement of rolling blocks.
77	30°53'35" 78°15'42" 53J/5	2500	500	Massive quartzite	Rock fall	Located SW of Gauna. Dislodgement due to structural discontinuity.	Dense forest to act as natural barrier and to arrest movement of rolling blocks.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
78	38°51'27" 78°17'16" 53J/5 (d/s of Khanera)	250 -300	200	Overburden quartzite basic rocks	Rock cum debris slide	Toe cutting by Yamuna, distressed basic and quartzitic rocks acting as loose debris failing under saturated condition during rains.	Concrete toe support, removal of overhangs and distressed mass, back dressing and erection of retaining walls at suitable bench level.
79	30°51'38" 78°17'19" 53J/5	20	20	Quartzite	Rock slide (planer failure)	Toe removal due to road cut.	Rock bolting, fallen blocks forming toe support.
80	30°52'30" 78°18'40" 53J/5 (NE of Kuthnaur)	40	80	Overburden and shattered quartzite	Debris slide	Overburden resting on steep slope, failed under saturated condition.	-
81	30°53'15" 78°18'31" 53J/5	70 – 80	40	River terrace material	Debris slide	Removal of toe support during road cut.	Retaining wall at toe.
82	30°53'12" 78°18'29" 53J/5	100	40 – 70	Weathered quartzite and over-burden cover	Debris slide	Toe removal due to road cut, scars above crown, tilting of trees.	Toe support by retaining wall, removal of trees to decrease overburden weight.
83	30°47'33" 78°15'32" 53J/5	50	80	Overburden soil with basic blocks	Debris slide	Road cut on steep over-burden slope, tilting of trees are noticed.	Toe support at road levels.
84	30°46'15" 78°15'27" 53J/5 (At Rari pass)	50	30	Phyllite	Rock slide (wedge failure)	Toe removal due to road cut, Thin soil layer along joint plane causing slip during rains, Valley facing joints forming vulnerable plane.	Removal of overhangs, rock bolting.
85	30°47'52" 78°15'10" 53J/5	25	70	Basic rocks	Rock fall/ Wedge failure	Toe removal due to road cut exposed overhangs, soil along joint plane and highly distressed condition of rock mass due to weathering leads to failure during rains.	Removal of overhangs and shattered mass. Bench and retaining wall at break point.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
86	30°53'35" 78°19'12" 53J/5	50	50	Quartzites	Rock fall	Toe removal by road cut, highly jointed and distressed, wedges formed by intersection of joints; master joint forms slip plane.	Removal of overhangs/distressed mass and rock bolting of master joint sets.
87	30°54'34" 78°20'01" 53J/5	50	> 80	Mesocratic gneiss	Rock fall/ Wedge failure	Mechanical weathering forms joints. Proximity to MCT.	-
88	30°54'10" 78°21'38" 53J/5 (Nr Saina Chatti)	100	> 220	Overburden (mostly) and weathered gneissic blocks	Debris slide	Toe erosion by <i>Nala</i> flowing along contact of hard rock and overburden mass. Steep slopes.	Back dressing of slope.
89	30°55'08" 78°22'22" 53J/5	50 – 70	40	Overburden material	Debris slide	Toe removal by road cut, fresh scar seen, creep on overburden.	Retaining wall at toe.
90	30°55'48" 78°23'58" 53J/5	50	80	Overburden material	Debris slide	Road cut causing toe removal, slide triggered due to rain; creeping of overburden mass (>4m).	Retaining wall at toe, back dressing and benching with retaining wall.
91	30°55'48" 78°24'24" 53J/5	60	40	Augen gneiss	Rock slide	Toe removal due to road cut and power house excavation.	Retaining wall at toe and removal of loose blocks.
92	S of Yamunotri	40	120	Overburden debris	Debris slide	Toe removal by Yamuna, Overburden ~ 1 m resting on steep slope.	Retaining wall at toe to arrest further erosion.
93	30°59'57" 78°27'51" 53I/8 (at Yamunotri)	10	50	Overburden with quartzite debris	Debris slide	Overburden resting on steep slope, slide under charged condition along with blocks of quartzite (formed due to block dislodgement as a result of freezing and thawing action).	Removal of fallen trees, and overhangs, rock bolting and erection of wall (high tension) above escarpment slope.
94	30°56'24" 78°24'23" 53J/5	40	20	Overburden mixed with schist/gneiss debris	Debris slide	Toe cut by road activity.	Retaining wall at toe.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
95	30°56'37" 78°24'30" 53J/5	70-80	30	Overburden mixed with gneissic debris	Debris slide	Toe cut by road, creep observed.	Retaining wall at toe.
96	30°57'03" 78°24'54" 53J/5 (N of Hanuman Chatti)	100	60	Overburden soil mixed with gneissic/schist debris	Debris slide	Road cut causing toe removal, steep slope and water seepage through overburden mass leading to creep.	Toe support at road level, proper drainage and diversion of <i>Nala</i> to avoid seepage.
97	30°52'13" 78°18'40" 53J/5 (Nr. Kuthnaur)	250	+80	Quartzite/slate debris and terrace	Debris slide (subsidence zone)	Toe erosion by Kuthnaur <i>gad</i> during high discharge condition (water rises to 5 m), rise in water level leads to water transgression from sub tributaries and seepage.	Concrete retaining wall (>5m) along bank and provision of surface drainage.
98	30°53'32" 78°18'04" 53J/5 (Nr Pali)	>80	40	Quartzite debris in sandy matrix	Debris slide	Toe erosion by Pali <i>gad</i> in high discharge condition.	Concrete wall along bank to a height >5 m, scaling of overburden mass and benches with retaining structure.
99	30°56'50" 78°15'20" 53J/5 (N of Gauna)	Along 1st/2nd order <i>Nala</i>	60 - 80	Phyllite and overburden mass	Rock cum debris slide	Toe erosion by <i>Nala</i> .	Back dressing of slope, concrete lining of <i>Nala</i> .
100	30°52'04" 78°17'11" 53J/5	100	120	Loose quartzite debris	Debris slide	Initiated due to toe erosion by <i>Nala</i> and further aggravated due to road cut; failing under charged condition.	Retaining wall at road level.
101	30°58'17" 78°28'45" 53J/5	40	100	Schists	Rock slide	Initiated due to toe erosion by <i>Nala</i> .	Back dressing of overhangs.
Area: Along Haldwani-Badrinath and Badrinath-Rishikesh National Highway, Uttarakhand							
102	Aamparao Distt: Nainital	150	70	Sandstone Shale	Land subsidence	<i>Nala</i> cutting.	Channelising <i>nala</i> courses flowing down the slope.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
103	Balia <i>Nala</i> (right bank near RIES Hotel) Distt: Nainital	150-200	100	Slate-Shale	Land Subsidence/ planar failure.	<i>Nala</i> cutting.	Retaining wall and heavy buttress to be constructed.
104	Ayarpata (near DSB college) Distt: Nainital	100	70	Dolomite	Planar failure	Water seepage.	Retaining wall construction and drainage management.
105	Ratighat Distt: Nainital	140	60	Quartzite/ volcanics	Debris slide	Road cutting	Retaining Wall construction to give cascading effects.
106	Kakrighat Distt: Nainital	70	30	Phyllite/ quartzite	Debris slide	Road cutting	Limited formation cutting and limited blasting.
107	Pines Distt: Nainital	90	50	Shale, slate	Debris slide	Road cutting	Limited formation cutting and limited blasting.
108	Lax-emeshw-ar, Distt: Almora	70	50	-	Debris slide	Road cutting	Limited formation cutting and limited blasting.
109	2 km from Chaukhatia on way to Gairsen Distt: Chamoli	50	20	-	Debris slide	Road cutting	Limited formation cutting and limited blasting.
110	1 km from Pan-dukesh-war	70	50	-	Debris slide	Road cutting	Limited formation cutting and limited blasting.
111	14 km before Gairsen	50	30	Overburden	Debris slide	Road cutting & toe erosion	Limited formation cutting and limited blasting.
112	15 km before Gairsen	-	-	-	Debris slide	Road cutting & toe erosion	Limited formation cutting and limited blasting.
113	2 km from mahalchauri -Maithan	70	60	Quartzite	Planner failure	Toe erosion	Construction of flexible retaining structure at toe. Removal of overhangs and fixing of wire net at critical locations.
114	Devpuri	-	-	Quartzite phyllite	Debris/mud flow	Cloud bust	Drainage management.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
115	14 km before Gairsen from Mahalchauri	100	30	Phyllite	Sinking zone	Toe erosion	Arrest of toe wall damage through retaining structures.
116	2 km from Diwalikhal	100	90	Quartzite	Rock cum debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
117	2.5 km from Diwalikhal	50	30	-	Debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
118	25 km before Kamprayag	30	25	-	Debris slide	Planer failure	Saturation at crown to be checked and regulated.
119	15 km before karanpryag	70	40	-	Debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
120	12 km before karanpryag	60	40	-	Debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
121	Simli	100	70	-	Debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
122	500 m on Simli -Gwal-dam road	120	80	-	Debris slide	Road cutting	Over cutting and over-blasting is to be avoided.
123	1 k.m. from Nandpryag	80	60	-	Debris slide	Nala Cutting/ Road cutting.	Over cutting and over-blasting is to be avoided.
124	Pokhari band	100	70	-	Debris slide	Nala Cutting.	Over saturation of the crown and over-burden material to be checked through water management.
125	1km west of Giopeshwar	200	140	Phyllite quartzite	Debris slide	Nala Cutting.	Protective measure for toe area and drainage management.
126	9 km before Pipalkoti	100	80	Quartzite	Debris slide	Canal Cutting.	Protective measure for toe area and drainage management.
127	2 km before pipalkoti	50	30	-	Debris slide	Canal Cutting.	Protective measure for toe area and drainage management.
128	1 km before Pipalkoti	60	40	Quartzite/ phyllite	Debris slide	Road Cutting.	Overhang are to be avoided due to excessive blasting and limited formation cutting.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
129	1.5 km before Pipalkoti	70	40	Quartzite	Debris slide	Road Cutting.	Overhang are to be avoided due to excessive blasting and limited formation cutting.
130	2.2 km before Pipalkoti	70	50	Quartzite	Debris slide	Nala Cutting.	Protective measure for toe area and drainage management.
131	2.3 km before Pipalkoti	-	-	Quartzite	Debris slide	Nala Cutting.	Protective measure for the area and drainage management.
134	2.3 km before Pipalkoti	100	60	Quartzite/ phyllite	Debris slide	Road Cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
135	2.0 km before Nandpryag	70	50	Quartzite/ phyllite	Debris slide	Road Cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
136	2.0 km after Nandpryag	60	40	Phyllite	Debris slide	Nala Cutting	Protective measure for toe area and drainage management.
137	3 km from Badrinath -Joshimath	100	80	-	Debris slide	Water seepage and excessive rainfall	Water spread on the landslide face and overburden material is to be avoided through drainage management.
138	Lambagar right bank	120	80	Quartzite	Debris slide	Overburden slide due to toere-moval	Toe protection is to be constructed.
139	Lambagar-left bank	100	80	Quartzite	Debris slide	River undercutting	Toe protection and training of river channel in limited area.
140	200 meter SE of Lambagar	100	85	-	Planner	Planer failure	Flexible retaining structures are to be constructed in cascading manner.
141	Govindghat	70	65	Debris of gneisses	Debris slide	Nala cutting	Toe protection and drainage management.
142	4 km before Govinghat	70	60	Debris of gneisses	Debris slide	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
143	2 km from Vishnupryag-Joshimath	150	100	Debris of gneisses	Debris slide	River cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
144	2 km from Joshimath-Helang	70	50	Debris of gneisses	Debris slide	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
145	8 km from Joshimath-Helang	90	70	Debris of gneisses	Debris slide	Nala cutting	Toe protection and drainage management.
146	1 km before Helang	50	30	Debris of gneisses	Sinking zone	Excessive Rain Fall	Construction of retaining structure at toe level and buttress at intermediate level with drainage management.
147	1 km after Helang	150	120	Gneisses	Planner	Road Cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
148	Left Bank of Alaknand near loc-44	90	70	Gneisses	Wedge	Road Cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
149	2 k.m. from Helang	120	90	Debris of quartzite	Debris slide	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
150	2.5 km from Helang	70	50	Quartzite	Planner	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
151	3 km from Helang	150	120	Debris of quartzite	Debris slide	Road cutting	Overhangs are to be avoided due to excessive blasting and limited formation cutting.
152	12-16 km before Pipalkoti	220	180	Debris of quartzite	Debris slide	Glacial deposit/slope failure	Avoidance of the saturation of the debris/overburden material through drainage management.
153	Right bank of river near Tagni	120	100	Debris of quartzite	Debris slide	Nala cutting	Toe protection and drainage management.
154	1km before Tagni	200	180	Debris of quartzite	Debris slide	Nala cutting	Toe protection and drainage management.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
155	Tagni	300	100	Quartzite	Wedge	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
156	1 km from Kampryag-Srinagar road	130	70	Slate	Wedge	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
157	8 km after Kampryag-Srinagar	30	20	Quartzite slate	Sink	Water Seepage	Water spread on the landslide face and overburden material is to be avoided through drainage management.
158	3 km before Gaucher	150	140	Slate	Planner	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
159	22-27 km before Srinagar	-	-	Quartzite slate	Wedge planner/ Debris slide	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
160	16-19 km before Srinagar	-	-	Quartzite slate	-	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
161	6 km after Devpryag	140	110	Debris of Phyllite	Debris slide	Road cutting	Overhang are to be avoided due to excessive blasting and limited formation cutting.
162	4 km before Saknidhar	170	140	Limestone	Debris slide	Road cutting.	Overhang are to be avoided due to excessive blasting and limited formation cutting.
163	4 km from Saknidhar -Totaghati	160	140	Limestone	Wedge failure	Road cutting.	Overhang are to be avoided due to excessive blasting and limited formation cutting.
164	Totaghati	150	140	Dolomite	Overburden	Excessive rain fall.	Construction of retaining structure at toe level and buttress at intermediate level with drainage management.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
165	Saknidhar 30°05'15" 78°33'00" 53J/16	150	-	Phyllite/ quartzite	Rock cum debris slide	Triggered at 11 PM on 31 August 2011. Highly weathered rock got saturated, causing slope failure.	Remove the loose material and scoop out hang over rock mass/material on failure slope. Properly lined drainage systems (cemented) across and along the road are required especially around slide areas for controlled water flow.
166	Bachhe- ligaun (near Simswara mal- la) 30°05'15" 78°35'00"	200	-	Rock, over- burden-phyllite	Rock cum debris slide	Triggered on 1st week of July 2011. Bank erosion and toe cutting of Alaknanda river during high flood, causing slope failure.	Slope moderation by benching of failure slopes at less than 15°.
167	Shirobagad/ Kaliasaur 30°15'30" 78°58'00"	400	-	Rock-quartzite and metavolcanic	Rock	Triggered on July, August and September 2011. Old and active slide-Recurring every year /1st time occurred in 1940. Active movement on crown portion. Multi-causative factors, including numerous active fault and complex geology, bank erosion and toe cutting of Alaknanda river during high flooding.	Construction of cut-and-cover type traffic short length tunnel (about 300-400 m length) is required. Reoccurrence of slide can also be minimised by slope moderation by benching of failure slopes at less than 15°. Monitoring of slope behavior through pedestal is required.
168	Chamdhar 30°14'40" 78°51'50" 53J/16	400	-	Rock, over- burden-cry- talline	Rock cum debris slide	Triggered on 1st week of August 2011. Continuous heavy rainfall and highly weathered rock. It has led to the saturation of thick deposits of slope wash debris material.	It can also be minimized by slope moderation by benching of failure slopes at less than 15°.
169	Nagrasu 30°17'20" 79°07'20" 53N/3	100	-	Rock quartzite with overburden	Rock cum debris slide	Triggered on July, August and September 2011. Continuous heavy rainfall led to the saturation of thick deposits of slope wash debris material.	To minimize/mitigate the imminent slide 5 m to 6 m high concrete breast wall is required.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
170	Gauchar 30°16'00" 79°10'30" 53N/ 3	50	-	Schist/ phyllite	Rock cum debris slide	Continuous heavy rainfall has led to the saturation of thick debris material initiating dip slope movement.	6 m to 8 m high concrete breast wall, slope moderation by benching of failure slopes at less than 15°.
171	Kanprayag 30°16'00" 79°12'45" 53N/ 3	25	-	Quartzite	Rock slide / Fall in quartzite	Triggered on night of September 2011. One casualty. Caused due to cloudburst and subsequently heavy rainfall.	Remove the loose rock material/boulders and scoop out of hang over rock mass on failure slope. Erection of 5 m to 7 m high concrete breast wall.
172	Dewali 30°18'15" 79°18'10" 53N/ 3	150	-	Rock, over-burden	Rock cum debris slide	Triggered in August and September 2011. Continuous heavy rainfall has led to the saturation of thick deposits of slope wash debris material. Other factors being, bank erosion and toe cutting of Alaknanda river during high flood, causing slope failure.	A 5 m to 7 m high concrete breast and slope moderation by benching of failure slopes at angle less than 15°.
173	Sirkot/ Chinka near Birahi 30°24'45" 79°23'45" 53J/16	300	-	Rock, over-burden-granite gneiss and schist	Rock cum debris slide	Triggered in last week of August 2011. Continuous heavy rainfall has led to the saturation of thick deposits of slope wash debris material and highly weathered rocks.	To protect the loose material a 5 m to 7 m high concrete breast wall at hard rock foundation level is required. It can also be minimised by slope moderation by benching of failed slopes at angle less than 15°.
Area: Pithoragarh district, Uttarakhand							
174	29°37'43" 80°08'57" 62C/2	55	50	Debris (quartzite boulder)	Debris slide	After road cutting because of no protection at site, rain might have motivated the slope failure.	Protection wall with line drainage having weephole along road. Protection wall toward valley side.
175	29°38'28" 80°14'32" 62C/2	35	20-30	Highly weathered phyllite and limestone	Rock cum debris slide	Heavy rainfall and Road cuts.	Protection wall extension. Removal of debris material at road level.
176	29°42'32" 80°09'27" 62C/2	150	100	Sheared quartzite, Phyllite, limestone	Debris slide	Heavy rainfall accelerated sheared material to move along slope dipping north.	Retaining wall with drainage system. Fast growing bushes cultivation along slope from crown to toe.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
177	29°43'02" 80°11'55" 62C/2	150	120	Boulder of limestone	Rock fall	Closely spaced jointed Limestone. Heavy rainfall.	Construction of retaining wall and its extension along Road. Cultivation of bushes, removal of existed slide material.
178	29°43'41" 80°04'25" 62C/2	45	35-40	Sheared limestone/dolomite	Rock cum debris slide	Heavy rainfall and Road cuts.	Toe wall may be constructed above the road level. Existing toe wall may be extended in length.
179	29°38'24" 79°59'34" 62C/2	95	80	Debris of slate and phyllite	Rock cum debris slide	Heavy rainfall. Road cuts.	Construction of toe wall along with lined drainage along affected road.
Area: Around Bageswar-Are-Harsila-Kapkot-Ritahbagar-Kharbagar-Naukori-Kanda-Dophad, Bageshwar district, Uttarakhand							
180	Near Narendra palace hotel, Bageswar	15	10	Older alluvium	Old terrace failure	Over saturation of terrace after intense rain during July-September 2010.	Breast wall along the failure surface at toe level. Treatment done.
181	Near Ara - Tamchaura village	150	100	Quartzite berinag formation	Rock cum debris slide	Highly weathered rock. Triggered after intense rain during July -September 2010.	Breast /retaining wall along the failure surface at toe level. Treatment done.
182	Near Manikhet village, 1.5 km from Balighat	10	45	Carbonaceous phyllite/slate Pithoragarh Formation	Slide (mud-flow type)	Highly weathered rock. Triggered after intense rain during July -September 2010.	Breast wall along the failure surface at toe level.
183	At Anarsa village	20	12	Thinly bedded limestone	Debris slide	Highly weathered rock. Triggered after intense rain during July -September 2010.	Breast wall along the failure surface at toe level.
184	Near Harsila village	110	35	Thinly bedded limestone	Debris slide	Highly weathered rock. Triggered after intense rain during July -September 2010.	Breast wall along the failure surface at toe level.
185	Near Golaun village	60	20	Limestone	Rock cum debris slide	Highly weathered rock. Triggered after intense rain during July -September 2010.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
186	Near Golaun village	40	20	Limestone	Rock cum debris slide	Over saturation of overburden triggered after rain during July-September 2010.	Breast wall along the failure surface at toe level.
187	Near Chirang village, on road	15	40	Quartzite, schist	Debris slide	Due to fault triggered after rain during July-September 2010.	Breast wall along the failure surface at toe level.
188	100 m after Chirang village, on road	20	15	Quartzite	Rock cum debris slide	Highly fractured and shattered rock. Triggered during July-September 2010.	Breast wall along the failure surface at toe level.
189	300 m after Chirang village, on road	22	15	Metavolcanics Pithoragarh Formation	Rock cum debris slide	Highly fractured and shattered rock. Triggered during July-September 2010.	Breast wall along the failure surface at toe level.
190	400 m after Chirang village, on road	200	20	Quartzite Pithoragarh Formation	Rock cum debris slide	Highly fractured and shattered rock. Triggered during July-September 2010.	Breast wall along the failure surface at toe level.
191	Before Dungri village	40	30	Quartzite Pithoragarh Formation	Debris-mud flow/slide	Over saturation of jointed and fractured rock after intense rain during July-September 2010.	Breast wall along the failure surface at toe level.
192	Near Dungri village	180	30	Metavolcanics	Debris slide	Over saturation of jointed and fractured rock after intense rain, one house damage, July-September 2010.	Breast wall along the failure surface at toe level.
193	At 500 m from above slide Near Naugaun village	160	25	Quartzite Pithoragarh Formation	Debris slide	Highly fractured and shattered rock. Triggered during July-September 2010.	Breast wall along the failure surface at toe level.
194	Naghar village	150	25	Metavolcanics	Rock cum debris slide	Over saturation of jointed and fractured rock after intense rain in July-September 2010.	Breast wall along the failure surface at toe level.
195	Near Gadgaun village, Bag-eswar- Kanda road	20	30	Quartzite Berinag Formation	Rock cum debris slide	Geological cause – highly weathered rock, dip-slope movement, July-September 2010.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
196	At 1 km above slide between Gadgaun-Chhati road	200	50	Metavolcanics	Rock cum debris slide	Geological cause – highly weathered rock and deformation, July-September 2010.	Breast/retaining wall along the failure surface at toe level. Treatment done.
197	At 1 km from above slide Between Gadgaun-Chhati road	75	40	Quartzite Berinag Formation	Rock cum debris slide	Geological cause – highly weathered rock July-September 2010.	Breast/retaining wall along the failure surface at toe level.
198	At 100 m above slide Between Gadgaun-Chhati road	30	25	Quartzite Berinag Formation	Rock cum debris slide	Geological cause – highly weathered rock. July-September 2010.	Breast/retaining wall along the failure surface at toe level.
199	At 500 m above slide Between Gadgaun-Chhati road	50	30	Metavolcanics	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
200	Near Chhati, Bageswar – Kanda road	30	20	Quartzite Berinag Formation	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
201	At 300 m above slide, Bageswar – Kanda road	10	15	Quartzite Berinag Formation	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
202	Near Mankot malla, Kanda Bageswar road	100	1000	Limestone and phyllite Pithoragarh Formation	Slide with subsidence	Over saturation of cultivated terrace after intense rain, Road damage.	Breast/retaining wall.
203	At 1 km from Mankot Malla, Bageswar – Kanda road	20	30	Quartzite Berinag Formation	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall.
204	At 2 km from Mankot malla, Bageswar – Kanda road	20	15	Quartzite Berinag Formation	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
205	At 4 km from Mankot malla, Bageswar Kanda road	18	15	Quartzite Berinag Formation	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
206	At Biaunasara village	20	10	Bedded limestone	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
207	At 1 km from above slide	20	12	Bedded limestone/phyllite Pithoragarh Formation	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
208	At Pauridhar	10	20	Bedded limestone	Slide (mud-flow type)	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
209	At 1 km from Pauridhar	20	10	Bedded limestone	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
210	At 2 km from Pauridhar	25	15	Bedded limestone	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
211	Near Salikhet tok of Chachai village	120	300	Massive limestone Pithoragarh Formation	Rock cum debris slide	Geological cause- highly fractured rock, August 2007.	Breast/retaining wall along the failure surface at toe level.
212	At 1 km from Salikhet tok of Chachai village	80	200	Limestone and phyllite Pithoragarh Formation	Rock cum debris slide	Highly fractured rock, August 2007.	Breast/retaining wall along the failure surface at toe level.
213	On left bank of Kanal gad, near Harsila	60	100	Limestone and phyllite	Rock cum debris slide	Highly weathered rock. July-September 2010.	Breast/retaining wall along the failure surface at toe level.
214	On right bank of Kanal gad, on Harsil-Kali-yanikot road	200	150	Limestone and phyllite Pithoragarh Formation	Rock cum debris slide	Highly weathered rock, July-September 2010.	Breast/retaining wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
215	Near Kharbagar	500	200	phyllite/slate quartzite/limestone	Rock cum debris slide	Major fault/shear plane, jointed/fractured rock couple with intense rain, road damage, July-September 2010.	Breast/retaining wall along the failure surface at toe level. Treatment done.
216	Near Baret	150	300	phyllite/slate quartzite/limestone	Rock cum debris slide	Major fault/shear plane.	Moderation /benching of slope upto low angle 18°.
217	Near Naukori	200	400	phyllite/slate quartzite/limestone	Rock cum debris slide	Major fault/shear plane, jointed and fractured rock couple with intense rain, July-September 2010.	Breast/retaining wall along the failure surface at toe level.
218	Near Are	20	30	Quartzite Berinag Formation	Rock fall	Along Joint planes, road damage. September 2011.	Breast/retaining wall along failure surface at toe level.
219	Near Balighat	35	20	phyllite/slate	Rock slide	Jointed/fractured rock, intense rain, road damage, September 2011.	Breast/retaining wall along the failure surface at toe level.
Area: Around Bageshwar-Garur-Bainath-Gwaldam-Sahyna, Bageshwar district, Uttarakhand							
220	Near Bahuli village	20	10	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
221	Near village Runakhet	15	25	Quartzite	Debris slide	Geological cause – highly weathered rock, September 2010.	Breast wall along the failure surface at toe level.
222	Near village Bamanari	15	15	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, September 2010.	Breast wall along the failure surface at toe level.
223	Near village Mostgaun	12	10	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
224	At village Rawaikhal	12	14	Granite-gneiss	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
225	Near Simar village	50	40	Quartzite	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
226	On Dangoli-Gwaldam road	22	28	Granite-gneiss	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
227	On Dangoli-Gwaldam road	18	35	Granite-gneiss	Rock cum debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
228	Channi-Kopahalgair road	22	15	Quartz arenite	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
229	Channi-Kopahalgair road	18	15	Quartz arenite	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
230	Takula-Kopahalgair road	10	8	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
231	Takula-Kopahalgair road	17	15	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
232	Takula-Kopahalgair road	25	15	Granite-gneiss	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
233	Wajulya-Sylyana road	20	25	Schist	Debris slide	Geological cause – highly weathered rock, July-September 2010.	Breast wall along the failure surface at toe level.
234	Kameridevi 53O/13	8	12	Gneiss	Rock slide/fall	Geological cause-Jointed rock mass.	Retaining wall at the toe.
235	Kameridevi 53O/13	24	15	Quartzite	Rock slide	Wedge failure.	None.
236	Kameridevi 53O/13	15	8	Quartzite	Rock fall	Wedge failure.	None.
237	Jalmani 53O/13	40	35	Quartzite	Debris/ rock fall	Planar & wedge failure of rock mass.	Retaining wall at the toe.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
238	Bantola (near sera) 53O/13	60	35	Quartzite	Debris/ rock slide	Anthropological & active slide.	Cutting Benches at higher level and Retaining wall at the toe.
239	Right bank of Meher gad 1.5 km north of Machhera village 62C/1	100	60	Dolomite	Debris/ rock slide	Anthropological & active slide.	Cutting Benches at higher level and Retaining wall at the toe.
240	Left bank of Meher gad 1.5 km NNE of Machhera village 62C/1	30	80	Thinly bedded dolomite of Pithoragarh Formation	Debris/ rock slide	Anthropological & old slide.	Providing toe support.
241	Left bank of Meher gad east of Machhera village 62C/1	70	100	Thinly bedded dolomite of Pithoragarh Formation	Debris/ rock slide	Toe cutting of Meher gad and heavy rains & active slide.	Toe support.
242	Right bank of Ramganga near Haldwani 62C/1	30	80	Dolomite of Pithoragarh Formation	Debris slide	Heavy rains & dormant slide.	Cutting benches and providing proper drainage.
243	Left bank of Meher gad near Sukchauna 62C/1	60	50	Highly fractured Dolomite of Pithoragarh Formation	Rock -Debris slide	Heavy rains & active slide.	Cutting benches and providing toe support.
244	Right bank of Meher gad 1 km SSE of Sukchauna 62C/1	40	50	Highly fractured Dolomite of Pithoragarh Formation	Debris -rock slide	Heavy rains & dormant slide.	Cutting benches and providing toe support.
245	Right bank of Meher gad opposite the confluence of Baori gad 62C/1	40	60	Dolomite of Pithoragarh Formation	Debris-rock slide	Anthropogenic & active slide.	Toe support.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
246	Right bank of Ramganga river near Ramari village 62C/1	2040	550	Dolomite of Pithoragarh Formation	Debris slide	Heavy rains and weak rock, partly anthropogenic & active slide.	Cutting benches and planting vegetation.
247	Right bank of Ramgan ganga near Timtiya village 62C/1	50	250	Slate of Pithoragarh Formation	Rock slide	Anthropogenic & active slide.	Cutting of benches and SFR shotcreting.
248	Right bank of Ramganga SW of Nachhni village 62C/1	60	50	Thinly bedded dolomite of Pithoragarh Formation	Debris slide	Heavy rains & active slide.	Cutting of benches and toe protection.
249	Near Silangra 53O/13	50	35	Metavolcanic	Rock-Debris slide	Anthropological & active slide.	Toe protection wall.
250	Near Paithan 53O/13	40	45	-	Debris slide	Toe cutting of Nala & old active slide.	Breast wall with weep holes.
251	Near Basi 53N/16	50	40	-	Debris slide	Anthropological & active slide.	Breast wall at the toe.
252	Kaplani village, left bank of river Sarju	100	50	-	Debris-rock slide	Planar failure & active slide.	Toe support wall with weep holes and benches at higher reaches.
Area: Along Harkidun - Tiuni road, Uttarakhand							
253	At Tiuni marker 77°50'45" 30°56'45" 53F/13	10	12	Phyllite and limestone	Rock fall	Caused due to percolation of excess water into joints and loss of shearing resistance in rocks.	Flattening/moderation of slope upto low /stable angle.
254	77°50'45" 30°56'50" 53F/13	25	20	Old terrace compact deposits	Terrace failure	During rain fall boulders of terrace deposits have lost their matrix support as result slope failure.	Flattening/moderation of slope upto low /stable angle. Retaining wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
255	77°51'50" 30°56'50" 53F/13	21	25	Phyllite and limestone	Rock-cum debris slide	Caused due to percolation of excess water into joints and losing shearing resistance of rocks as result sliding of whole exposure along foliation dip and joint plane.	Retaining/Breast wall on the failure surface at the toe. Proper cemented/ lined drainage system along road side for runoff of water.
256	77°51'55" 30°57'00" 53F/13	8	6	Phyllite and limestone	Debris slide	After saturation of overburden and highly weathered rock it has led to debris moment	3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
257	77°51'56" 30°57'05" 53F/13	21	15	Phyllite and limestone	Debris slide	After saturation overburden and highly weathered rock has led to debris moment.	3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
258	77°51'35" 30°57'20" 53F/13	11	20	Jointed quartzite	Rock fall	Wedge failure.	3 m retaining wall along the failure surface at the toe to protect further movement of rock boulder.
259	77°51'46" 30°57'15" 53F/13	42	20	Phyllite (highly weathered)	Debris slide	Due to warping of folded strata it has dipped towards road side as result debris failure.	3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
260	77°51'50" 30°57'10" 53F/13	20	30	Phyllite (highly weathered)	Debris slide	After saturation overburden and highly weathered rock has led to debris moment.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
261	77°51'55" 30°57'05" 53F/13	70	35	Phyllite (highly weathered)	Debris slide	After saturation overburden and highly weathered rock has led to debris moment.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
262	77°52'00" 30°57'00" 53F/13	25	16	Phyllite (highly weathered)	Rock-cum Debris slide	Due to overburden and highly weathered rock has led to debris moment.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
263	77°52'20" 30°56'40" 53F/13	40	30	Bedded limestone (highly weathered)	Rock-cum Debris slide	Due to warping of folded strata it has been dipping towards road side as result debris failure.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
264	77°52'25" 30°56'40" 53F/13	55	12	Bedded limestone (highly weathered)	Creeping fall as debris cone	Anthropogenic Due to disturbance in overburden and highly weathered rock it has led to creeping moment at road.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
265	77°52'30" 30°56'40" 53F/13	20	20	Bedded limestone (highly weathered)	Creeping fall as debris cone	Anthropogenic. Due to disturbance in overburden and highly weathered rock it has led to creeping moment.	Remove the loose slide material. 3-4 m retaining wall along the failure surface at the toe to protect the further movement of loose material.
266	77°53'15" 30°56'45" 53F/13	50	20	Bedded limestone	Debris /scree fall	Anthropogenic. Due to disturbance in overburden and highly weathered rock it has led to creeping moment.	Remove the loose falling material. Retaining wall along the road at road/toe level.
267	77°53'25" 30°56'45" 53F/13	55	15	Jointed quartzite	Rock cum debris fall	Due to crumbling and highly weathered rock, during heavy rain fall it has led to movement.	Remove the loose falling material. Retaining wall along the road at road/toe level.
268	77°53'30" 30°57'00" 53F/13	75	10	Weathered phyllite	Series of debris fall	Due to crumbling and highly weathered rock during heavy rain fall it has led to movement.	Remove the loose falling material. Retaining wall along the road at road/toe level.
269	77°53'45" 30°57'00" 53F/13	35	20	Weathered phyllite	Rock cum debris fall	Planer Failure. Due to Bedding dip and Bedding joint towards road/ valley side during heavy rain fall it has led to movement.	Remove the loose falling material. Retaining wall along the road at road/toe level. Proper cemented/lined drainage system.
270	77°54'00" 30°56'50" 53F/13	12	8	Phyllite (highly weathered)	Rock cum debris fall	Wedge failure.	Retaining wall along the road. Proper cemented /lined drainage system.
271	77°53'50" 30°56'45" 5 F/13	10	15	Jointed quartzite	Rock fall	Wedge failure.	Retaining wall along the road. Proper cemented /lined drainage system.
272	77°53'48" 30°56'30" 53F/13	20	15	Jointed quartzite	Prone to rock fall	Hanging boulder may fall along joint plane.	Remove the loose falling material. Retaining wall along the road. Proper cemented/lined drainage system along road side for runoff of water.
273	77°53'48" 30°56'30" 53F/13	15	8	Weathered phyllite	Debris fall facing west	Due to crumbling and high wreathing of rock.	Remove the loose falling material. Retaining wall along the road. Proper cemented/lined drainage system along road side for runoff of water.
274	77°53'50" 30°56'35" 53F/13	20	10	Jointed quartzite with schist	Debris fall	Due to extensive wreathing of rock slide has occurred.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
275	77°54'05" 30°57'05" 53F/13	18	10	Jointed Quartzite/ overburden of sandy material	Rock cum debris fall	Material has moved due to roots penetration of trees through joints. Pine tree may fall again.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
276	77°54'10" 30°57'07" 53F/13	5	4	Jointed quartzite/ overburden of sandy material.	Rock cum debris fall wedge failure	Material has moved due to roots penetration of trees through joints. Pine tree may fall again.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
277	77°54'15" 30°57'10" 53F/13	40	12	Jointed quartzite/ overburden of sandy material	Rock cum debris fall wedge failure	Material has moved along joints plane.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
278	77°54'20" 30°57'15" 53F/13	70	15	Jointed quartzite/ overburden of sandy material	Rock-cum- de- bris fall wedge failure facing north	Material has moved along joints plane.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
279	77°54'30" 30°57'15" 53F/13	15	30	Jointed quartzite/ overburden of sandy material	Rock cum debris fall wedge failure	Material has moved along joints plane.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
280	77°54'35" 30°57'17" 53F/13	15	30	Jointed quartzite/ overburden of sandy material	Rock cum debris fall facing north	Material has moved along joints plane.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
281	77°54'35" 30°57'20" 53F/13	25	8	Jointed quartzite/ overburden of sandy material	Rock cum debris fall	Material has moved along joints plane.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
282	77°54'40" 30°57'22" 53F/13	25	12	Jointed Quartzite/ overburden of sandy material	Rock cum debris fall	Due to weathering material has moved along joints plane with sandy soil and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
283	77°54'45" 30°57'27" 53F/13	8	10	Quartzite/ overburden of sandy material	Debris fall facing North-East	Due to weathering material has moved with sandy soil and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
284	77°54'47" 30°57'30" 53F/13	6	10	Quartzite/ overburden of sandy material	Debris fall	Due to weathering material has moved with sandy soil.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
285	77°54'50" 30°57'25" 53F/13	20	15	Quartzite/ overburden of sandy material	Rock cum debris fall	Due to weathering material has moved along joints plane with sandy soil and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
286	77°54'50" 30°57'30" 53F/13	12	8	Quartzite/ overburden of sandy material	Rock-cum- debris fall facing north	Due to weathering material has moved along joints plane with sandy.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
287	77°54'10" 30°57'45" 53F/13	15	10	Quartzite/ overburden of sandy material	Rock-cum- debris fall facing west	Due to weathering material has moved along joints plane with sandy.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
289	77°56'10" 30°58'20" 53F/13	10	15-20	Gneiss and schist	Rock fall with soil	Due to saturation of material and roots penetration of trees material has moved and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
290	77°56'15" 30°58'22" 53F/13	14	7-8	Gneiss and schist	Rock fall (boulder)	Due to saturation of material it has moved and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
291	77°56'20" 30°58'24" 53F/13	10	7-8	Gneiss and schist	Rock fall (boulder)	Due to saturation of material it has moved and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
292	77°56'30" 30°58'20" 53F/13	20	16	Gneiss and schist	Rock fall (boulder)	Due to saturation of material it has moved and flooded on road.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
293	77°57'00" 30°58'30" 53F/13	25	10	Gneiss and schist (boulder)	Slump type movement of debris material	Due to saturation of material and roots penetration of trees. Pine tree may fall Main road damaged due to cutting by water.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
294	77°57'40" 30°58'32" 53F/13	40	10	Jointed quartzite	Rock cum debris fall	Due to roots penetration of trees in joints. Wedge failure.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
295	77°59'45" 30°58'50" 53F/13	70	20	Jointed quartzite	Rock cum debris fall	Due to roots penetration of trees in joints. Wedge failure. Main road damaged.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
296	77°58'50" 30°59'00" 53F/13	30	20	Jointed quartzite	Rock cum debris fall	Wedge failure. 5 nos. Pine tree have fallen. Few Pine tree may fall again due to weight of itself.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
297	77°58'55" 30°59'00" 53F/13	20	20	Jointed quartzite	Rock cum debris fall	Wedge failure.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
298	77°1'05" 30°59'05" 53F/13	25	12	Jointed quartzite	Rock-cum-debris fall	Wedge failure.	Remove the loose falling material. Retaining wall at toe level. Proper lined drainage system along road side for runoff of water.
299	77°1'30" 30°0'00" 53I/4	8	3	Jointed quartzite and gneiss	Rock fall (boulder)	Wedge failure.	Remove the loose falling and overhang material.
300	78°2'45" 31°1'00" 53I/4	6	8	Jointed quartzite and gneiss	Debris fall	Slide occurred in overburden of slope wash material due to saturation of material.	Remove the loose falling and overhang material.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
301	78°3'10" 31°0'45" 53I/4	12	15	Jointed quartzite and gneiss	Debris fall	Slide occurred in overburden of slope wash material due to saturation of material.	Remove the loose falling and overhang material.
302	78°3'15" 31°0'40" 53I/4	-	-	Jointed quartzite and gneiss	Rock cum debris fall	Due to saturation of material.	Remove the loose falling and overhang material.
303	78°3'20" 31°0'30" 53 I/4	17	10	Jointed quartzite and gneiss	Rock cum debris fall	Due to saturation of material (20-40 m thick) and roots penetration of trees. Tilted Pine tree may fall.	Remove the loose falling and overhang material.
304	78°3'30" 31°05'05" 53I/4	200	130	Jointed quartzite	Rock slide Facing	Due to cloud burst movement has taken place along joints plane and flooded upto/into the Gadu gad. Wedge failure. Kiyari/garden cemented/lined irrigation nali/canal damaged.	Remove the loose falling and overhang material/ boulder.
305	78°2'50" 31°1'15" 53I/4	10	10	Foliated gneiss (highly weathered)	Rock cum debris fall (Small slide)	Due to extensive weathering movement has taken place along joints plane.	Remove the loose falling and overhang material.
306	78°3'00" 31°1'30" 53I/4	10-12	4-5	gneiss with old terrace deposits	Terrace failure	During rain fall deposits boulders loosened their matrix support and fallen on road.	Remove the loose falling material. 3-4m retaining wall along the failure surface at toe/road level.
307	78°3'50" 31°2'40" 53I/4	37	30	Porphyro-blastic gneiss	Facing NN-West	Due to spring/flowing water material has moved. Main road damaged.	Remove the loose falling material. 3-4m retaining wall along the failure surface at toe/road level.
308	78°4'30" 31°3'00" 53I/4	800	20-40	Porphyroblastic gneiss with deposits of soil and boulder	Failure of old terrace deposits	Main road damaged.	Scooping of the loose material. 8-12 m high Retaining wall along the failure surface at toe/road level. Proper drainage.
309	78°3'05" 31°3'35" 53I/4	60	20	Weathered gneiss with thick overburden	Debris cum rock fall	Due to extensive weathering movement has taken place and flooded down into river.	Scooping of the loose material. 8-12 m high retaining wall along the failure surface at toe/road level. Proper drainage.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
310	78°5'10" 31°3'40" 53I/4	20	10	Weathered gneiss with thick overburden	Debris cum rock fall	Due to extensive weathering movement has taken place and flooded down into river.	Material has still laying on road, cleaning required.
311	78°5'35" 31°3'25" 53I/4	55	40-50	Weathered gneiss and schist with overburden	Slump type movement of debris and soil.	Due to extensive weathering and saturation of material, the movement has taken place and flooded across the road. E-W trending transverse cracks have developed. Main road damaged.	Material has still laying on road, cleaning required. 3-4 m Retaining wall along the failure surface at toe/road level.
312	78°5'40" 31°3'25" 53I/4	10	10	Weathered gneiss and schist with overburden	Debris slide facing North	Due to extensive weathering and saturation of material, the movement has taken place and flooded across the road. E-W trending transverse cracks have developed. Main road damaged.	Material has still laying on road, cleaning required. 3-4 m retaining wall along the failure surface at toe/road level.
313	78°5'40" 31°3'35" 53I/4	20	10	Weathered gneiss and schist with overburden	Debris slide facing North	Due to extensive weathering and saturation of material, the movement has taken place and flooded across the road. E-W trending transverse cracks have developed. Main road damaged.	Material has still laying on road, cleaning required. 3-4 m retaining wall along the failure surface at toe/road level.
314	78°5'00" 31°3'30" 53I/4	20	10	Gneiss and schist (highly weathered)	Rock fall facing South -West	Material has moved along joints plane.	Scooping of the loose material. 8-12 m high retaining wall along the failure surface at toe/road level.
315	78°5'55" 31°3'35" 53I/4	20	10	Gneiss and schist (highly weathered)	Rock fall facing South -West	Material has moved along joints plane.	Scooping of the loose and overhang material. 8-12 m high retaining wall along the failure surface at toe/road level.
316	78°5'55" 31°3'50" 53I/4	15	10	Schist (highly weathered)	Debris slide	Due to extensive weathering and saturation of material.	Remove the loose saturated and overhang material.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
317	78°6'10" 31°4'15" 53I/4	900	200	Quartz-mica Schist (highly weathered)	Debris slide with subsidence	During heavy rain fall and cloud burst after saturation of weathered material with couple of lateral cutting and toe cutting/erosion by three <i>Nala</i> coming down the hill has led the debris slide with subsidence. Main road, cultivated land and numerous houses damaged with one human death.	Retaining/breast wall, Benching of the failure surface, Proper cemented/lined drainage duct system along road side for runoff surface water, Resettlement of affected house away from slide zone.
318	78°6'00" 31°4'20" 53I/4	30-40	40	Foliated gneiss	14 year old slide rock fall	During heavy rain fall and cloud burst 2-3 m diameter rock boulders had fallen up to road and into habitation. Kiyari/ garden, property damaged.	Remove the loose boulders and overhang material.
319	78°5'40" 31°4'40" 53I/4	30	6-8	Gneiss	Rock cum debris fall	Due to toe cutting it has moved along joints plane with overburden.	Remove the loose falling and overhang material.
320	78°5'35" 31°4'35" 53I/4	13	12	Gneiss	Rock cum debris fall	Due to toe cutting material has moved along joints plane with overburden Pine tree may fall.	Remove the loose falling and overhang material.
321	78°11'50" 31°5'50" 53I/4	75-100	40	Quartz-mica schist (highly weathered)	Rock slide and adjacent debris fall	Movement along joints plane and bedding joint, Numerous tree roots are exposed and may fall during rainy season.	Remove the loose falling and overhang material, Mesh wire has to form to protect from further slide.
322	78°11'5" 31°6'15" 53I/4	25	20	Quartz-mica schist (highly weathered)	Debris fall	Movement along joints plane and bedding joint.	Remove the loose falling and overhang material, Mesh wire crates has to form to protect from further slide.
323	78°12'20" 31°6'25" 53I/4	30	25	Quartz-mica schist (highly weathered)	Debris fall	Movement along joints plane and bedding joint.	Remove the loose falling and overhang material, mesh wire crates has to form to protect from further slide.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
324	78° 13' 15" 31° 6' 40" 53I/4	20	20	Quartz-mica schist (highly weathered and jointed)	Debris cum rock fall	Movement along joints plane and bedding joint, About ½ km stretch is very prone to slide because of two flowing <i>Nala</i> and 2-3 minor drainage coming down and passing to this stretch.	Remove the loose falling and overhang material, mesh wire crates/retaining wall has to construct for protecting from further slide.
325	78° 13' 25" 31° 6' 50" 53I/4	20	10	Quartz-mica schist (highly weathered)	Slump type movement in soil	Due to high saturation, about 2.0 km stretch is very prone to this type of Slump movement.	2-4 m high retaining wall is required along road at road/toe level.
326	78° 13' 45" 31° 6' 45" 53I/4	150	150-500	Quartz-mica schist (highly weathered)	Debris fall with slump	During heavy rain fall after saturation of weathered material with couple of lateral cutting by three <i>Nala</i> it has led to debris flood on road. Main road damaged cultivated land and houses affected.	Retaining/Breast wall on the failure surface at the toe. Proper cemented/ lined drainage system along road side and lateral side <i>Nala</i> for proper runoff of surface water.
327	78° 9' 30" 31° 4' 30" 53I/4	1000	20-500	Quartz-mica schist, jointed quartzite	Rock cum debris slide facing	Activation of slide due to movement along the foliation dip, bedding joint plane and toe erosion during high flood of Phufraila and adjacent <i>Nala</i> . Main road, cultivated land and habitation damaged.	Retaining/Breast wall on the failure surface and mesh wire support on <i>Nala</i> to protect boulder movement.
328	78° 12' 10" 31° 3' 45" 53I/4	900	1200-1500	Jointed quartzite with basic body	Rock cum debris slide	Activation of slide due to movement along the bedding dip, bedding joint plane and toe erosion during high flood of Phufraila and adjacent <i>Nala</i> . Main road damaged.	Retaining/Breast wall on the failure surface at the toe and mesh wire support on <i>Nala</i> to protect boulder movement.
329	78° 12' 20" 31° 4' 00" 53I/4	100	400	Jointed quartzite with thick overburden	Debris slide	During heavy rain fall after saturation of weathered material with couple of high angle slope it has led to debris fall. Main road/trekking route damaged.	Flattening of high angle slope upto low stable angle. Remove the loose slide material. Retaining/breast wall on the failure surface.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
330	78°12'10" 31°4'15" 53I/4	200	150	Jointed quartzite with thick overburden	Debris slide	During heavy rain fall after saturation of weathered material it has led to debris fall.	Remove the loose slide material. Retaining/breast wall on the failure surface at road/toe level.
331	78°13'00" 31°4'00" 53I/4	60	200	Jointed quartzite with thick overburden	Rock cum debris slide	During heavy rain fall after saturation of weathered material jointed rock has led with debris fall. Trekking route damaged.	Remove the loose slide material. Retaining/breast wall on the failure surface at the toe.
332	78°14'00" 31°4'15" 53I/4	150	100-400	Jointed quartzite with overburden	Rock cum debris slide	During heavy rain fall jointed dipping strata has slide along the bedding and joint plane. Main Trekking route/road and concrete masonry bridge damaged.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
333	78°14'20" 31°4'15" 53I/4	1000-1200	100-200	Quartz-mica schist (highly weathered)	Debris slide	During heavy rain fall after saturation of weathered material it has led with debris fall.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
334	78°14'30" 31°4'30" 53I/4	20	10	Quartz-mica schist (highly weathered)	Debris slide	During heavy rain fall after saturation of weathered material it has led with debris fall. Trekking route damaged.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
335	78°14'15" 31°4'35" 53I/4	20	10	Quartz-mica schist (highly weathered)	Debris slide	During heavy rain fall after saturation of weathered material it has led with debris fall. Main road/trekking route damaged.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
336	78°16'15" 31°5'05" 53I/8	150	20-30	Gneiss and schist with old terrace deposits	Failure of old terrace deposits	During heavy rain high flood of water with couple of lateral/toe cutting of <i>Nala</i> has led to movement. Main Trekking route and concrete bridge damaged.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
337	78°17'00" 31°5'35" 53I/8	25	30-40	Gneiss and schist (highly weathered)	Rock slide facing -NNW	During heavy rain fall jointed dipping strata has slid along the bedding and joint plane.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
338	78°17'00" 31°5'30" 53I/8	15	25	Gneiss and schist (highly weathered)	Debris slide facing - NNW	During heavy rain fall after saturation of weathered material it has led to debris fall.	Remove the loose slide material. Retaining/breast wall along the failure surface at road/toe level.
339	78°18'15" 31°6'15" 53I/8	100	100-250	Gneiss and schist (highly weathered)	Rock cum debris slide	During heavy rain fall after saturation of weathered material with couple of lateral/toe cutting of <i>Nala</i> it has led to debris slide. Numerous Pine tree have fallen. Main Trekking route/road damage.	Retaining/breast wall on the failure surface at road/toe level.
340	78°18'20" 31°6'15" 53I/8	200	100-200	Gneiss and schist (highly weathered)	Rock cum debris slide	During heavy rain fall after saturation of weathered material with couple of lateral/toe cutting of <i>Nala</i> it has led to debris slide. Main Trekking route damage.	Retaining/breast wall on the failure surface at road/toe level.
341	78°19'00" 31°6'15" 53I/8	800-1000	100-150	Gneiss and schist (highly weathered)	A major incidence of Debris slide	During heavy rain fall after saturation of weathered material with couple of lateral/toe cutting of Murar <i>Gad</i> and Tons river it has led to debris slide. Main Trekking route/road, cultivated land and 20 houses damage.	Retaining/breast wall on the failure surface at road/toe level. Proper cemented/ lined drainage system along road side and lateral side of Murar <i>Gad</i> for proper runoff of surface water.
342	78°20'25" 31°6'45" 53I/8	45-50	35	Gneiss (highly weathered)	Debris slide	Heavy rainfall has led to debris fall. Exposed roots are indicating again instability condition and prone to debris slide.	Retaining wall along the failure surface at road/toe level that has already given.
343	78°20'35" 31°7'00" 53I/8	45	35	Gneiss (highly weathered)	Debris slide	During heavy rainfall after saturation of weathered material it has led to debris fall. Rupture surface indicating again instability condition slide.	Retaining wall along the failure surface at road/toe level has already done.
344	78°20'45" 31°7'00" 53I/8	150	120-150	Gneiss (highly weathered)	Debris slide	During heavy rain fall after saturation of weathered material along water fall <i>Nala</i> it has led to debris fall.	Retaining wall along the failure surface at road/toe level has already given.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
345	78°22'05" 31°7'25" 53I/8	500-600	150-200	Gneiss (highly weathered)	Debris slide	During heavy rain fall after saturation of weathered material has led to debris fall. Numerous Pine tree have fallen into the river.	Retaining wall along the failure surface at road/toe level has already given.
346	78°22'30" 31°7'50" 53I/8	20-25	30-35	Gneiss (highly weathered)	Debris slide	Activation of Debris slide has taken place due to toe erosion/cutting during high flood of <i>Nala</i> .	Retaining wall/training along the failure surface at road/toe level have already given.
347	78°22'35" 31°7'45" 53 I/8	20	30	Gneiss (highly weathered)	Debris slide	Activation of Debris slide along <i>Nala</i> due to toe erosion during high flood of <i>Nala</i> .	Retaining/training wall along the failure surface at road/toe level has already given.
348	78°25'15" 31°7'40" 53I/8	100-200	150-300	Gneiss (highly weathered)	Debris slide	During heavy rain fall after saturation of overburden material of slope wash it has led with debris fall.	Remove loose slided material.
349	78°25'15" 31°7'40" 53I/8	100-120	150	Gneiss (highly weathered)	Debris slide	During heavy rain fall after saturation of overburden material of slope wash it has led with debris fall.	Remove loose slide material.
350	78°11'15" 31°4'50" 53I/4	60	10	Jointed quartzite	Debris slide	During heavy rain fall after saturation of overburden material of slope wash it has led with debris fall.	Remove the loose slide material.
351	78°11'15" 31°4'50" 53I/4	20	20	Quartz-mica schist, jointed quartzite	Rock-cum debris slide	During heavy rain fall jointed dipping strata has slide along the bedding and joint plane. Main road damaged.	Remove the loose slided and overhang material. Retaining/breast wall on the failure surface at road/toe level.
352	77°50'15" 30°55'10" 53F/13	30	40	Old terrace deposits	Terrace failure	During rain fall deposits boulders loosed their matrix support and fallen/flooded on road.	Retaining/breast wall along the failure surface at road/toe level.
353	77°49'50" 30°53'15" 53F/13	100	20-40	Old terrace deposits	Terrace failure	During rain fall deposits boulders loosed their matrix support and fallen/flooded on road.	Retaining/breast wall along the failure surface at road/toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
354	77°49'00" 30°52'10" 53F/13	20-25	25-35	Phyllite/ mud stone	Talus-scrree fall	Anthropogenic. Due to disturbance by slope cutting for road widening.	Remove the loose slided material lying on road. Retaining wall along the failure surface at road/toe level.
355	77°49'00" 30°52'10" 53F/13	20	40	Phyllite/ mud stone	Talus-scrree fall	Anthropogenic. Due to disturbance by slope cutting for road widening.	Remove the loose slided material lying on road. Retaining wall along the failure surface at road/toe level.
356	77°48'45" 30°50'40" 53F/13	300-500	50-100	Highly shattered quartzite phyllite	Talus-scrree fall	Anthropogenic. Due to disturbance by slope cutting for road widening.	Remove the loose slided material. Retaining wall along the failure surface at road/toe level.
357	77°46'50" 30°50'15" 53F/13	90-100	50-80	Jointed quartzite with overburden	Talus-scrree fall	Anthropogenic. Due to disturbance by slope cutting for road widening.	Remove the loose slided material. Retaining wall along the failure surface at road/toe level.
358	77°50'05" 30°57'30" 53F/13	30	18-20	Jointed quartzite	Rock slide	Rock material has moved along joint plane.	Remove the loose slided material. Retaining wall along the failure surface at road/toe level.
Area: around Dwarahat and Chaukhutiya, Ranganga basin, Chamoli and Almora districts, Uttarakhand							
359	29°47'47" 79°27'22" 53O/5	7	45	Weathered basic rock	Rock slide	Toe cutting by 1st order <i>Nala</i> .	Easing of slope and removal of overhangs and distressed mass.
360	29°46'42" 79°28'29" 53O/5	30	15	Weathered basic rock	Rock cum debris slide	Toe, due to road cutting.	Retaining wall at the toe.
361	29°46'57" 79°31'09" 53O/9	20	15	Weathered gneiss	Rock slide	Toe, due to road cutting.	Retaining wall at the toe.
362	29°50'40" 79°22'50" 53O/5	15	40	Weathered schist	Rock fall	Toe, due to road cutting.	Retaining wall at the toe.
363	29°46'40" 79°26'18" 53O/5	50	40	Weathered basic rock	Rock cum debris slide	Toe, due to road cutting.	Retaining wall at the toe.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
364	29°49'04" 79°22'08" 53O/5	50	60	Weathered schist	Rock cum debris slide	Toe, due to road cutting and gully erosion by <i>Nala</i> .	Retaining wall and accumulation ditch at the toe.
365	29°49'04" 79°21'58" 53O/5	100	80	Schistose rock	Rock slide	Toe removal due to road cutting.	Removal of overhangs and rock bolting.
Area: around Gairsen - Chaukhutiya area, Ranganga basin, Almora and Chamoli districts, Uttarakhand							
366	29°58'46" 79°17'39"	20	50	Gneisses, schist	Rock slide	Anthropogenic, due to construction of road.	-
367	29°59'26" 79°19'20"	10	30	Gneisses, schist	Debris slide and rock slide	Anthropogenic, due to construction of road.	-
368	29°58'16" 79°20'00"	20	85	Phyllite, quartzite	Planar failure	Anthropogenic, due to construction of road.	-
369	30°3'45" 79°17'40"	15	40	Terrace Material	Debris slide	Anthropogenic, due to construction of road.	-
370	30°03'10" 79°17'50"	20	40	Fluvio-glacial terrace	Debris slide	Anthropogenic, due to construction of road.	-
371	29°58'10" 79°25'55"	70	200	Debris flow	Debris flow	Cloud burst.	-
372	29°58'10" 79°25'30"	20	45	Debris material	Debris slide	Road cutting.	-
373	29°58'15" 79°15'35"	40	90	Debris material cum rocks	Debris cum planar	Due to <i>Nala</i> cutting.	-
Area: Ranikhet - Manila- Bhatronjkan - Bhikyasen area, Chamoli and Almora districts, Ranganga Basin, Uttarakhand							
374	29°42'10" 79°20'15" 53O/6	60	150	Gneisses, schist	Debris slide	River under cutting.	-
375	29°35'45" 79°16'50" 53O/6	30	70	Gneisses, schist	Debris slide and rock slide	Anthropogenic, due to construction of road.	-
376	29°35'50" 79°16'52" 53O/6	10	40	Phyllite, quartzite	Planar failure	Anthropogenic, due to construction of road.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
377	29°36'10" 79°17'40" 53O/6	30	60	Terrace Material	Debris slide	Anthropogenic, due to construction of road.	-
378	29°37'30" 79°18'20" 53O/6	30	60	Schist and gneisses	Planar failure	Anthropogenic, due to construction of road.	-
379	29°37'10" 79°18'50" 53O/6	15	100	Debris flow	Debris flow	Anthropogenic, due to construction of road.	-
380	29°39'10" 79°18'30"	20	70	Quartzite, Phyllite	Wedge failure	Road cutting.	-
381	29°39'11" 79°15'05" 53O/6	10	60	Phyllite	Wedge failure	Due to <i>Nala</i> cutting.	-
382	29°40'50" 79°16'50" 53O/6	30	50	Phyllite/ quartzite	Wedge failure	Anthropogenic, due to construction of road.	-
383	29°42'10" 79°16'25" 53O/6	25	60	Phyllite	Debris slide	Anthropogenic, due to construction of road.	-
384	29°42'15" 79°16'55" 53O/6	25	50	Phyllite, schist	Debris slide	Anthropogenic, due to construction of road.	-
385	29°37'00" 79°16'05" 53O/6	30	60	Phyllite/ quartzite	Debris slide	Anthropogenic, due to construction of road.	-
386	29°35'50" 79°16'50" 53O/6	20	35	Phyllite/ quartzite	Wedge failure	Anthropogenic, due to construction of road.	-
387	29°35'50" 79°16'58" 53O/6	20	50	Phyllite/ quartzite	Planar failure	Anthropogenic, due to construction of road.	-
388	29°37'50" 79°16'55"	30	70	Phyllite/ quartzite	Planar failure	<i>Nala</i> cutting.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
389	29°42'45" 79°15'55" 53O/6	25	45	Phyllite	Debris slide	Anthropogenic.	-
390	29°42'00" 79°20'00" 53O/6	30	45	Phyllite, quartzite	Planar failure	Anthropogenic.	-
391	29°43'30" 79°29'50" 53O/6	50	70	Quartzite	Planar failure	Nala cutting.	-
392	29°4'05" 9°21'05" 53O/6	30	60	Quartzite/ phyllite	Debris slide	Anthropogenic.	-
393	29°35'45" 79°12'50" 53O/6	100	200	Quartzite/ phyllite	Debris slide	Anthropogenic.	-
394	29°33'10" 79°02'30" 53O/6	50	100	Sandstone	Debris slide	Nala cutting.	-
Area: Marchula-Nainidanda-Maulikhal-Manila-Harda-Nagchula, Chamoli, Nainital and Almora Districts, Uttarakhand							
395	79°7'45" 29°38'00" 53O/2	100	40	-	Debris slide	Anthropogenic- due to toe cutting after widening of road.	Flattening/moderation of slope upto low /stable angle.
396	79°9'00" 29°13'45" 53O/2	20	10	-	Debris slide	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
397	79°9'00" 29°43'20" 53O/2	10	8	-	Debris slide	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
398	79°6'00" 29°37'00" 53O/2	14	18	-	Debris fall	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
399	79°6'00" 29°37'10" 53O/2	10	10	-	Debris fall	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
400	79°6'00" 29°37'30" 53O/2	20	10	-	Debris fall	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
401	79°6'00" 29°37'15" 53O/2	10	12	-	Debris fall	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
402	79°6'00" 29°37'05" 53O/2	10	12	-	Debris fall	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
403	79°6'00" 29°37'20" 53O/2	25	15	-	Talus/scree fall	Geological cause-due to highly weathered rock with vertical slope.	Breast wall along the failure surface at toe level.
404	79°6'00" 29°37'10" 53O/2	12	10	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
405	79°6'00" 29°37'20" 53O/2	15	12	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
406	79°6'25" 29°37'20" 53O/2	15	20	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
407	79°6'25" 29°37'40" 53O/2	40	20	-	Rock cum debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
408	79°6'23" 29°37'35" 53O/2	30	40	-	Debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
409	79°6'22" 29°37'32" 53O/2	10	15	-	Debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
410	79°6'10" 29°37'05" 53O/2	100	20	-	Rock cum debris fall	Geological cause-due to percolation of excess water into joints & losing shearing resistance of rocks.	Breast wall along the failure surface at toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
411	79°6'15" 29°38'05" 53O/2	100	20	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
412	79°6'10" 29°38'00" 53O/2	40	25	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
413	79°6'05" 29°38'05" 53O/2	30	20	-	Debris fall	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
414	79°6'25" 29°38'30" 53O/2	40	15	-	Debris slide	Geological cause-due to saturation of weathered rock.	Breast wall along the failure surface at toe level.
415	79°6'15" 29°39'40" 53O/2	10	15	-	Debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
416	79°6'15" 29°39'45" 53O/2	10	10	-	Debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
417	79°5'55" 29°41'45" 53O/2	25	20	-	Debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
418	79°5'50" 29°42'00" 53O/2	30	25	-	Rock cum debris slide	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
419	79°5'55" 29°42'00" 53O/2	25	30	-	Rock cum debris slide	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
420	79°6'00" 29°42'30" 53O/2	30	15	-	Rock cum debris slide	Geological cause-due to highly weathered rock.	Breast wall along the failure surface at toe level.
421	79°5'45" 29°36'00" 53O/2	20	25	-	Rock cum debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
422	79°6'00" 29°35'45" 53O/2	60	20	-	Rock cum debris slide	Geological cause-due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
423	79°5'45" 29°35'15" 53O/2	16	12	-	Rock cum debris slide	Geological cause-sliding along bedding joint planes.	Breast wall along the failure surface at toe level.
424	79°5'45" 29°35'00" 53O/2	12	15	-	Debris slide	Due to saturation of highly weathered rock.	Remove loose material.
425	79°6'40" 29°35'00" 53O/2	40	12	-	Debris slide	Due to saturation of highly weathered rock.	Remove loose material.
426	79°7'20" 29°35'05" 53O/2	15	10	-	Rock cum debris slide	Geological cause-sliding along bedding joint planes.	Breast wall along the failure surface at toe level.
427	79°8'35" 29°35'10" 53O/2	10	25	-	Rock cum debris slide	Geological cause-sliding along bedding joint planes.	Breast wall along the failure surface at toe level.
428	79°10'00" 29°35'00" 53O/2	25	20	-	Rock cum debris slide	Geological cause-sliding along bedding joint planes.	Breast wall along the failure surface at toe level.
429	79°10'15" 29°35'20" 53O/2	20	15	-	Debris fall	Due to heavy rain.	Breast wall along the failure surface at toe level.
430	79°10'20" 29°35'30" 53O/2	25	20	-	Debris fall	Due to heavy rain.	Breast wall along the failure surface at toe level.
431	79°10'20" 29°35'50" 53O/2	50	30	-	Rock cum debris slide	Due to heavy rain material has saturated and moves along bedding plane, got failure.	Breast wall along the failure surface at toe level.
432	79°10'40" 29°35'55" 53O/2	50	60	-	Rock cum debris slide	Due to heavy rain material has saturated and moves along bedding plane, got failure.	Breast wall along the failure surface at toe level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
433	79°11'00" 29°35'00" 53O/2	12	10	-	Debris slide	Geological over saturation and Biological-penetration of tree root.	Breast wall along the failure surface at toe level.
434	79°11'05" 29°35'05" 53O/2	12	10	-	Debris fall	Due to heavy rain material has saturated and moves along bedding plane, got failure.	Breast wall along the failure surface at toe level.
435	79°11'10" 29°35'20" 53O/2	8	12	-	Rock cum debris slide	Due to sliding of overburden of slope wash material on adversely oriented bedding plane.	Breast wall along the failure surface at toe level.
436	79°11'05" 29°35'30" 53O/2	12	10	-	Debris slide	Due to sliding of overburden of slope wash material on adversely oriented joint plane.	Breast wall along the failure surface at toe level.
437	79°11'15" 29°35'30" 53O/2	15	18	-	Debris slide	Due to sliding of overburden of slope wash material on high angle steep slope.	Breast wall along the failure surface at toe level.
438	79°11'45" 29°35'30" 53O/2	100	25	-	Debris slide	Due to sliding of overburden of slope wash material on high angle steep slope.	Breast wall along the failure surface at toe level.
439	79°13'10" 29°36'45" 53O/2	200	800	-	Rock cum debris slide	Due to earthquake.	Proper lined drained catchments of runoff.
440	79°13'05" 29°41'25" 53O/2	20	30	-	Debris slide	Due to heavy rain material has saturated and moves along bedding plane, got failure.	Breast wall along the failure surface at toe level.
441	79°13'00" 29°41'25" 53O/2	40	20	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
442	79°13'15" 29°41'15" 53O/2	30	20	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
443	79°13'20" 29°41'15" 53O/2	10	15	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
444	79°13'30" 29°41'05" 53O/2	20	22	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
445	79°14'05" 29°41'15" 53O/2	30	20	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
446	79°12'45" 29°41'05" 53O/2	40	50	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure, Retaining wall damaged.	Breast wall along the failure surface at toe level.
447	79°12'30" 29°39'15" 53O/2	100	50	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
448	79°12'30" 29°39'15" 53O/2	20	25	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
449	79°12'20" 29°40'15" 53O/2	20	18	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
450	79°12'20" 29°40'30" 53O/2	15	20	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
451	79°12'05" 29°35'05" 53O/2	70	30	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
452	79°12'05" 29°35'10" 53O/2	40	25	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.
453	79°12'05" 29°36'05" 53O/2	60	50	-	Debris slide	Due to heavy rain material has saturated and moved, got failure.	Breast wall along the failure surface at toe level.
454	79°12'20" 29°36'05" 53O/2	80	25	-	Debris slide	Due to heavy rain material has saturated and moved along bedding and joint plane, got failure.	Breast wall along the failure surface at toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
455	79°9'20" 29°44'25" 53O/2	30	50	-	Debris slide	Due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
456	79°9'30" 29°44'10" 53O/2	30	20	-	Debris slide	Due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
457	79°9'45" 29°44'00" 53O/2	40	20	-	Debris slide	Due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
458	79°10'00" 29°44'00" 53O/2	150	35	-	Debris slide	Due to saturation of highly weathered rock.	Breast wall along the failure surface at toe level.
459	79°6'00" 29°36'30" 53O/2	20	50	-	Debris slide	Due to adversely orientated bedding and joint planes.	Breast wall along the failure surface at toe level.
460	79°5'45" 29°36'30" 53O/2	50	35	-	Rock cum debris slide	Due to adversely orientated bedding and joint planes.	Breast wall along the failure surface at toe level.
461	79°5'35" 29°36'45" 53O/2	40	30	-	Rock cum debris slide	Due to adversely orientated bedding and joint planes.	Breast wall along the failure surface at toe level.
462	79°5'35" 29°36'45" 53O/2	35	20	-	Terrace failure	Older alluvium as pebble/cobble loosed their matrix support and got failed.	Breast wall along the failure surface at toe level.
463	79°5'30" 29°37'15" 53O/2	50	45	-	Rock cum debris slide	-	Breast wall along the failure surface at toe level.
464	79°5'30" 29°37'20" 53O/2	50	300	-	Rock cum debris slide	Due to adversely orientated bedding and joint planes.	Breast wall along the failure surface at toe level.
465	79°5'20" 29°36'00" 53O/2	150	350	-	Rock cum debris slide	Due to poly phase deformation.	Breast wall along the failure surface at toe level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
466	79°3'30" 29°43'00" 53O/2	200	400	-	Subsidence	Subsidence due to deep toe/lateral cutting by local <i>Nala</i> , cracks have developed in houses.	Breast wall along the failure surface at toe level.
467	79°00'05" 29°40'20" 53O/2	100	800	-	Slide and subsidence	Due to adversely orientated bedding and joint planes, and deep toe/lateral cutting by <i>Nala</i> .	Breast wall along the failure surface at toe level.
468	79°00'20" 29°39'45" 53O/2	15	20	-	Rock cum debris slide	Due to adversely orientated bedding and joint planes.	Breast wall along the failure surface at toe level.
469	79°03'00" 29°40'30" 53O/2	200	300	-	Subsidence	Geological cause-surface erosion on highly weathered rock by runoff.	Breast wall along the failure surface at toe level.
470	79°04'30" 29°39'45" 53O/2	150	500	-	Subsidence	Geological cause -surface erosion on highly weathered rock by runoff.	Breast wall along the failure surface at toe level.
471	79°4'00" 29°37'45" 53O/2	12	15	-	Rock cum debris slide	Geological cause-due to highly weathered rock with vertical slope.	Breast wall along the failure surface at toe level.
Area: Joshinath, Chamoli district, Uttarakhand							
472	30°33'59" 79°33'72"	10	20	-	Debris slide	Removal of toe due to road widening.	Toe support by providing retaining structure.
473	30°31'84" 79°34'07"	200	50	-	Debris slide	Deep gully erosion.	Adequate slope draining through pipes/ Check dam.
474	30°33'39" 79°34'51"	10	30-40	Augen gneiss	Rock cum debris slide	Toe erosion/undercutting by river initiated sliding.	Toe support by providing retaining structure.
475	30°33'80" 79°34'33"	10	25	-	Debris slide	Removal of toe due to road widening.	Toe support by providing retaining structure.
476	30°34'01" 79°33'39"	5	15	-	Debris slide	Removal of toe support due to road widening, water seepage.	Retaining structure at road level.
477	30°31'59" 79°34'04"	5	10	-	Mud Flow	Removal of toe due to road widening.	Retaining structure at road level.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
478	30°32'64" 79°34'71"	25	90-100	-	Debris slide	Nala erosion.	Slope flattening and benching with provision for proper drainage design/ check dam.
479	30°32'80" 79°34'71"	5	15	Augen gneiss	Rock cum debris slide	Removal of toe due to road widening.	Retaining structure at road level.
480	30°32'33" 79°34'59"	5	15-20	-	Debris fall	Nala erosion.	Check dam/debris flow basin.
481	30°32'89" 79°34'93"	5	10	-	Debris slide	Toe erosion by Nala.	Bioengineering.
482	30°33'34" 79°32'62"	20	125	Streaky gneiss	Overhang	Old slide aggravated due to road widening.	Toe support by providing retaining structure.
Area: Kailash-Mansarovar Pilgrim route between Pithoragarh and Lipu Lekh, Pithoragarh district, Uttarakhand							
483	30°13'52" 80°55'38" 62B/16	175	60	Limestone scree	Debris slide	Old slide. Toe erosion and road cut developed the slide.	Retaining structure to contain the slide.
484	30°13'38" 80°55'07" 62B/16	150	140	Moraines with limestone boulders	Debris slide	Old slide. Toe erosion developed the slide.	-
485	30°10'58" 80°52'48" 62B/16	300	350	Moraines	Debris slide	Old slide. Toe erosion, poor strength of variegated shale.	-
486	30°10'50" 80°50'48" 62B/16	200	500	Moraines	Debris flow	Old slide. Snow/avalanche driven active slide. Napalchu village at risk.	-
487	30°10'34" 80°51'14" 62B/16	60	400	Moraines	Debris flow	Old slide. Snow/avalanche driven active slide.	-
488	30°10'29" 80°51'17" 62B/16	50	400	Moraines	Debris flow	Old slide. Snow/avalanche driven active slide.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
489	30°08'58" 80°52'16" 62B/16	70	100	Moraines	Debris slide	Recent slide. Toe erosion.	-
490	30°07'29" 80°51'29" 62B/16	500	200	Glacio lacustrine (varve)	Subsidence	Subsidence due to toe erosion. Rehabilitation of villagers made due to gradual sinking of the area.	-
491	30°00'41" 80°50'26" 62B/16	1000	400	Moraines	Debris slide	Chhiyalekh slide. Old slide. Toe erosion.	-
492	30°05'52" 80°48'57" 62B/16	150	200	Moraines	Debris slide	Old slide. Toe erosion by River Kali and gully erosion.	-
493	30°04'24" 80°47'33" 62B/16	100	100	Moraines	Debris slide	Old slide. Toe erosion cascading in river due to slide blocks.	-
494	30°03'03" 80°46'30" 62B/16	300	200	Quartzite and psammitic gneiss	Rock fall	Malpha landslide. Old slide. Rock fall due to adverse structural features, pore pressure due to rainfall. Killed over 200 people in August 1998.	-
495	30°01'03" 80°46'30" 62B/16	50	400	Augen gneiss migmatites	Rock slide	Lakhampur landslide. Rock slide due to adverse structural features. People Killed.	-
496	30°00'06" 80°44'20" 62B/16	280	120	Augen gneiss	Debris slide	Garba slide zone. Old slide. Toe erosion.	-
497	30°11'00" 80°42'23" 62B/16	400	400	Gneiss migmatite	Rock cum debris slide	Ghatiyabagar slide zone. Old slide. Toe erosion by Nala and road cut. Some slides are in terrace material.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
498	29°58'00" 80°37'48" 62C/9	250	200	Augen biotite gneiss	Rock fall	Temple Point Tintola slide zone. Old slide. Adverse joint disposition, high relief. Killed 6-7 people in 2000-01.	-
499	29°57'52" 80°36'58" 62C/9	150	280	biotite gneiss	Debris slide	Jiunti Nala slide. Old slide. Toe erosion by Nala, slide breached the bridge during July-August 2001.	-
500	29°52'00" 80°33'27" 62C/9	400	200	Phyllitic debris	Debris slide	Tapovan-Dobat slide zone. Old slide. Initiated due to road cut.	-
501	29°45'52" 80°19'28" 62C/5	250	240	Overburden boulders in micaceous clay	Debris slide	Daulkot slide zone. Old slide. Toe erosion by Nala, road section sinking.	-
Area: Kailash-Mansarovar Pilgrim route between Almora and Askot via Bajinath, Uttarakhand							
502	29°32'47" 79°31'50" 53O/10	50	250	slate	Rock slide	Highly sheared and shattered rock, steep slope and road cut overhangs developed.	-
503	29°42'45" 79°37'53" 53O/10	200	140	Gneiss with bands of mica schist	Rock cum debris slide	Toe and gully erosion by Nala.	-
504	29°50'11" 79°47'27" 53O/13	150	70	Gneiss	Rock cum debris slide	Gorkhyura slide. Toe and gully erosion by Nala.	-
505	29°49'52" 79°53'15" 53O/13	500	250	Quartzite	Rock cum debris slide	Annapurna slide. Rock fall in cliff portion due to road cut.	-
506	29°52'17" 79°46'59" 53O/13	50	25	Quartzite	Debris slide	Toe cutting by River Sarju. Ghir-di village at risk.	-
507	29°49'36" 80°07'11" 62C/1	150	20	Glacial deposit	Debris slide	Toe cutting due to road cut.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
508	29°50'35" 80°09'45" 62C/1	150	200	Sheared quartzite	Rock slide	Road section persistently gets damaged following rains. Large to small rock wedges are exposed along the road.	-
509	29°49'07" 80°14'57" 62C/1	250	100	Quartzite	Rock cum debris slide	New road cutting induced the slide.	-
510	29°29'30" 80°04'53" 53O/11,O/7	350	400	Sheared quartzite	Rock slide	Close to Ramgarh Thrust. Caused due to toe and gully erosion.	-
511	29°26'12" 79°29'45" 53O/7	1000	200	Meta volcanics	Rock slide	Steep slopes, highly jointed and sheared metavolcanics.	-
Area: Chamba district, Himachal Pradesh (top sheets: 52P/13 and 52P/14)							
512	32°45'08" 76°00'20"	120	20	Shale	Debris slide	Toe erosion of Nala.	-
513	32°46'22" 75°37'06"	80	20	Quaternary sediments	Debris slide	Anthropogenic due to construction of road.	-
514	32°47'05" 75°56'39"	100	200	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	-
515	32°47'19" 75°56'51"	60	30	Shale	Rock slide	Anthropogenic, due to construction of road.	-
516	32°50'13" 75°54'34"	50	20	Siltstone	Rock slide	Anthropogenic due to construction of road.	-
517	32°50'09" 75°54'45"	20	25	Siltstone	Rock slide	Anthropogenic due to construction of road.	-
518	32°49'59" 75°54'34"	30	20	Quaternary sediments	Debris slide	Glacial action.	-
519	32°49'19" 75°54'54"	20	50	Quaternary sediments	Debris slide	Glacial action.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
520	32°48'39" 75°55'04"	180	80	-	Debris	Gully Erosion/Toe cutting.	-
521	32°48'32" 75°55'20"	10	5	Quaternary sediments	Mud flow	Anthropogenic due to construction of road.	-
522	32°48'32" 75°55'20"	10	5	Shale	Mud flow	Anthropogenic due to construction of road.	-
523	32°47'27" 75°56'24"	50	200	Siltstone	Rock cum debris slide	Anthropogenic road cutting by River Suil.	-
524	32°46'11" 75°57'06"	80	200	Shale	Rock cum Debris	Anthropogenic due to construction of road.	-
525	32°45'34" 75°58'45"	100	50	Shale	Rock cum debris slide	Anthropogenic due to construction of road.	-
526	32°41'18" 75°59'35"	20	70	Siltstone	Debris slide	Due to excessive <i>Nala</i> .	-
527	32°50'42" 75°53'14"	25	15	Phyllite	Debris slide	Toe erosion of River Suil.	-
528	32°41'00" 75°58'45"	40	200	Phyllite	Rockslide	Anthropogenic, road cutting by River Suil.	-
529	32°41'08" 75°58'37"	40	30	Phyllite	Rock cum debris slide	Anthropogenic road cutting by River Suil.	-
530	32°41'04" 75°58'42"	40	70	Shale	Debris slide	Anthropogenic due to construction of road.	-
531	32°41'04" 75°58'45"	35	50	Shale	Debris slide	Anthropogenic due to construction of road.	-
532	32°41'22" 75°58'50"	70	20	Quartzite/Phyllite	Debris slide	Anthropogenic, contour cutting by Irrigation canal.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
533	32°41'07" 75°59'23"	100	30	Quartzite/ Phyllite	Debris slide	Anthropogenic due to construction of road.	-
534	32°41'25" 75°58'21"	35	100	Phyllite	Rock cum debris slide	Anthropogenic due to construction of road.	-
535	32°42'02" 75°58'08"	60	200	Phyllite	Rock cum debris slide	Anthropogenic due to construction of road.	-
536	32°42'09" 75°57'55"	30	50	Quartzite/ Phyllite	Debris slide	Anthropogenic due to construction of road.	-
537	32°42'04" 75°58'06"	30	60	Quartzite/ Phyllite	Debris slide	Gully Erosion.	-
538	32°42'14" 75°57'47"	40	80	Phyllite	Rock cum debris slide	Anthropogenic due to construction of road.	-
539	32°42'35" 75°58'14"	35	30	Phyllite	Debris slide	Anthropogenic due to construction of road, contour farming.	-
540	32°42'33" 75°58'36"	30	20	Phyllite	Rock cum debris slide	Anthropogenic due to construction of road.	-
541	32°42'43" 75°58'54"	40	25	Phyllite	Rockslide	Anthropogenic due to construction of road.	-
542	32°42'11" 75°59'05"	15	20	-	Debris slide	Anthropogenic due to construction of road.	-
543	32°41'39" 75°59'22"	20	15	Phyllite	Rockslide	Anthropogenic, due to road cut, failed along bedding joint.	-
544	32°40'59" 75°59'20"	80	20	Phyllite	Debris slide	Gully Erosion/toe cutting.	-
545	32°35'22" 75°59'20"	25	20	Granite	Rock cum debris slide	Reworking slide induced due to road cut.	-

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
546	32°34'43" 75°59'46"	20	100	Phyllite	Debris slide	Anthropogenic due to construction of road.	-
547	32°34'09" 75°58'54"	80	20	Phyllite	Debris slide	Toe erosion.	-
548	32°34'08" 75°58'31"	15	10	Limestone	Debris slide	Toe Erosion/gully erosion.	-
549	32°30'28" 75°56'33"	100	120	Granite gneiss	Rock slide	Anthropogenic, due to construction of road.	-
550	32°30'30" 75°56'16"	35	20	Shale	Debris slide	Anthropogenic, due to construction of road.	-
551	32°30'31" 75°56'11"	40	100	Shale	Debris slide	Anthropogenic due to construction of road.	-
552	32°30'45" 75°55'53"	20	10	Granite gneiss	Debris slide	Anthropogenic due to construction of road.	-
553	32°32'10" 75°57'49"	25	20	Quaternary sediments	Debris slide	Toe erosion of clayey material.	-
554	32°30'29" 75°53'55"	40	70	Sandstone/clay	Debris slide	Toe erosion of clay bands.	-
555	32°30'45" 75°54'45"	150-200	1000	Volcanic rock	Rock slide	Anthropogenic due to construction of road.	-
556	32°40'44" 76°00'29"	15	30	Phyllite/Quartzite	Rock slide	Anthropogenic due to construction of road.	-
557	32°41'25" 75°59'54"	150	80	Phyllite/Quartzite	Debris slide	Toe erosion.	-
Area: Chamba, Himachal Pradesh (toposheets: 52D/3 and 52D/7)							
558	32°27'30" 77°28'05"	200	300	Shale	Rock cum debris slide	Road cut and further breaking along weak planes.	Toe support by providing retaining structure.
559	32°21'30" 77°29'15"	150	200	Quaternary sediments	Rock slide	Anthropogenic, due to construction of road.	Toe support by providing retaining structure.

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Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
560	32°23'45" 76°20'50"	100	100-150	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
561	32°23'35" 76°28'50"	200	300	Shale	Rock slide	Anthropogenic due to construction of road.	Toe support by providing retaining structure.
562	32°23'30" 76°29'05"	200	250	Siltstone	Rock slide	Anthropogenic due to construction of road.	Retaining Structure.
563	32°23'10" 77°28'40"	40	40	Shale	Debris slide	Toe erosion of <i>Nala</i> .	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
564	32°23'40" 77°29'00"	50	200	Quaternary sediments	Rock slide	Anthropogenic due to construction of road.	Toe support by providing retaining structure.
565	32°25'20" 77°29'10"	100-120	40-50	-	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
566	32°26'20" 77°28'05"	20	40	Shale	Debris slide	Anthropogenic due to construction of road.	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
567	32°26'55" 77°28'15"	200	300	Siltstone	Rock cum debris slide	Anthropogenic due to construction of road.	Toe support by providing retaining structure.
568	32°27'25" 77°28'15"	80	20	Shale	Debris slide	Toe erosion of <i>Nala</i> .	Scaling to remove rock overhangs and retaining structure at the base.
569	32°27'55" 77°27'30"	200	300	Quaternary sediments	Debris slide	Anthropogenic due to construction of road.	-
570	32°27'50" 77°27'10"	200	200	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	Retaining Structure.
571	32°25'40" 77°29'15"	50	100	Shale	Debris slide	Anthropogenic due to construction of road.	-
572	32°28'20" 77°15'40"	250	100	Siltstone	Rock slide	Anthropogenic due to construction of road.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
573	32°28'35" 77°16'40"	200	100	Shale	Rock cum debris slide	Toe erosion of <i>Nala</i> .	Toe support by providing retaining structure.
574	32°29'45" 77°17'10"	400	150	Quaternary sediments	Debris slide	Anthropogenic due to construction of road.	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
575	32°29'25" 77°16'35"	150	100	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	Easing of overburden slope profile. Providing benches and boulder wall with proper drains.
576	32°28'45" 77°16'55"	100	80	Shale	Debris slide	Anthropogenic due to construction of road.	Scaling to remove rock overhangs and retaining structure at the base.
577	32°28'55" 77°17'30"	200	250-200	Siltstone	Debris slide	Anthropogenic due to construction of road.	Scaling to remove rock overhangs and retaining structure at the base.
578	32°29'05" 77°19'00"	100	50	Shale	Debris slide	Toe erosion of <i>Nala</i> .	Scaling to remove rock overhangs and retaining structure at the base.
579	32°28'55" 77°19'10"	40	150	Quaternary sediments	Rock cum debris slide	Anthropogenic due to construction of road.	Scaling to remove rock overhangs and retaining structure at the base.
580	32°27'20" 77°21'05"	20	50	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, old landslide zone.	Toe support by providing retaining structure.
581	32°26'50" 77°21'00"	500	100	Shale	Rock cum debris slide	Anthropogenic due to construction of road.	Provision of accumulation ditch at the toe. Retaining structure at road level.
582	32°28'20" 77°13'05"	50	20	Siltstone	Rock slide	Anthropogenic due to construction of road.	Provision of accumulation ditch at the toe. Retaining structure at road level.
583	32°28'10" 77°12'55"	120	20	Shale	Debris slide	Toe erosion of <i>Nala</i> .	Provision of accumulation ditch at the toe. Retaining structure at road level.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
584	32°28'30" 77°11'20"	200	300	Quaternary sediments	Debris slide	Anthropogenic due to construction of road.	-
585	32°29'10" 77°11'20"	50	100	Quaternary sediments	Debris slide	Anthropogenic due to gully erosion, Old Landslide Zone.	Toe support by providing retaining structure.
Area: Holi-Bharmaur area, Chamba district, Himachal Pradesh (toposheet: 52D/11)							
586	32°27'10" 76°32'50"	150	100	Arenite, siltstone	Rock slide	Anthropogenic due to construction of road.	-
587	32°27'15" 76°32'30"	75	50	Arenite, siltstone	Rock slide	Anthropogenic due to construction of road.	-
588	32°27'40" 76°31'05"	75	50	Arenite, siltstone	Rock slide	Anthropogenic due to construction of road.	-
589	32°28'40" 76°30'30"	200	400	Shale/slate	debris slide	Anthropogenic due to construction of road.	-
590	32°27'45" 76°30'45"	45	65	Shale and slate	Debris slide	Toe erosion of Budhil Nala.	-
591	32°28'10" 76°30'15"	40	100	Black shale/slate	Debris	Due to construction of road.	-
592	32°28'50" 76°30'45"	200	360	Shale-slate	Debris and rock slide	Due to Nala cutting.	-
593	32°33'41" 76°15'04"	500	200	Arenite, siltstone	Rock fall	Undercutting of Ravi River.	-
594	32°20'05" 76°32'30"	100	100	Arenite	Debris slide	Anthropogenic, due to construction of road.	-
595	32°20'25" 76°32'10"	100	150	Arenite/slate	Debris slide	Overburden failure due to construction of road.	-
596	32°20'50" 76°31'50"	50	75	Black shale/slate	Planar failure	Overburden failure due to Nala cutting.	-
597	32°21'40" 76°31'25"	150	70-80	Shale/slate and arenite	Planar failure slide	Toe erosion of Ravi River.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
598	32°22'30" 76°31'05"	200	100	Arenite/slate	Wedge failure	Toe cutting by Ravi River.	-
599	32°22'35" 76°30'30"	80	50	Arenite/slate	Debris slide	Toe cutting but now stable.	-
600	32°21'45" 76°30'40"	120-130	70-80	Arenite/slate	Debris slide	Toe cutting but now stable.	-
601	32°18'55" 76°34'10"	50-70	150-170	Arenite/slate	Rock failure	Toe cutting but now stable.	-
602	32°18'10" 76°34'40"	40-60	70-80	Arenite/slate	Debris slide	Toe cutting and erosion by <i>Nala</i> .	-
603	32°19'30" 76°34'45"	50-60	80-90	Arenite/ shale-slate	Debris slide	Erosion and snow action.	-
604	32°18'30" 76°35'15"	40-50	60-70	Arenite/ shale-slate	Planar failure	Wedge failure.	-
605	32°18'50" 76°36'45"	50-60	80-90	Arenite/ shale-slate	Planar failure	Wedge failure.	-
606	32°18'10" 76°35'45"	50-60	150-170	Arenite/ shale-slate	Planar failure	Wedge failure.	-
607	32°18'40" 76°36'15"	50-60	100-110	Arenite/ shale-slate	Planar failure	Wedge failure.	-
608	32°18'40" 76°36'15"	50-60	100-110	Arenite/ shale-slate	Planar failure	Wedge failure.	-
609	32°18'45" 76°36'50"	30-40	50-70	Arenite/ shale-slate	Debris slide	Toe cutting and erosion by <i>Nala</i> .	-
610	32°18'45" 76°36'50"	30-40	50-70	Arenite/ shale-slate	Debris slide	Toe cutting and erosion by <i>Nala</i> .	-
611	32°18'05" 76°37'10"	1501-60	50-70	Arenite/ shale-slate	Planar failure	Planar failure.	-
612	32°17'10" 76°38'50"	50-60	70-80	Arenite/ shale-slate	Planar failure	Due to road cutting.	-
613	32°27'50" 76°30'45"	240-250	190-200	Arenite/ shale-slate	Debris slide	Wedge failure.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
614	32°22'50" 76°32'45"	90-100	140-150	Arenite/ shale-slate	Planar failure	Planar Failure along dip slope.	-
615	32°27'55" 76°34'15"	90-100	140-150	Arenite/ shale-slate	Planar failure	Planar Failure along dip slope.	-
616	32°27'52" 76°34'17"	40-60	50-70	Arenite/ shale-slate	Debris slide	Due to <i>Nala</i> cutting.	-
617	32°27'05" 76°38'05"	40-60	70-80	Arenite/ shale-slate	Debris slide	Due to toe cutting.	-
618	700 m south of Rajindu village	15	10-15	Black shale/ slate	Rock slide	Anthropogenic due to construction of road.	-
619	400 m south of Rajindu village, Near Kakrait	500	40-60	Black shale/ slate	Debris slide	Anthropogenic due to construction of road.	-
620	300 m south of Rajindu village	20	10	Black shale/ slate	Debris slide	Anthropogenic due to construction of road.	-
621	Down side of Rajindu on the road towards village Kurtha	160	60	Black shale/ slate	Rock slide	Anthropogenic due to construction of road.	-
622	Between Khar- ga and Sindah villages	175	50-57	Black shale/ slate	Debris slide	Anthropogenic due to construction of road.	-
623	Back side of Dorgi village	20	10-15	Black shale/ slate	Rock cum debris	Anthropogenic due to construction of road.	-
624	North of Dhangram	100	40-50	Shale	Debris slide	Anthropogenic due to construction of road.	-
625	500 m south of Laga village	10	15-20	Shale	Rock slide	Anthropogenic due to construction of road.	-

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
626	750 m south of Laga village	40	20	Shale	Rock slide	Anthropogenic due to construction of road.	-
627	About one km south of Laga village	75	25-30	Shale	Debris slide	Overburden failure due to excess rain fall.	-
628	Opposite to village Mandolu	10	15-20	Black shale/slate	Debris slide	Overburden failure due to excess rain fall.	-
629	Opposite to Kiri village	80-100	70-80	Black shale/slate	Debris slide	Toe erosion by Kiri Nala.	-
630	32°11.205 76°13.148	50	70	River borne material	Debris	Due to road cutting and toe erosion by river.	Toe support by providing retaining structure.
631	32°10.106 76°15.390	50	80	Conglomerate	Debris slide	Toe erosion by river.	Retaining wall.
632	32°10.591 76°18.604	60	50	Conglomerate	Debris slide	Toe erosion by river.	Toe support by providing retaining structure.
633	32°14.252 76°08.974	20	40	Sandstone, red clay	Debris slide	Nala erosion, failure in overburden mass resting on dip slopes.	Slope flattening and benching with provision for proper drainage design. Retaining wall needed.
634	32°23.270 75°59.967	40	100	Grey shale/conglomerate	Debris slide	Severe toe erosion by river.	Toe support by providing retaining structure.
635	32°23.270 75°59.967	150	50	Boulder bed	Debris slide	Deep gully erosion.	Provision for proper drainage design.
636	32°25.249 75°58.069	30	50	Boulder conglomerate	Rock cum debris slide	Deep rill/gully erosion.	Smoothening of slope profile with retaining structure at the base and proper drainage lining.
637	32°25.335 75°57.659	10	20	Boulder conglomerate	Debris Slide	Removal of toe due to road widening.	Retaining structure at road level.
638	32°25.635 75°57.499	50	200	Boulder conglomerate/red shale	Debris slide	Deep rill/gully erosion.	Scaling to remove rock overhangs and retaining structure at the base.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
639	32°25.635 75°57.499	200	25	conglomerate/red shale	Debris slide zone	Deep rill/gully erosion.	Provision for proper drainage design. Retaining structure at road level.
640	32°27.311 75°56.242	200	25	Quartzite/shale and grey slates with clay	Rock fall zone	Failure along two sets of joints and their intersection, rocks highly shattered, aggravated due to road widening and resulted in the detachment of rock mass.	Scaling to remove rock overhangs, spot bolting of rock mass and shot crate using wire mesh.
641	32°25.635 75°57.499	50	250	Schistose gneiss	Rock cum debris slide	Removal of toe due to road widening as well as toe erosion by <i>Nala</i> cutting.	Toe support by providing retaining structure.
642	32°30.128 75°55.970	50	100	Schistose gneiss	Planar slide	Failure along two sets of joints, aggravated due to toe erosion by river.	Toe support by providing retaining structure.
643	32°30.346 75°56.376	50	150	Schistose gneiss	Planar slide	Failure along two sets of joints, aggravated due to toe erosion by river.	Toe support by providing retaining structure.
644	32°30.772 75°58.088	50	60	Schistose gneiss	Debris slide	Road cutting.	Toe support by providing retaining structure.
Area: Jammu-Katra-Batote-Ramban sector along National Highway-1A, Jammu & Kashmir							
645	33°15.35 75°12.13	80	50-60	Slate and phyllite with pebbles	Debris slide	Toe erosion/undercutting by <i>Nala</i> initiated sliding, water seepage along joint plane facilitate sliding.	Toe support by providing retaining structure.
646	33°14.70 75°13.39	500	40-60	Sandstone, siltstone and mudstone	Debris cum rock slide	Removal of toe due to road widening.	Scaling to remove rock overhangs and retaining structure at the base.
647	33°14.10 75°13.25	20	10	Slate and phyllite	Debris slide	Toe erosion/undercutting by <i>Nala</i> initiated sliding, overburden lying on steep slope.	Toe support by providing retaining structure.
648	33°14.09 75°14.75	160	60	Alternate quartzite and slate	Debris slide	Ramban slide. Valley facing joint forming critical slip plane, aggravated due to removal of toe due to road widening.	Scaling to remove rock overhangs and retaining structure at the base.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
649	33°13.55 75°15.43	100	40-50	Sandstone, siltstone and mudstone	Debris slide	Astar <i>Nala</i> slide zone. <i>Nala</i> erosion, Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris.	Slope flattening and benching, boulder pitched wall with wire crate at the road level.
650	33°14.70 75°13.39	50	40-50	Purple shale with slate	Rock cum debris	Removal of toe due to road widening, Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris	Adequate rock scaling and smoothing of slope profile with retaining structure at the base.
651	33°13.32 75°16.11	40	20	Black shale	Debris slide	Toe erosion/overburden lying on steep slope, water seepage along joint plane facilitate sliding.	Provision of accumulation ditch at the toe. Retaining structure at road level.
652	33°13.31 75°16.11	250	20-40	Alternate slate and phyllite	Debris slide	Failure in overburden mass resting on dip slopes. Removal of toe due to road widening, contains 2 slides.	Toe support by providing retaining structure.
653	33°13.48 75°15.79	100	40	Quartzite with slaty partitions	Rock slide	Failure of distressed rock mass along smooth valley facing joint, aggravated due to road widening.	Slope flattening and benching, boulder pitched wall with wire crate at the road level.
654	33°13.49 75°16.00	120	40-60	Black shale with quartzite and slate	Debris slide	<i>Nala</i> erosion, freezing and thawing action of snow and melt water resulting gully erosion of overburden mass.	Back dressing/easing of over burden slope profile near the head, benching, boulder pitched wall with wire crate at critical spots besides providing geojute cover all along the slide surface.
655	33°10.49 75°18.23	250	40-60	Quartzite and slate with basic intrusive	Rock fall	Failure along two sets of joints and their intersection, rocks highly shattered, aggravated due to road widening and resulted in the detachment of rock mass.	Scaling to remove rock overhangs, spot bolting of rock mass and shot crate using wire mesh.
656	33°13.31 75°16.11	80-100	50-70	Grey/purple phyllite	Debris slide	Removal of toe due to road widening as well as toe erosion by <i>Nala</i> cutting.	Road subsidence is clearly seen. Toe support by providing retaining structure.
657	33°10.17 75°17.90	25	20	Grey sandstone	Debris slide	Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris. Removal of toe due to road widening.	Retaining wall with provision for adequate slope draining.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
658	33°09.77 75°18.43	40	20-25	Purple clays with sandstone	Mud/ debris flow	Failure in overburden mass resting on dip slopes, due excavation for foundation of power cable tower.	Retaining wall with provision for adequate slope draining.
659	33°09.26 75°17.90	100	150	Purple clays with sandstone	Debris slide	<i>Nala</i> erosion along the stream.	Toe support by providing retaining structure with proper drainage design.
660	33°10.20 75°18.10	60-80	20-30	Overburden	Debris slide	Gullies along the <i>Nala</i> section, removal of toe due to river undercutting.	Retaining wall with provision for adequate slope draining.
661	33°09.53 75°18.39	100	30-40	Purple clay with sandstone	Rock cum debris slide	Compatibility contrast between two different lithologies aggravated by toe removal for road widening.	Toe support by providing retaining structure with proper drainage design.
662	33°08.73 75°18.29 Nashiri slide zone	500	80-120	Sandstone with inter beds of purple shale and siltstone	Debris slide	Gullies along the <i>Nala</i> section.	Easing of overburden slope profile. Providing benches and boulder wall, with properly designed weep holes.
663	33°08.38 75°18.10	80-100	40-50	Overburden	Debris slide	<i>Nala</i> erosion and aggravated due to removal of toe due to road widening activity.	Diversion of <i>Nala</i> along the road can save the road.
664	33°07.97 75°18.14	20-25	10-15	Sandstone, siltstone, clay and shale	Debris Slide	Removal of toe due to road widening activity.	Toe support by providing boulder pitched wall with wire crate at the road level.
665	33°04.98 75°19.59	20-30	15-20	Sandstone with shale and clay	Rock fall	Rock failure due to compatibility contrast, and removal of toe due to road widening activity.	Toe support by providing boulder pitched wall with wire crate at the road level.
666	33°02.81 75°17.40	50	10-15	Sandstone with shale and clay	Rock fall cum debris slide	Rock failure due to compatibility contrast, and removal of toe due to road widening activity.	Easing of overburden slope profile. Providing benches and boulder wall, with properly designed weep holes.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
667	33°01.70 75°15.90	30	15-20	Sandstone, siltstone, clay and shale	Debris slide	Gullies along the <i>Nala</i> section.	Easing of overburden slope profile. Providing benches and boulder wall, with proper drains.
668	33°01.74 75°15.48	50-60	25-30	Sandstone with shale and clay	Rock cum debris slide	Rock failure due to compatibility contrast, and removal of toe due to road widening activity.	Providing benches and boulder wall, with properly designed weep holes.
669	32°59.72 75°11.74	30-40	15	Sandstone with shale and clay	Rock slide	Rock failure due to competency contrast, and removal of toe due to road widening activity.	Providing benches and boulder wall, with properly designed weep holes.
670	32°59.36 75°11.40	80-100	20	Sandstone with shale and clay	Rock cum debris slide	Toe undercutting by river, and competency contrast between the beds of sandstone and clay.	Providing benches and boulder wall, with properly designed weep holes.
671	32°59.30 75°12.00	25-30	15-20	Overburden mass Debris slide	Gullies along the <i>Nala</i> section.	Easing of overburden slope profile.	Providing benches and boulder wall, with proper drains.
672	32°57.00 75°09.50	60-80	15-20	Sandstone with shale and clay	Rock fall	Rock failure due to competency contrast, and aggravated due to removal of toe due to road widening activity.	Easing of overburden slope profile. Providing benches and boulder wall, with proper drains.
673	32°58.74 75°59.44	20-25	10-15	Overburden mass	Debris slide	Toe erosion by river action, freezing and thawing action of snow and melt water resulting gully erosion of overburden mass.	Easing of overburden slope profile. Providing benches and boulder wall, with proper drains.
674	33°57.47 75°58.14	10-15	15-20	Overburden mass	Debris slide	Toe erosion by river action, freezing and thawing action of snow and melt water resulting gully erosion of overburden mass.	Easing of overburden slope profile. Providing benches and boulder wall, with proper drains.
675	32°53.84 74°58.00	20-25	10-12	Sandstone, siltstone, clay and shale	Debris slide	Removal of toe due to road widening activity.	Providing benches and boulder wall, with properly designed weep holes.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
676	32°53.67 74°57.84	10-15	20-25	Sandstone, siltstone, clay and shale	Debris slide	Removal of toe due to road widening activity.	Providing benches and boulder wall, with properly designed weep holes.
Area: Around Vaishnodevi, Udhampur district, Jammu & Kashmir							
677	Opp. Sham-shan Ghat on R/B of Balganga	80	50-60	Shale, siltstone and clay conglomerate	Debris fall	Toe erosion/undercutting by <i>Nala</i> initiated sliding.	Toe support by providing retaining structure.
678	Near check Post, 200 m from Darshan Jodi	200	70-80	Limestone	Debris cum rock slide	Removal of toe due to road widening.	Scaling to remove rock overhangs and retaining wall with provision for adequate slope draining.
679	At bridge, 100m from check Post on the L/B of Balganga	30	40	Crushed dolomite	Debris cum rock slide	Toe erosion/undercutting by river initiated sliding.	Toe support by providing retaining structure.
680	Near Dhaba Shiv Mandir	40	60	Limestone with pebbles	Debris slide	<i>Nala</i> erosion, Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris.	Slope flattening and benching with provision for proper drainage design.
681	Northern Railway Tunnel Site, after the bridge on the Katra-Reasi Road	20	40-50	Alternate bands of sandstone, siltstone and mudstone	Debris slide	Removal of toe due to road widening, Failure in overburden mass resting on dip slopes, rock pieces belonging to old debris.	Toe support by providing retaining structure.
682	Before the bridge on Balganga on Katra-Reasi Road	30	40-50	Alternated bands of sandstone, siltstone and mudstone	Debris slide	Removal of toe due to road widening.	Smoothing of slope profile with retaining structure at the base.

contd.

Annexure - I (contd.)

Sl. No.	Location details	Length (m)	Height (m)	Material	Slide type	Causative factors & other details	Temporary remedial measures
683	Along New track from Ardhkunwari at 6.4 Km from Darshan Jodi	40	60	Stromatolitic Limestone	Wedge Failure	Removal of toe support due to cross cut relationship of joint planes; water seepage along joint plane facilitate sliding.	Retaining structure at road level.
684	Along New track from Ardhkunwari at 6.75 Km from Darshan Jodi	50	30-40	Dolomite	Debris cum rock slide	Removal of toe due to road widening.	Retaining structure at road level.
685	Along New track from Ardhkunwari at 7 km from Darshan Jodi	40	150	Stromatolitic and Cherty Dolomite	Wedge Failure	Failure of distressed rock mass along smooth valley facing joint, aggravated due to road widening.	Scaling to remove rock overhangs and retaining structure at the base. Grouting and rock bolting of unstable blocks.
686	Along New track from Ardhkunwari at 10 km from Darshan Jodi	50	100	Dolomite	Debris cum rock slide	Valley facing joint forming critical slip plane, aggravated due to removal of toe due to road widening.	Back dressing/easing of overburden slope profile near the head, benching, boulder pitched wall with wire crate at critical spots besides providing geojute cover all along the slide surface.
687	Along New track from Ardhkunwari at 10.125 km from Darshan Jodi Shooting stone site	30	90-100	Sheared dolomite	Rock fall	Failure along two sets of joints and their intersection, rocks highly shattered, aggravated due to road widening and resulted in the detachment of rock mass.	Scaling to remove rock overhangs, spot bolting of rock mass and shot crate using wire mesh.
688	At Bhavan besides Laxmi complex	40	150-200	Limestone and Dolomite	Planar slide	Removal of toe due to road widening as well as toe erosion by <i>Nala</i> cutting.	Toe support by providing retaining structure.
689	At Purana-kot near Stiar Dhaba	15	30	Stromatolitic Limestone	Debris cum rock slide	Failure along two sets of joints; aggravated due to road widening.	Toe support by providing retaining structure.

contd.

Uttarakhand Disaster 2013: Preliminary and detailed post-disaster geological investigations and landslide inventory

A: 1st Note on Reconnaissance Geological Assessment of Mandakini and Alaknanda Valleys of Uttarakhand after the disaster of 15-17 June 2013 (Geological survey of India, SU: Uttarakhand, Dehradun)

Introduction

As a follow up to the letter from Joint secretary, Ministry of Mines, Govt. of India, the Dy. Director General, Mission IV-A formed a team of officers from Dehradun, Lucknow, Chandigarh and Jammu offices of GSI, NR to take up the preliminary assessment of the areas affected by recent floods/cloud burst in different parts of Uttarakhand of 15th - 17th June 2013. Two teams consisting of 5 officers from Uttarakhand Unit, GSI, Dehradun were immediately rushed to take up the work along Mandakini and Alaknanda valleys. The assessment along Mandakini valley was undertaken by S/shri S. K. Tripathi, Suptdg. Geologist (Nodal Officer), P. V. S. Rawat, Suptdg. Geologist and Harish Bahuguna, Senior Geologist whereas the assessment along Alaknanda Valley was done by Bhupendra Singh, Senior Geologist and A. P. Thapliyal, Geologist.

Background Information

The hills of Uttarakhand witnessed heavy to very heavy rainfall between 15th and 17th of June 2013 affecting Uttarkashi, Tehri, Pauri, Rudrapur and Chamoli districts of Garhwal region and Bageshwar, Almora and Pithoragarh districts of Kumaon region. Following the incessant and very heavy rain fall, the major rivers like Bhagirathi, Asiganga, Alaknanda, Mandakini, Dhauliganga, the Ganges and Kali rivers swelled monstrously and swept away many villages and townships along their valleys. The worst affected areas in the Garhwal region are the Kedarnath, Rambara, Gaurikund Sonprayag, Agastmuni, Vijaynagar, Chandrapuri, Silli, Tilaknagar, Sumari, and Tilwara in Mandakini valley; Hanuman Chatti, Lambagar, Govindghat, Birahi, Kamra and Srinagar in Alaknanda valley and Harshil, Bhatwari, Gangori and Uttarkashi in Bhagirathi valley. The tragedy struck at Kedarnath, Rambara and Gaurikund and thousands of people were swept away, buried under the buildings or have perished for other reasons. The local administration and the Government is yet to come out with the final tally of

missing and dead people.

Observations

In Mandakini valley traverses were taken along Guptkashi – Kund, Guptkashi – Kalimath, and Guptkashi – Sonprayag sections. The areas covered for collecting data for preparing landslide inventory include Tilaknagar, Nalupani, Tilwara, Sumari, Guptkashi, Semi village, Kalimath, Khat, Phata, Barasu, Rampur, Sitapur and Sonprayag (Beyond which NH is not connected).

- At a number of locations fresh landslides have been triggered mostly due to toe erosion by the swollen mighty rivers. The landslides have severally disrupted the road alignments, both the National Highways and State Highways. The supply of essentials like ration, kerosene, milk and medicines etc has been hampered which is adding to the woes of local people.
- Several bridges (suspension and steel girder) have been washed away by the rivers and a number of remote villages have been cut-off from the Tehsil and District headquarters.
- Landslides have also damaged the means of communication like telephone lines etc.
- A number of helipads have also been badly damaged particularly in Mandakini and Alaknanda valleys which are also affecting the relief works.
- The massive floods have also damaged few of the commissioned and under construction hydro power projects like Barrage of Vishnuigad Project (IC 400 MW) in Alaknanda, barrage of Phat- Byung Project (IC 76MW) and barrage and powerhouse area of Singoli – Bhatwari Project in Mandakini valley.
- The heavy silt load in the swollen rivers forced a shutdown to many of the running power projects like Maneri stage – I (IC 90 MW) and Maneri Stage – II (IC 304 MW) in Bhagirathi valley.
- The holy Gurudwara at Govindghat, a sacred place for Sikh Pilgrims has been totally damaged because of toe erosion by Alaknanda river. The 14 Km foot track between Govindghat and Shri Hemkund Sahib (Holy

Shrine of Sikhs) was damaged at a number of locations which left thousands of Sikh Pilgrims stranded between Govindghat and Hemkund Sahib.

- At Kamera, 3 km downstream of Karnaprayag (Alaknanda valley) a new sinking zone has developed which has damaged the NH-58.

Assessment

- The very heavy and incessant rains between 15th and 17th June 2013 resulted in exceptionally high rise in the river discharges. The rise in the river level was of the order of 5 – 7 m where the valley was wide and 10 – 12 m where the valley was narrow.
- In the upper stretches of Mandakini, the stream gradient is high and valley profile is mostly narrow. The gush of water running down from Kedarnath and Rambara areas brought mammoth sediment load which consisted huge rock boulders 3 – 10 m in longest diameter. The heavy sediment load along with big boulders acted as tools of destruction and took away everything coming in their way.
- The heavy volume of water induced toe erosion along all the river valleys which in turn triggered landslides at a number of places.
- Preliminary assessment reveals that slope failures in overburden/RBM are more as compared to those in rocks. Even in composite slides the rock failure/fall has been preceded by fall in overburden.
- The damage to the national highways is more where the alignment is closer to the river bed level. The areas badly affected by floods like Sonprayag, Vijaynagar, Chandrapuri, Silli, Agastmuni etc. are located either on T-1 level terrace or on the outer margins of T-2 terrace. In some cases some of the structures were at T-0 level. These are the areas where maximum damage to the houses and property has been reported.

Tentative Scheme of the Proposed Detailed Geological Studies in Uttarakhand

- Slope stability studies and landslide incidence detailing along State and National highways are to be carried out with main focus on the remedial measures and also along the new alignment proposals, as a part of

'Reconstruction Efforts of the State Govt'.

- Extent of damage in the villages and areas in the close vicinity of the river banks. It is to be decided whether the villages may be stabilized by providing remedial measures or they need to be relocated elsewhere. Proper geological studies on appropriate scale will be required to suggest stable areas for relocation/rehabilitation in consultation with natives and district officials. This is a time consuming mammoth task requiring proper planning and manpower deployment and it should be taken separately from the assignment of assessing the stability along the National Highways and State Highways.
- Approximate length of national and state highways, no. of toposheets particularly 4-5 districts and approx. area to be covered (In km² or m²) will constitute important inputs after the preliminary assessment is over, hopefully by the end of July.
- Whether the geological studies should be outlined w.r.t. to national/state highways or river valleys or district boundaries- this needs to be well mooted and clarified before formulating the FSP programme (for at least three field- seasons). Thereafter, a standard GSI-publication compiling the entire field data may be contemplated. Publishing piecemeal/incomplete observations may be avoided. However, brief notes/letters of advisory nature may be issued to the State Govt./BRO/PWD officials, as and when required, by the Unit Incharge/Nodal officer without many procedural / hierarchical obstructions.
- In order to accord highest priority to the proposed studies (post Uttarakhand Disaster) all other GSI items/RFD items (excluding MoU based engineering geological items) pertaining to Uttarakhand Unit should be suspended with immediate effect.
- As far as deputing a nodal officer for each affected district is concerned, the state government has already deputed one geologist for each district and they are reporting to the Dy. Director, Geology and Mining Unit (GMU)/Director, Dept. of Industries, Govt of Uttarakhand.
- Once the proposed geological studies and the time frames are properly outlined, the issues like manpower deployment (formation and mandate of teams), the

logistics and expenditure involved may be thoroughly deliberated and specified.

- To take up investigations/studies as elaborated above, the GSI Unit at Dehradun is in dire need of man power i.e. 8 – 10 young field going officers with some background of landslide hazard investigations. At present, the permanent strength at Dehradun comprises two Suptg Geologists (presently working as project supervisors, HOO as well as field officers), two Senior Geologists and one Geologist. Out of this, one senior geologist is likely to be promoted very soon as Suptg Geologist. Further, the unit has only two regular drivers (one of them is seriously ill and cannot do long and strenuous field duties) and two contract drivers (ex-GSI) for local duties. Hence, road worthy vehicles along with regular drivers is another important prerequisite to take up this huge assignment.

Aerial survey of Satopath Glaciers and surrounding areas, Chamoli District, Uttarakhand

NRSC had reported from remote sensing studies that a big-sized lake is formed as an aftermath of Uttarakhand event on 15th-17th June 2013. A team comprising of GSI, Wadia Institute of Himalayan Geology and Indian Army made an aerial survey on 13th July 2013 and observed that the water body as shown by NRSC in satellite imagery is perhaps a thick pile of morainic deposits as clearly observed from a flight 5000 feet above ground and the existence of any reported water body is negated by the visiting experts.

B: Status Note submitted by DG, GSI to the Ministry of Mines, Government of India on GSI's immediate initiatives in the Uttarakhand disaster 2013.

Introduction

On 16th and 17th June, 2013, due to excessive rains and cloud burst in higher reaches of Uttarakhand, flash floods and landslides have caused heavy and unprecedented destruction to villages, property, infrastructure and loss of life. Kedarnath shrine and Mandakini valley is one of the worst hit areas where massive relief and rescue operations are underway. The satellite imageries published in the newspapers indicate that perhaps due to cloud burst the loose

morainic deposits from the upstream of Kedarnath valley got remobilized and inundated the whole area including the temple complex and also wreaked havoc further downstream in Rambara, Guptakashi and Gaurikund where thousands of pilgrims were stationed. The possibilities of a lake breach in the upstream area (Chorabari or Gandhinagar Lake) cannot be ruled out at the moment. However, this may be confirmed only after extensive ground check. The death toll is massive and unprecedented in the history of Uttarakhand religious tourism.

GSI Initiatives

1. Following initiative from Shri Durga Shanker Mishra, Jt. Secretary, Ministry of Mines, Govt. of India, vide his letter dated on 26.06.2013, GSI, CHQ has constituted a ten member team under the control of NR, with Shri S. K. Tripathi, Superintending Geologist as Nodal Officer, to conduct a preliminary geological assessment of the accessible areas and roads, in cooperation and coordination with the State Govt.
2. Shri S. K. Tripathi, Superintending Geologist, the Nodal Officer attended meetings with the Chief Secretary and other senior officers of the Govt of Uttarakhand and briefed the senior officers of GSI through letters. The Nodal Officer also attended a meeting with the Chief Minister, Uttarakhand on 03.07.2013 and appraised the studies to be taken up by the GSI in the devastated areas of the state. It is reported that the GSI has been requested to take up necessary studies and to suggest remedial measures, especially towards identifying stable areas for relocation of people and in realigning the roadways.
3. The Dy. Director General (PSS-P&M) has ascertained that the GSI to take up the assignment immediately. Considering the extent and importance of this national calamity, it is suggested that the officers of Engineering/Landslide Divisions of all State Units of Northern Region should join in the post-disaster geological studies. Further, Shri Tripathi has been advised to act as Liaison Officer for all transactions and requested to be in touch with the State Administration for coordinating the works.
4. In this regard, it is requested that the team may focus their study in preparation of inventory of recent

landslide incidences and to suggest immediate corrective measures. The team is also requested to submit a preliminary report by the end of July, 2013 and subsequently final report by the end of September, 2013. Based on the studies, further programmes may be launched in the area for further detailed evaluation and to work out long term corrective measures.

5. As mandated by the Ministry of Mines and NDMA and

to document the change-detection of events in the affected areas by studying the high-resolution imageries of Pre- and Post- event scenarios. This exercise seems to be very much useful in delineating unstable zones, effectively suggesting suitable and safer areas for relocation of habitation, identifying further areas of imminent vulnerability, understanding the causes and track of the events etc. These will also aid in carrying out detailed field investigations and ground truth surveys. It is opined that the above endeavours

1. Shri S. K. Tripathi	Supdt. Geologist	SU: UP & UK, Dehradun.
2. Shri P.V.S. Rawat	Senior Geologist	SU: UP&UK, Dehradun.
3. Shri Harish Bahuguna	Senior Geologist	SU: UP&UK, Dehradun.
4. Shri Bhupendra Singh	Senior Geologist	SU: UP&UK, Dehradun.
5. Shri A.P. Thapliyal	Geologist	SU: UP&UK, Dehradun.
6. Shri D.P. Dongwal	Geologist	SU: Punjab & H.P., Chandigarh.
7. Shri K. Lakshmanan	Geologist	SU: Punjab & H.P., Chandigarh.
8. Shri Ajai Kumar	Geologist	SU: J&K, Jammu.
9. Ms. Jyoti Dubey	Senior Geologist	E.G. Div. SU: UP & UK, Lucknow.
10. Ms. Neetu Chauhan	Geologist	E.G. Div. SU: UP & UK, Lucknow.

as per the requests received from Uttarakhand Government, GSI field parties have proceeded to the site on 8th of July 2013 for collecting onsite information on i) landslide inventory data, ii) identifying suitable and safer areas for immediate relocation of villages including safer routes for public to escape in the event of similar disaster, iii) identifying vulnerable / unstable slopes that requires immediate attention to contain future failures in current monsoon, and, iv) suggesting short-term remedial measures to protect the affected slopes etc.

6. Accordingly, it is reported as on 09.07.2013, two teams have left Dehradun on 08.07.2013. The first team (consisting of three Geoscientists) has reached Guptkashi and they will work in Kedarnath area (Mandakini Valley). The second team (consisting of two Geoscientists) has reached Bishwapriya and they will work in Badrinath area (Alakananda Valley). The third team (comprising five members including two lady Geoscientists) will leave Dehradun on 15.07.2013.

Proposal for collaborative study with NRSC

It is learned from some of the uploaded maps of NRSC's "Bhuvan" portal that they have initiated work in this regard

of GSI could successfully be accomplished if a suitable pre- and post- event map documenting the change-detection of this large disastrous event is made available to the field geologists. Under these circumstances, an attempt has been made to collaborate with NRSC for a joint study in this regard. The proposal is NRSC to extend help and support in providing relevant soft copies, ortho rectified imageries in digital format to be processed in GIS environment jointly by NRSC and GSI.

Public Accounts Committee (2013-2014)

The meeting was attended by GSI on 1st July, 2013, wherein the Committee discussed the Disaster Preparedness in India based on CAG Report No. 5 of 2013. During the meeting, one of the Members of the PAC informed that there is a report that GSI has carried out extensive studies at Kedarnath Township and indicated the vulnerability of the township. Following that, the Chairman, PAC directed that GSI to submit a report on the issue within a week's time. Accordingly, the following points were submitted to the MoM and for onward transmission to the PAC. GSI carried out geological studies at Kedarnath and its surrounding areas during Field Seasons 1991-92, 1992-93 and 1993-94 and prepared/ submitted a report entitled "Report on integrated ice, snow avalanche and Quaternary Glaciological studies in

Mandakini valley around Kedarnath, District Chamoli, Uttar Pradesh” by Deepak Srivastava, S. Swaroop, S.P. Shukla and B.P. Mukherjee. Pradesh” by Deepak Srivastava, S. Swaroop, S.P. Shukla and B.P. Mukherjee.

Salient recommendations made in the report are as under:

The terraces between Kedarnath temple and downstream upto Lenchuri village on the left side of the valley can be developed for further expansion of Kedarnath Township. Bunding should be constructed on the right side of the Kedarnath temple, along the Mandakini river to check the toe erosion of the terrace. Though the study is as per GSI's Annual Programme, but since it pertains to Kedarnath

Shrine, the report was also submitted to Kedarnath Temple authorities. However, the follow up action for the last two decades is not known. GSI being an agency for carrying out geoscientific investigations recommends corrective measures for stabilization. The stakeholders, in present case, the Temple authorities and the State of Uttarakhand have the responsibility of implementing the recommended corrective measures. In case of necessity while constructing remedial structures for any more specific details, GSI forwards its expertise to the implementing agency at specific request. For further geo-scientific investigations, if required, State Govts present the requirements in the State Geological Programming Board and Central Geological Programming Board meetings.



Sirohbagar (Kaliyasaur) Landslide near Srinagar (Pauri Garhwal)



Lower part of Sirohbagar (Kaliyasaur) Landslide near Srinagar (Pauri Garhwal)



Middle part of Sirohbagar (Kaliyasaur) Landslide near Srinagar (Pauri Garhwal)



Quartzites of Garhwal Group at Sirohbagar (Kaliyasaur) Landslide



Composite Landslide at Phata, 6 km for Guptkashi



Too Erosion by Mandakini, Phata Landslide



**Road Breach in RBM Near Naulapani
(Tilwara-Rudraprayag)**



Slide in RBM at Naulapani (Tilwara-Rudraprayag)



**Debris floe along nala channel at Naulapani (Tilwara -
Rudraprayag)**



**Failure by toe erosion in Terrace involving River Borne
Material (RBM)**



Toe erosion by Mandakini on the right bank below Sumari - Bharsaar village



Damaged to civil structure in Sumari area

NDMA Meeting on National Landslide Mitigation Plan

NDMA conducted National Landslide Mitigation Plan and as Nodal Agency, GSI attended the meeting on 5th July, 2013. The devastation took place in Uttarakhand state was prominently discussed in the meeting.

C. A Note on Preliminary Geological Assessment of Kedarnath area after the disaster of 15th-17th June 2013 (State Unit: Uttarakhand, Geological Survey of India, Dehradun with additional suggestions from Central Headquarters)

Introduction

A team of two officers, S/Shri P. V. S. Rawat, Superintending Geologist and Harish Bahuguna, Senior Geologist, from SU: Uttarakhand, Geological Survey of India, Dehradun, carried out preliminary geological assessment of Kedarnath area including the Holy Shrine of Shri Kedarnathji, from 02-08-2013 to 03-08-2013.

The temple town of Kedarnath, located on the left bank of Mandakini River, is situated on an outwash plain (Photo-1) and it spans about 1 km in length and 0.5 km in width. The channels of Mandakini emanate from Chorabari and Companion Glaciers (Photo-2) and its channels encircle the outwash plain one from the left side and the other from the right side. These two channels meet below the township where the outwash plain ends. River Saraswati descends down from Companion Glacier and has its channel to the east of Kedarnath temple. Saraswati joins Mandakini about 500 m

downstream of Kedarnath temple. A lake, popularly known as Gandhi Sarovar or Chorabari Lake was present down below Chorabari glacier, which is at about 1.5 km upstream of Kedarnath Township. The rocks belonging to Central Crystalline Group represented by Augen Gneisses and Migmatites are seen exposed around Kedarnath area especially on the higher reaches. The preliminary geological assessment has been carried out and detailed geological assessment is planned wherein detailed geological and geotechnical studies will be carried out for giving necessary inputs to the reconstruction around the Kedarnath area.

Authors are thankful to Director General, Geological Survey of India, Kolkata and Dy. Director General & HOD, Geological Survey of India, Northern Region, Lucknow for kindly permitting them to take up this study. Sincere thanks are also due to the Chief Secretary Government of Uttarakhand and other officials from Government of Uttarakhand for providing necessary logistics including the facility of airlifting to the GSI team for Kedarnath. The cooperation and help extended by Uttarakhand Police and officials of National Disaster Relief Force, at Kedarnath, is also thankfully acknowledged.

Observations

- The area in and around the Kedarnath Temple has been badly damaged during the floods of 16th and 17th June 2013 (Photos-3 and 4)
- There is a thick pile of debris consisting of large boulders measuring in the longest dimension between 1 and 8 m. These boulders are of granitic gneisses, augen gneiss, tourmaline granite, quartzite and amphibolites.

- The pile of debris is making a gentle slope (10° – 15°) towards the temple from the bifurcation point of the two channels of Mandakini River (Photo-5).
- The higher reaches of Mandakini valley experienced unprecedented heavy rain fall during 15^{th} - 17^{th} June, 2013, (210 mm in between 17.00 hrs of 15^{th} and 05.00 hrs of 16^{th} June and 115 mm between 05.00 hrs of 16^{th} and 17.00 hrs of 16^{th} June, 2013.) (*Report from WIHG Meteorological Observatory, Dobhal et. Al., 2013; Current Science, Vol. 105, No. 2, 25th July, 2013.*) The heavy rain fall ultimately lead to breach of Chorabari Lake.
- After the floods of 16^{th} and 17^{th} June, the bed levels of both the channels of Mandakini and that of Saraswati River have been raised. Because of the raised bed level, the water (near the bifurcation point of the two channels towards upstream of the temple) was flowing at a higher level than the base level of the Kedarnath Temple.
- The water, from the left side channel (looking downstream) of Mandakini, which is joining Saraswati, is also seeping below the heap of debris. It is thus apprehended that the lower part of this pile of debris may be in a saturated condition.
- Minor seepage of this water (saturating the debris back of the Temple) is also seen through the walls and the floor area inside the *sanctum-sanctorum* (the *Garbh-Griha*).
- Two new rills have been formed, back of the Temple, on eastern and western sides. The one on the western side joins the Mandakini, whereas, the one on the eastern side makes its way towards the erstwhile market area in front of the temple.
- The large size boulder measuring 8.40 m x 2 m x 3 m at the back side (North side) of the temple (Photo-6) has in fact saved the temple structure from further damage during subsequent splash.

Damage to the Temple Structure

The damage to the temple complex has been in many ways as discussed below

- i) The Shankaracharya Samadhi (made up of concrete and marble), located on the backside (NNW) of the temple, has been razed to ground.
- ii) The temple of Eeshaneshwar (Lord of North-eastern

corner), located on the North-eastern part of the temple complex has been totally damaged (Photo-7) and the remains are buried under the debris.

- iii) The initial impact of the surge of the water laden with such big sized boulders might have inflicted damage to the platform on which the temple (main structure) is standing. The extent of damage to this platform could not be assessed as presently it is covered under the pile of debris.
- iv) The outer walls of the main Kedarnath Temple have been damaged from three sides i.e. back (North), left (East) and right (West) sides.
- v) The impact of the boulders was such that it dislodged many building blocks near the eastern gate (Photo-8), from where the water rushed into the temple and western gate (Photo-9) from where the water came out.
- vi) Few blocks from the basal part of the western gate have also got removed (Photo-10).
- vii) Displacement of the blocks has been noticed on eastern and western sides (Photo-11).
- viii) The impact marks of the boulders (Photo-12) are clearly seen on the building blocks on the eastern, north-eastern sides and at the back wall.
- ix) A big sized boulder (Photo-6) measuring roughly 8.40 m x 2 m x 3 m got arrested just back (Approximately 2 m) of the temple complex, amidst the flowing debris and acted as a barrier to the boulders rolling subsequently. This boulder in fact saved the subsequent damage to the temple structure.
- x) There is accumulation of about 3 m – 4 m thick debris around the temple complex *inter-alia* main entrance and parikrama path.

Assessment for finding Safer Areas

Preliminary and rapid geological assessment of two areas viz. i) Area around the Kedarnath Temple and erstwhile town and ii) Terrace located 1Km downstream of the temple was carried out with an objective to locate safer areas where future activities can be planned.

i) Area around Kedarnath Town

The rapid assessment revealed that all the structures in the erstwhile Kedarnath Town have suffered damage differing in degrees and orders. The area located to the

back side of the Temple is studded with pile of debris and only ruins of some structures are visible. Other remaining civil structures have either been hit badly by the rolling boulders or by gigantic water waves, thus shaking them from the foundation level.

ii) Terrace Located 1 km Downstream of Temple

Feasibility of the Terrace, located roughly 1 Km downstream of the Kedarnath temple, on the left bank of Mandakini River, was also assessed geologically. This terrace is approximately 700 – 800 m long (u/s - d/s) and 50 – 70 m wide (Photo-13) and it has few small water bodies on its surface. No rock is exposed along its margins. The ground has gentle rolling surface. This area (terrace) has not been ravaged by the recent floods of 16th and 17th June 2013. It is the same area which, at present, is being used, by the state Government, as the camping site for different teams. It is worth mentioning that Shri Deepak Srivastava and his team of GSI during 1991-94, in their report entitled "Report on Integrated Ice, Snow Avalanche and Quaternary Glaciological studies in Mandakini Valley around Kedarnath, District Chamoli, Uttar Pradesh" has already identified the same area as avalanche free zone and recommended for future expansion of Kedarnath Township. The same holds good even today.

Conclusions and Recommendations

1. The erstwhile township of Kedarnath, located on the left bank of Mandakini River, on an outwash plain, has been badly damaged by the recent floods of 16th and 17th June 2013.
2. The incessant rainfall on 15th and 16th June, in the catchment of Mandakini and Saraswati Rivers, resulted in swelling of water levels, in these streams, which brought large amount of debris in them. The flood on 16th June damaged the area to the west of Kedarnath temple.
3. The rains, which continued in the night between 16th and 17th June lead to overfilling of Gandhi Sarovar (Chorabari Lake). It has been reported that the event of 17th June was a result of breach/burst of Gandhi Sarovar and was mainly responsible for destruction that occurred at the township around Kedarnath temple. The big boulders carried down the slope by the gushing water acted as tools of destruction and ravaged everything that came in the way.
4. The Holy Shrine of Shri Kedarnathji escaped the brunt miraculously, however the northeast part of the temple complex having "Eeshaneshwar" temple was damaged.
5. There are damages on the three outer walls of the temple. Removal of blocks, dislodgement of the blocks, gaping joints between the blocks (Photo 8, 9, 10 and 11) and impact marks on the blocks are clearly seen (Photo-12).
6. The condition/damage to the platform or foundation on which the main structure/building of the temple is standing could not be assessed as it is covered beneath the pile of debris.
7. The heap of debris, making a gentle upslope, from back side of the temple up to the bifurcation point of the two channels of Mandakini, is in a saturated state. The boulders stacked up against the back wall of the temple are lying in a precarious condition. At this stage it is not advisable to rapidly remove the pile of debris stacked back of the temple; else it may disturb the critical state of balance of the foundation of the main structure. Any disturbance may result in displacement/instability of the already disturbed temple blocks. It will be advisable to keep the large boulder lying back of the temple (Photo-6), at its present place and also to provide some support (if possible by iron girders and cementing) at its base, as it will protect any direct impact to the temple in the event any boulder slides/moves towards the temple.
8. It is suggested that use of explosives, in any form, for removal of debris/boulders or dismantling of damaged civil structures should be strictly avoided as it would transmit both ground and aerial vibrations, which may further endanger the safety of the existing temple structure. It (blasting) would also have extreme adverse effects on the glaciers which occur in the close proximity to the Kedarnath area. At this stage there should not be any movement or use of heavy machinery/earthmovers etc. close to the temple complex to avoid any untoward vibration transmitting into the foundation area.
9. It is recommended to get the analysis of the present old temple building done by a competent structural engineer so as to get an idea about the health, safety and stability of the existing temple structure. Necessary archaeological retrofitting of the existing shrine may be carried out.
10. The terrace, located 1km downstream of the temple, on the left bank of Mandakini River has not been affected.

However, active toe erosion by Mandakini River in the bottom part of this terrace is clearly evident. Toe protection measures should be undertaken at the bottom of the terrace (located 1 km downstream) to ensure further stability to this platform for use of any future developmental work.

11. Considering the location of the temple and surrounding area on an outwash plain, heap of morainic dump in the upstream area and further up slope, close proximity of the glaciers and seismic sensitivity of the area, the area in and around the Kedarnath temple is geologically assessed as “Vulnerable” having high hazard potential. The degree of vulnerability will increase during the recurrence of similar such events in future.

A team of experts at GSI, Central Headquarters, Kolkata also examined and assessed the observations and conclusions drawn by the field officers of GSI, Dehradun Unit and proposed certain specific recommendations as under:

- (i) GSI made certain studies at Kedarnath area during 1991-94 and identified a piece of land at about 1 km downstream of the Temple complex for future expansion of Kedarnath Township (report is also available in GSI portal). But it is noted that the recommendation was never followed by the State Government of Uttarakhand or by the Shrine authority. It is observed that the identified area

was least affected during the recent devastation. Now, with this experience, the recommendation may be followed for future activities. However, a detailed multi-hazard/multi-disciplinary study and geotechnical assessment of this terrace is warranted before planning any new township there.

- (ii) The Temple structure (post disaster event) is not safely disposed. Hence, it is necessary to provide archaeological retrofitting.
- (iii) Training of existing and newly formed channels by dredging and deepening to their original bed levels may be attempted, so that surface water is drained properly without saturating the temple area.
- (iv) As breach in Chorabari Lake was considered one of the main reasons to the devastation occurred, it is suggested to provide proper spillway and spill channel arrangements to the lake, so that the possibilities of similar incidences are adequately managed in the future.
- (v) Considering the vulnerability and importance of the area, IMD may be requested to establish a suitable automated Weather Station in the area for early warning of such heavy rainfall event.
- (vi) More detailed geological, geotechnical and structural investigations are required at the Temple complex for sustainable and safer resettlement or relocation.



Panoramic view of Kedarnath Area (Post Disaster)



Panoramic view of two glaciers north of Kedarnath



Kedarnath Temple (Post Disaster)



Market Area near Kedarnath Temple (Post Disaster)



Heap of boulders at the rear side of the temple



Closeview from backside of the temple along with the Rock Boulder which saved in Temple



Damage on eastern and western sides of the Temple



Damage on the Eastern side of the Temple from where the water rushed in



Damage on the western gate of the temple from where water gushed out



Shifting of blocks of pillars



Dislodgement of blocks from the basal part of the temple



Impact marks on northeastern part of the temple



View of Terrace about 1 km down stream of Kedarnath Temple, assessed safer for future developmental activities

D. Detailed geological mapping and evaluation by GSI Task Force for the proposed post-disaster treatment measures in the Kedarnath area (State Unit: Uttarakhand, Geological Survey of India, Dehradun)

Shri T. S. Pangtey, Dy. Director General, SU: Uttarakhand, Dehradun visited Kedarnath area, between 9th and 12th July 2014 along with members of Task Force comprising Shri P. V. S. Rawat, Suptdg. Geologist, Shri A. P. Thapliyal, Sr. Geologist and Km Ruchi Mehrotra, Geologist, to review the post disaster studies/geotechnical assessment undertaken by Geological Survey of India, SU: Uttarakhand and also to monitor the status of measures being adopted by the State Government as recommended by GSI.

On the basis of review by this GSI Team in July 2014, the following recommendations have been made and submitted to the Uttarakhand Government. The following recommendations are primarily based on large scale (1:5000) geological map of Kedarnath area (Enclosed large scale map) by a team of GSI officers of SU: Uttarakhand and SU: PHP, Chandigarh (S/Shri P.V.S.Rawat, S.K.Tripathi, A.P.Thapliyal, K. Lakshmanan, Jina Mondal and Ruchi Mehrotra) as part of the site specific geological investigation and also to suggest effective reconstruction and remedial measures.

1. During the visit of the GSI Task Force led by Shri T. S. Pangtey, Dy. D.G., SU: Uttarakhand, it was observed that the earlier recommendations made by GSI, by and large, are being successfully implemented. However, in some parts of the NH-109 measures like erection of gabions walls with deeper foundation and their placement and spacing, do not appear to be proper wherever maximum impact of flood water has been observed. Moreover, the foundation for the gabion does not appear to be properly designed as per the existing site conditions. As a result, failures/subsidences have been observed at various locations along NH-109. It is, therefore, strongly suggested that suitably designed masonry walls with RCC columns in between, with deeper foundation, may be constructed in place of gabions so that the structures could be long lasting and further damage could be avoided.
2. The boulder spread (Photo- 1a & 1b; Plate- Annex-II/1), occurring north of the Kedarnath Temple (i.e. just behind) and west of the confluence (Post-Disaster) of Mandakini river and the stream descending from the Companion

glacier (as indicated by C1 in Enclosed large scale map; Photo-2), should not be disturbed. In order to achieve effective interlocking of boulders, the inter spaces and gaps between the boulders should be filled up with small boulders and cobbles of variable sizes. If possible, the area behind the temple (boulder heap) should be covered with wire mesh with deep nailing wherever required/feasible, as it would act as a natural barrier in case of recurrence of such kind of event in future. The north-south trending elongated depression/channel (as indicated by 'CH' in Enclosed large scale map; Photo-3 & 4) formed by flash flood water at the time of disaster, located about 30-35 m west of Kedarnath Temple, should be filled up with the boulders/cobbles etc. up to the existing boulder/ground level of the temple complex.

3. River training walls preferably concrete walls with deeper foundation as per the existing ground conditions on both the banks of Mandakini river (along the new course), should be constructed downstream of the Proposed Diversion Area ('PDA'-as shown in Enclosed large scale map; Photo-2) up to point 'C2' and along the old course of Mandakini River upto 'C4'. From 'C2' to 'C3' concrete claddings and retaining/gabion walls should be constructed, along the right and left bank of Saraswati River, respectively. Similarly, concrete claddings should also be constructed along Mandakini River (original course) from 'C4' to 'C3' on the left bank i.e. up to the bridge located near the confluence (Photo-5 in enclosed large scale map).
4. During the visit, it was found that most of the buildings surrounding the Shrine have been damaged during the disaster. Hence, it is suggested that all the damaged settlements in Kedarnath Township may be completely removed. The material/debris resulting from the damaged settlements (as indicated in Enclosed large scale map; Photo-6) may be utilized for backfilling of the existing depressions in the area to achieve existing ground level around the Temple premises. The filled spaces should only be utilized for construction of pre-fabricated structures for providing facilities exclusively for the temple staff. Concrete lined domestic drains should be provided so that the water is drained effectively from the temple complex area. Any other civil construction should not be allowed and Natural Landscaping of the area should be done without blasting with the help of an expert town planner.

5. Part of glacial terrace (as indicated in Enclosed large scale map by 'A'; Photo-7 a & b in the enclosed large scale map), which is located near the confluence of Saraswati and Mandakini rivers, shows its continuity further downstream on the left bank upslope of Mandakini River. It is water charged zone with undulating surface. To control the discharge in the rills or to make the area free from slushy conditions, a catch drain aligned in north-south direction depending upon the ground conditions may be constructed. It should be constructed just at the base of the ridge to drain the water into the *nala* descending from the Bhairongarhi Temple ridge.
6. The terrace, indicated in the map (Enclosed large scale map) by 'A', provides open space for erection of prefabricated structures. The channels/streams draining the surface of this geomorphic landform can be trained and lined to check further erosion. The rills/*nalas* draining the western slope of the Bhairongarhi Temple have limits of the debris fans extending over the eastern part of the glacial terrace/surface. Hence, these rills/*nalas* require training arrangements and check walls to be constructed along and across their courses at different levels to prevent further erosion.
7. The part of the glacial terrace, indicated by 'B' in the map (Enclosed large scale map), has its up slopes subjected to extensive rills erosion resulting from the avalanche zone occurring above the ridge line (left morainic ridge) with avalanche chutes descending from further up slopes (Photo- 8; Enclosed large scale map). The drainage, descending from up slopes, joins southward directing drainage lines which further join the *nala* adjoining Bhairongarhi Temple and the *nala* located east of the ridge respectively. The depression, which existed before the disaster, got filled by the supply of huge amount of debris material (as indicated by 'D' in the map at Enclosed large scale map) coupled with heavy discharge resulting from a number of subsidences due to very heavy precipitation in the catchment area. The steep gradient and newly acquired straight course led to toppling of the sediment load over the ridgeline debouching it down the western slope of the ridge. This is indicated by intensive rill formation and huge amount of debris material widely spread on the surface of the glacial terrace.
8. The zone of debris filled area (as indicated by 'D' in Enclosed large scale map), close to the ridge line, and requires construction/erection of debris deflectors (Photo- 8; Enclosed large scale map) to divert the flow of debris along the original northward (i.e. *nala* adjoining Bhairongarhi Temple) and southward directing drainage lines/depressions. Some amount of excavation in the debris filled zone is also required to train/channelize the discharge descending from up slopes to divert them into their original courses.
9. The proposed helipad (as indicated by 'PHP' in Enclosed large scale map), to be constructed on the glacial terrace, falls in the debris spread zone, which requires protection measures such as training of channels marked by debris flow. A buffer zone of about 20-30 m width should be kept between the helipad and the edge of the terrace, which is located on the left bank upslope of Mandakini River and is affected by active subsidence due to toe erosion and bank erosion (Photo-7b; Enclosed large scale map).
10. The western part of the glacial terrace i.e. the left bank of the Mandakini river, downstream of its confluence with Saraswati river, needs bank protection and river training measures to prevent further subsidence, which is advancing and enveloping the fresh areas of the glacial terrace as evident by fresh cracks/scars of ground subsidence (Photo- 7b & 13; Enclosed large scale map).
11. The southern part of the glacial terrace (as indicated by 'C' in Enclosed large scale map; Photo-9), located on the left bank up slope of the Mandakini river displays a gentle undulating topography for considerable distance and provides wide and open area for locating pre-fabricated structures/settlements with effective domestic lined drains to meet the infrastructure requirements in future. The structures should be erected away from the edge on the western side of the glacial terrace towards valley side. The cross and elongated toe drainage lines in the area, as per the ground conditions, should be properly trained and lined to check the erosion.
12. The freshly developed cluster of rills exposing eroded top soil cover (Photo-10; Enclosed large scale map) for considerable length (as indicated by 'R' in Enclosed large scale map) on the western slope of the ridge, on the left bank upslope of Saraswati River, require conservation measures such as allowing growth of vegetation through grass seed spray in consultation with forest officials.

13. The subsidence (debris slide) located on the left side of the foot track (Photo- 11 & 12; Enclosed large scale map) and on the right bank of the nala, down slope of Rudra Point, needs treatment measures to check its further expansion. The treatment measures include retaining wall (along the foot track), step walls and contour check walls with provision of weep holes on the *nala* side. At this location, the foot track crosses the *nala* (with a narrow and steep course) which acts as an ice/avalanche chute in winter season. As the valley just downstream of this location is narrow and provides a favourable site/location, a light steel bridge for *nala* crossing may be considered keeping in view the safety of the pilgrims.
14. The gaps/pits, left after removal of rock blocks from the slope for the construction purpose of the newly aligned foot track, should be back filled with debris- soil mixture to prevent further deterioration of the slope surface. Excavation and removal of the rock blocks from the existing stable slope surface should be discouraged.
15. The side slope cut/excavated for the preparation of foot track should be provided with stone pitching/retaining wall, as required to prevent instability of the overlying slopes.
16. The detailed assessment of Sonprayag to Guptkashi road has already been discussed in the final report of Rudraprayag District. However, the realignment, as suggested from village Sitapur to Mundkata Ganesh in the report, may be executed in consultation with geologist from GSI.

*E. Salient details of landslides that are triggered by the 2013 disaster in five affected districts of Uttarakhand**Annexure-II*

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	4.5 km from Bageshwar	79.789	29.837	32	50	32	Rock cum debris slide	Natural failure	Blockade of road network
Bageshwar	5 km from Bageshwar	79.792	29.839	12	20	12	Debris slide	Natural failure	Partial sinking of road
Bageshwar	Gwar village	79.792	29.891	30	30	30	Rock slide	Adverse geological structure	Road network partly damaged
Bageshwar	Natural slope	79.915	29.997	120	60	120	Rock cum debris slide	Adverse geological structure	Damage to power line
Bageshwar	Right bank of Saryu River	79.910	29.993	180	60	180	Rock cum debris slide	Adverse geological structure	Damaged barren land
Bageshwar	Near Gason Village	79.908	29.993	100	120	70	Rock cum debris slide	Adverse geological structure	Damaged forest land
Bageshwar	Upstream of Gason Gad	79.907	29.993	70	150	70	Rock cum debris slide	Adverse geological structure	Road damaged
Bageshwar	Near Chhati Village	79.798	29.832	11	70	11	Debris slide	Road cutting	Blockade of road
Bageshwar	Mankot road subsidence	79.816	29.825	30	45	30	Debris slide	Natural failure	Road damaged due to sinking
Bageshwar	Kanda 12 km milestone	79.961	29.844	10	10	10	Rock slide	Wedge failure	Blockade of road
Bageshwar	NW of Jhopra village	79.976	29.961	25	25	25	Rock slide	Adverse geological structure	Rockfall damage
Bageshwar	Jhusiathaura village	79.992	29.958	15	20	15	Earth slide	Natural failure	Sinking of road
Bageshwar	Siri village	80.007	29.964	100	60	100	Debris slide	Adverse geological structure	Agricultural land affected
Bageshwar	Chirang Village	79.820	29.868	40	10	40	Rock cum debris slide	Adverse geological structure	Blockade of road
Bageshwar	Chirang Village	79.820	29.868	20	6	20	Rock cum debris slide	Adverse geological structure	Blockade of road

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	Sem Devta village	79.826	29.867	10	8	10	Rock slide	Natural failure	Blockade of road
Bageshwar	Mahatgaon village	79.843	29.871	10	30	10	Rock slide	Adverse geological structure	Blockade of road
Bageshwar	Naghar Village	79.899	29.878	10	18	10	Rock slide	Adverse geological structure	Minor rockfall hazards
Bageshwar	NE of Parai Village	79.905	29.875	12	80	12	Rock slide	Adverse geological structure	Blockade of road
Bageshwar	SW of Binari Village	79.929	29.889	70	15	70	Rock slide	Adverse geological structure	Damage to road
Bageshwar	South of Bilaun-sera Village	79.773	29.808	8	15	8	Rock slide	Road cutting	Blockade of road
Bageshwar	Rikholi Chak Village	79.775	29.795	8	15	8	Rock slide	Road cutting	Blockade of road
Bageshwar	Katpuriya Chhina	79.771	29.759	10	15	10	Rock slide	Road cutting	Blockade of road
Bageshwar	Katpuriya Chhina	79.772	29.756	12	50	12	Debris slide	Rill erosion led to the failure	Blockade of road
Bageshwar	Katpuriya Chhina	79.766	29.751	10	120	10	Debris slide	Rill erosion led to the failure	Blockade of road
Bageshwar	Nr.Bageshwar	79.792	29.839	12	20	12	Debris slide	Natural failure	Partial sinking of road
Bageshwar	Nr.Bageshwar	79.757	29.752	8	12	8	Debris slide	Rill erosion led to the failure	Partial sinking of road
Bageshwar	Nr.Bageshwar	79.758	29.754	10	18	10	Debris slide	Rill erosion led to the failure	Partial sinking of road
Bageshwar	Saukhola Village	79.877	29.824	7	12	7	Rock slide	Adverse geological structure	Damage to slope
Bageshwar	Ghanshyam Nagri	79.765	29.938	10	25	10	Rock slide	Adverse geological structure	Minor damage to slope
Bageshwar	Kanyalikot Govt. Inter College	79.771	29.931	55	28	55	Rock slide	Toe erosion by river	Damage to road

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	On left bank of the Kanal Gad	79.790	29.918	80	30	80	Rock slide	Adverse geological structure	Damage to road
Bageshwar	Village Chachai	79.795	29.918	50	25	50	Rock slide	Road cutting	Damage to road
Bageshwar	Bhitalgaon	79.799	29.917	15	10	15	Debris slide	Natural failure	Damage to road
Bageshwar	Left bank of Kanal Gad	79.800	29.917	60	38	60	Rock cum debris slide	Road cutting	Damage to road
Bageshwar	Right bank of Kanal Gad	79.809	29.912	8	18	8	Rock slide	Adverse geological structure	Damage to road
Bageshwar	Bijaipur Ora-Dhupti Road	79.928	29.840	10	40	10	Rock cum debris slide	Adverse geological structure	Damage to road
Bageshwar	Bijaipur Ora-Dhupti Road	79.921	29.839	20	10	20	Rock cum debris slide	Road cutting	Damage to road
Bageshwar	Dhupti Road	79.875	29.835	8	50	8	Rock cum debris slide	Slumping of debris	Damage to road
Bageshwar	Dhalmalla- Khamoli Road	79.873	29.834	9	100	9	Rock cum debris slide	Slumping of debris	Damage to road
Bageshwar	Kharbagad village	79.930	29.991	200	30	200	Rock cum debris slide	Toe erosion by river	Electrical lines and local trek damaged
Bageshwar	Kharbagad Village	79.932	29.990	120	150	120	Rock cum debris slide	Toe erosion by river	Damage to slope
Bageshwar	Left bank of Revti Ganga	79.933	29.989	80	300	80	Rock cum debris slide	Adverse geological structure	Damage to slope
Bageshwar	Left bank of Revti Ganga	79.939	29.989	20	50	20	Rock slide	Adverse geological structure	Damage to slope
Bageshwar	Left bank of Revti Ganga	79.942	29.989	85	70	85	Rock cum debris slide	Adverse geological structure	Damage to slope
Bageshwar	Right bank of Revati Ganga	79.943	29.988	60	50	60	Rock cum debris slide	Toe erosion by river	Damage to slope
Bageshwar	Birmol village	79.972	29.983	55	30	55	Rock cum debris slide	Natural failure	Damage to slope

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	Bhulia Village	79.966	29.983	50	30	50	Rock slide	Toe erosion by river	Damage to slope
Bageshwar	Left bank of Revti Ganga	79.963	29.983	38	20	38	Rock cum debris slide	Adverse geological structure	Temporary blockade of road
Bageshwar	Left bank of Revti Ganga	79.959	29.984	24	25	24	Rock slide	Adverse geological structure	Temporary blockade of road
Bageshwar	Baret Village	79.956	29.985	40	30	40	Rock slide	Adverse geological structure	Damage to slope
Bageshwar	Chetabagar Village	80.099	29.921	30	30	30	Rock slide	Adverse geological structure	Damage to slope
Bageshwar	Right bank of Mehar Gad	80.101	29.920	25	60	25	Rock slide	Adverse geological structure	Road was damaged
Bageshwar	Right bank of Mehar Gad	80.108	29.920	100	100	100	Rock slide	Adverse geological structure	Temporary blockade of road
Bageshwar	Left bank of the Mehar Gad	80.119	29.914	130	50	130	Rock slide	Adverse geological structure	Damage to road
Bageshwar	Right Bank of Mehar Gad	80.119	29.914	25	20	25	Debris slide	Natural failure	Temporary blockade of road
Bageshwar	SW of Kheti villages.	80.126	29.910	25	50	25	Debris slide	Natural failure	Damage to slope
Bageshwar	Kheti villages.	80.128	29.909	80	30	80	Rock cum debris slide	Adverse geological structure	Damage to slope
Bageshwar	Near Kheti village	80.130	29.909	90	35	90	Rock cum debris slide	Gully erosion	Damage to slope
Bageshwar	Road Kismi-la-Machhera village	80.133	29.908	12	12	12	Debris slide	Gully erosion	Damage to slope
Bageshwar	On road	80.139	29.907	50	90	50	Rock slide	Gully erosion	Temporary blockade of road
Bageshwar	On road	80.142	29.907	50	90	50	Rock slide	Natural failure	Damage to slope
Bageshwar	On road	80.033	29.897	15	15	15	Rock cum debris slide	Adverse geological structure	Damage to slope

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	1 km short of Dwari	80.028	29.899	12	10	12	Rock slide	Road cutting	Partially blocked road
Bageshwar	0.5 km short of Dwari	80.028	29.901	6	20	6	Rock slide	Road cutting	Partially blocked road
Bageshwar	Dwari village	80.032	29.908	15	15	15	Rock slide	Road cutting	Blockade of road
Bageshwar	1 km short of Dwari	80.026	29.903	10	18	10	Rock slide	Natural failure	Partially blocked road
Bageshwar	Jalmuni bridge	79.969	29.883	30	7	30	Rock slide	Adverse geological structure	Partially blocked road
Bageshwar	Deval Chaura Village	79.795	29.892	50	20	50	Debris slide	Natural failure	Damage to slope
Bageshwar	500 m down of Gason Gad	79.912	29.992	90	80	90	Rock cum debris slide	Adverse geological structure	Periodic blockade of the road
Bageshwar	Gason Village	79.912	29.992	90	8	90	Debris slide	Natural failure	Partial blockade of road network
Bageshwar	NE of Mal-ladesh village	79.959	29.965	8	15	8	Rock cum debris slide	Road cutting	Damage to slope
Bageshwar	Yuti Nala	79.914	29.979	25	12	25	Debris slide	Natural failure	Road and the bridge damaged
Bageshwar	Harsila	79.820	29.911	70	40	70	Debris slide	Natural failure	Damage to slope
Bageshwar	6.5 km from Bageshwar	79.797	29.843	8	15	8	Rock cum debris	Adverse geological structure	Partial blockade of road
Bageshwar	East of Kirauli Village	79.939	29.963	0	70	0	Rock and debris	Adverse geological structure	Road network partially damaged
Bageshwar	Left bank of Revti Ganga	79.920	29.990	35	30	35	Rock slide	Adverse geological structure	Damage to slope
Bageshwar	Right bank of Revti Ganga	79.922	29.990	12	25	12	Rock cum debris slide	Adverse geological structure	Damage to slope
Bageshwar	On Khathi Dwali trek route	79.966	30.141	150	500	150	Debris slide	Toe erosion by river	1 km of Dwali- Khathi trek damaged
Bageshwar	On Khathi Dwali trek route	79.958	30.131	80	200	80	Debris slide	Toe erosion by river	300 m of Dwali-Khathi trek damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Bageshwar	On Khati Dwali trek route	79.953	30.125	30	10	30	Debris slide	Toe erosion by river	20 m of Dwali-Khati trek damaged
Bageshwar	On Khati Dwali trek route	79.938	30.108	26	10	26	Debris slide	Toe erosion by river	Damage of Trek but revived by locals
Bageshwar	Shuding Village	79.950	30.039	20	30	20	Debris slide	Toe erosion by nala	Trek route partially damaged
Bageshwar	Kathpuria Chinnabaudi Road	79.782	29.753	10	35	10	Rock cum debris slide	Road cutting	Damage to road
Bageshwar	Kathpuria Chinnabaudi Road	79.780	29.751	8	12	8	Rock cum debris slide	Road cutting	Damage to road
Bageshwar	Kathpuria Chinnabaudi Road	79.801	29.742	15	20	15	Rock cum debris slide	Road cutting	Damage to road
Bageshwar	SE of triangulation point 2054	80.028	29.960	200	50	40	Rock slide	Planar and wedge failure	Road blocked, agriculture and forest land affected
Bageshwar	North of Kaphlani village	79.945	30.017	100	50	40	Rock cum debris slide	Planar and wedge failure	Road blocked and forest land affected
Bageshwar	North of Kaphlani village on left bank of Sarju river	79.947	30.017	60	30	25	Rock cum debris slide	Planar and wedge failure	Agricultural land affected
Bageshwar	NNW of Kaphlani village	79.952	30.023	80	60	40	Rock cum debris	Planar and wedge failure	01 building damaged and 02 buildings partially damaged
Chamoli	On road	79.665	30.488	150	80	150	Debris	Toe erosion by river	Sinking of 80 m length of road
Chamoli	BRO Chainage 468.300 km	79.514	30.532	40	40	40	Rock slide	Adverse geological structure	20 m road length breached
Chamoli	On road	79.513	30.531	25	80	25	Debris slide	Adverse geological structure	40 m road length breached
Chamoli	500 m up of Helang Bridge	79.510	30.530	30	30	30	Debris slide	Natural failure	40 m road length breached
Chamoli	Kachra nala near Lambagarh	79.524	30.649	0	50	0	Debris slide	Natural failure	Road (NH-58) breached partially

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Chamoli	Pagla Nala	79.480	30.473	150	200	150	Rock slide	Natural failure	25 m road length breached
Chamoli	Along road right bank of Alagad	79.257	30.225	40	150	40	Rock cum debris slide	Adverse geological structure	125 m stretch of road affected
Chamoli	Harnani slide	79.432	30.099	170	300	170	Debris slide	Toe erosion by river	300 m of road was affected
Chamoli	Near Kakra village along SH	79.470	30.086	90	150	90	Rock cum debris slide	Natural failure	Road of about 150 m affected
Chamoli	Near Sunila village road	79.485	30.084	75	80	75	Debris slide	Toe erosion by river	100 m road length damaged
Chamoli	Narayanbagarh	79.458	30.143	90	325	90	Rock cum debris slide	Toe erosion by river	325 m road was damaged
Chamoli	Upstream of Amsaur	79.330	30.179	10	60	10	Rock slide	Toe erosion by river	60-70 m road length affected
Chamoli	Patalganga	79.485	30.487	55	50	55	Debris slide	Adverse geological structure	Part of road breached and blocked
Chamoli	At Pokhri	79.295	30.380	30	60	30	Debris slide	Natural failure	50 m road sinking in patches
Chamoli	Near Sonla village	79.292	30.378	45	30	45	Debris slide	Natural failure	Part of road breached & blocked
Chamoli	On road	79.275	30.368	45	60	45	Debris slide	Natural failure	About 2m subsidence in road
Chamoli	State Highway	80.117	29.826	15	45	15	Rock cum debris slide	Natural failure	Road (SH) affected
Chamoli	On road	79.281	30.360	40	60	40	Rock slide	Adverse geological structure	Partial breach of road formation
Chamoli	On road	79.222	30.382	270	250	270	Debris slide	Adverse geological structure	Road blockade of about 200 m
Chamoli	On NH 58	79.119	30.289	70	150	70	Debris slide	Road cutting	150 m of road damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Chamoli	Rinni Village.	79.678	30.488	0	60	0	Subsidence zone	Natural failure	Sinking of 60-70 m part of road
Chamoli	Near Saldhar village	79.669	30.488	25	40	45	Debris slide	Road cutting	40-50 m road length affected
Chamoli	About 200 m u/s of hot spring	79.660	30.488	100	70	100	Debris slide	Road cutting	Blockade of 70 m road length
Chamoli	500 m NW of Ringi Village	79.651	30.490	30	40	30	Debris slide	Road cutting	Blockade of 40 m road length
Chamoli	Kathadhar village	79.621	30.494	90	90	90	Debris slide	Road cutting	Blockade of 100 m road length
Chamoli	On road	79.485	30.504	20	70	20	Debris slide	Road cutting	Breach of 25 m of road formation
Chamoli	Nr. Gaucher township.	79.969	30.590	130	200	130	Rock cum debris slide	Adverse geological structure	Road was breached
Chamoli	Near Jaypee guest house	79.534	30.652	25	160	25	Debris slide	Toe erosion by river	Breach of 160 m of road formation
Chamoli	On road	79.518	30.655	60	550	60	Debris slide	Toe erosion by river	Breach of 550 m of road formation
Chamoli	Just below Par-gasi village	79.521	30.651	120	300	120	Debris slide	Toe erosion by river	Road of about 250 m damaged
Chamoli	Near Govind-ghat	79.553	30.626	115	90	115	Debris slide	Toe erosion by river	About 90 m of road washed out
Chamoli	D/s of Ghat village	79.569	30.606	50	60	50	Debris slide	Toe erosion by river	70 m road length washed away
Chamoli	RD 490 km stone	79.560	30.565	18	300	18	Debris slide	Toe erosion by river	Part of the road breached
Chamoli	1 km NE of Bapkund	79.843	30.668	90	170	90	Debris slide	Toe erosion by river	Road of about 100 m affected
Chamoli	Near village Devkhal	-	30.340	80	60	80	Debris slide	Natural failure	Partial breach of road formation

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Chamoli	Between Daya bridge and Vish-nuprayag HEP barrage	79.515	30.672	30	2000	20	Debris slide	Toe erosion by river	Damage to Vish-nuprayag barrage and complete wash out of Daya bridge
Uttarkashi	Badhethi Chungi slide	78.351	30.718	75	65	75	Rock cum debris slide	Toe erosion & road cutting	265 m stretch of NH damaged
Uttarkashi	Tekhla slide	78.351	30.718	14	100	14	Debris slide	Toe erosion by river	112 m stretch of NH damaged
Uttarkashi	Gangori slide	78.351	30.718	20	120	20	Debris slide	Toe erosion by river	270 m of NH-108 damaged
Uttarkashi	Ganwan slide	78.351	30.718	58	300	58	Debris slide	Toe erosion by river	360 m of NH-108 damaged
Uttarkashi	Ganeshpur slide	78.351	30.718	38	45	38	Debris slide	Natural failure	Blockade of NH-108
Uttarkashi	Naitala slide	78.351	30.718	68	300	68	Rock cum debris slide	Adverse geological structure	500 m of NH-108 damaged
Uttarkashi	Heena slide	78.351	30.718	60	225	60	Debris slide	Natural failure	150 m of NH-108 damaged
Uttarkashi	Aungi slide	78.351	30.718	80	150	80	Rock cum debris slide	Adverse geological structure	300 m of NH-108 damaged
Uttarkashi	NH-108, Laldang slide	78.351	30.718	58	200	58	Rock cum debris slide	Adverse geological structure	250 m of NH-108 damaged
Uttarkashi	NH-108, Bishanpur slide	78.351	30.718	49	210	49	Rock cum debris slide	Adverse geological structure	700 m of NH-108 damaged
Uttarkashi	NH-108, Helgu slide	78.654	30.868	72	50	72	Debris slide	Natural failure	50 m of NH damaged
Uttarkashi	NH-108, Sunagar slide-1	78.669	30.885	20	45	20	Debris slide	Reduction in shear strength	Sinking of 45 m of NH-108
Uttarkashi	NH-108, Sunagar slide-2	78.674	30.894	72	100	72	Debris slide	Road cutting	270 m of NH108 damaged
Uttarkashi	NH-108, Gangnani slide	78.679	30.901	130	130	130	Rock cum debris slide	Adverse geological structure	180 m of NH108 damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Uttarkashi	NH-108, Jyoti slide	78.684	30.931	60	170	60	Rock cum debris slide	Adverse geological structure	192 m of NH108 sub-sided
Uttarkashi	NH-134, Chinyalisaur slide	78.326	30.582	32	130	32	Debris slide	Toe erosion by river	Sinking of 138 m stretch NH-134
Uttarkashi	NH-134, Dharasu slide	78.317	30.614	33	50	33	-	Toe erosion by river	40 m stretch of NH damaged
Uttarkashi	NH-134, Kalyani slide	78.307	30.644	40	30	40	Debris slide	Road cutting	NH-134 was blocked
Uttarkashi	Hanuman Chatti slide	78.282	30.848	48	73	48	Debris slide	Natural failure	124 m of NH134 blocked
Uttarkashi	Narad Chatti slide-I	78.282	30.848	0	130	0	Debris slide	Natural failure	150 m of road damaged
Uttarkashi	Near Darasu bend	78.327	30.635	120	300	100	Rock cum debris slide	Natural failure	National highway blocked and damaged, forest land affected
Uttarkashi	200 m before Nalupani Gad	78.332	30.649	20	153	18	Rock slide	Planar and wedge failure	1 km stretch of NH-108 damaged and forest land affected
Uttarkashi	Near Maharshi Vigyan Vidhya Peeth School	78.360	30.725	32	260	31	Debris slide	Natural failure	01 ashram and 01 hotel washed out
Uttarkashi	Opposite bank of Athali village	78.356	30.740	75	80	65	Debris slide	Toe erosion by river	Road damaged and forestland affected
Uttarkashi	Bandarkot village	78.362	30.743	150	85	120	Rock cum debris slide	Planar and wedge failure	08 shops completely washed away, 06 houses damaged
Uttarkashi	Left bank of Shylam Gad near confluence with Bhagirathi River	78.410	30.737	80	65	75	Debris slide	Toe erosion by river	265 m stretch of National highway and agricultural land damaged
Uttarkashi	250 m u/s of a bridge, near Hotal Great Ganga	78.453	30.752	15	100	14	Debris slide	Natural failure	112 m stretch of National highway and water pipeline damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Uttarkashi	400 m SE of Gangori Baily bridge	78.457	30.759	23	120	20	Debris slide	Natural failure and toe erosion	270 m stretch of NH-108 damaged, forest and agricultural land affected
Uttarkashi	D/s of Ganwan (Garam Pani) village	78.462	30.758	60	300	58	Debris slide	Natural failure	360 m stretch of NH-108 damaged and forest land affected
Uttarkashi	Near Ganeshpur	78.479	30.755	50	45	38	Debris slide	Natural failure	Blockade of NH-108
Uttarkashi	Opposite bank of Siroli village	78.493	30.743	85	300	68	Rock cum debris slide	Natural failure	500 m stretch of NH-108 damaged and forest land affected
Uttarkashi	D/s of Heena village	78.501	30.739	75	225	60	Debris slide	Natural failure and toe erosion	01 house totally damaged and 01 partially damaged; 300 m stretch of NH-108 washed away, right abutment of one iron bridge near Heena village breached
Uttarkashi	Near milestone of Maneri	78.528	30.742	20	20	18	Debris slide	Natural failure and toe erosion	About 71 m stretch of NH-108 damaged
Uttarkashi	Maneri reservoir	78.533	30.739	10	113	10	Debris slide	Natural failure	113 m stretch of NH-108 damaged
Uttarkashi	Opposite of New Dedsari village	78.544	30.742	30	70	28	Debris slide	Natural failure	70 m stretch of NH-108 damaged and forest land affected
Uttarkashi	D/s of Heena village	78.550	30.747	90	150	80	Rock cum debris slide	Planar and wedge failure	01 house damaged and 150 m stretch of NH-108 washed away, forest land affected
Uttarkashi	500 m d/s of Bishanpur	78.560	30.755	60	200	58	Rock slide	Planar and wedge failure	250 m stretch of NH-108 damaged
Uttarkashi	U/s of Bishanpur village	78.571	30.756	50	210	49	Rock slide	Planar and wedge failure	700 m stretch of NH-108 damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Uttarkashi	U/s of Lata village	78.606	30.777	60	30	52	Debris slide	Natural failure	125 m stretch of NH-108 damaged and agricultural land affected
Uttarkashi	U/s of Malla village	78.608	30.779	100	100	86	Debris slide	Natural failure	Electric transmission line damaged, forest land affected and subsidence of NH-108
Uttarkashi	Near Malla village	78.614	30.783	250	150	180	Rock cum debris slide	Natural failure	700 m stretch of NH-108 damaged and agricultural land washed away
Uttarkashi	NE of Malla village	78.616	30.788	40	30	25	Debris slide	Natural failure	30 m stretch of NH-108 damaged and agricultural land washed away
Uttarkashi	Near Bhatwari market	78.620	30.812	80	120	74	Rock cum debris slide	Natural failure	GNVN guest house washed away, 04 houses tilted, 700 m stretch of NH-108 subsided, agricultural land washed away
Uttarkashi	Opposite bank of Markand village	78.795	31.040	-	-	-	Debris slide	Natural failure	80 m stretch of NH-108 damaged and forest land affected
Uttarkashi	2.5 km from Dharali village	78.801	31.041	130	40	-	Debris slide	Natural failure	80 m stretch of NH-108 blocked and agricultural land damaged
Uttarkashi	3 km d/s from Jangla bridge	78.814	31.044	200	42	180	Debris slide	Natural failure	50 m stretch of NH-108 blocked and damaged, forest land affected
Uttarkashi	1 km from Dharasu bend	78.327	30.625	45	160	38	Rock cum debris slide	Road widening	170 m stretch of NH-108 damaged and forest land affected
Uttarkashi	1.5 km from Pali village	78.316	30.890	25	78	20	Rock cum debris slide	Natural failure	NH blocked and forest land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Uttarkashi	Opposite bank of Achuna Gad	78.321	30.894	127	125	125	Debris slide	Toe erosion by river	12 kuchha houses and 77 m stretch of NH damaged, agricultural land washed away
Uttarkashi	1 km from Wajri village	78.327	30.899	20	45	18	Rock cum debris slide	Natural failure	60m of NH-108 damaged and forest land affected
Uttarkashi	2 km before Sainachatti	78.365	30.910	20	78	19	Rock cum debris slide	Natural failure	80 m of NH-108 damaged and forest land affected
Uttarkashi	Near Rana Chatti village	78.383	30.922	40	120	32	Rock cum debris	Natural failure	130 m of NH-108 damaged and forest land affected
Uttarkashi	Below Wariya village	78.393	30.928	95	212	85	Debris slide	Natural failure and road widening	215 m of NH-108 damaged and forest land affected
Uttarkashi	500 m NE of Wariya village	78.399	30.931	18	78	16	Debris slide	Natural failure	247 m of NH-108 blocked and damaged and agricultural land affected
Uttarkashi	250 m SE of Hanuman Chatti	78.403	30.930	65	250	57	Debris slide	Natural failure and toe erosion	01 house damaged and 300 m stretch of road connecting Hanuman Chatti to the power-house area of Hanuman Ganga HEP damaged and forest land affected
Uttarkashi	East of Durbil village	78.402	30.934	53	73	48	Debris slide	Natural failure	120 m stretch of NH-134 blocked and forest land affected
Uttarkashi	600 m SE of Banas village	78.414	30.950	-	-	-	Debris slide	Natural failure	75 m stretch of road damaged and forest land affected
Uttarkashi	250 m u/s of confluence of Sauri Gad with Yamuna river	78.407	30.942	-	130	-	Debris slide	Natural failure	150 m stretch of road damaged and forest land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Uttarkashi	750 m NE of Banas village	78.421	30.958	-	40	-	Debris slide	Natural failure	GNVN guest house, 90 m stretch of NH, agricultural land damaged
Uttarkashi	300m u/s of Yamunotri temple	78.463	31.000	-	-	-	Rock cum debris slide	Planar and wedge failure	Rooms of Dharm-shala tilted
Rudraprayag	350 m north of Gaurikund, right bank of Mandakini river	79.028	30.657	30	25	25	Rock cum debris slide	Toe erosion by river	20 to 25 commercial settlements washed away
Rudraprayag	Opposite to main Gaurikund market	79.029	30.653	200	300	150	Debris slide	Toe erosion by river	30 to 40 commercial settlements washed away
Rudraprayag	500 m south of Gaurikund market above NH-109	79.024	30.650	120	30	100	Debris slide	Toe erosion by river	Part of NH-109 washed away
Rudraprayag	Opposite to main Gaurikund parking space	79.021	30.645	80	25	60	Debris slide	Toe erosion by river	Part of NH-109 washed away
Rudraprayag	Left bank of Mandakini river and 500 m south of Gaurikund main parking space	79.018	30.642	75	100	50	Debris slide	Toe erosion by river	Forest land affected
Rudraprayag	Opposite to Mundkatiya Ganes village, left bank of Mandakini river	79.012	30.638	40	500	30	Debris slide	Toe erosion by river	Forest land affected
Rudraprayag	Immediate south of Mundkatiya village, left bank of Mandakini river	79.005	30.638	900	5	6.5	Debris slide	Bank erosion	About 1.5 km of NH-109 completely washed away

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Sonprayag	79.001	30.634	100	100	80	Debris slide	Toe erosion by river	Part of NH-109 washed away, forest land affected
Rudraprayag	4.5 km before Sonprayag on NH-109, left bank of kaldungi nala	79.014	30.614	200	200	150	Rock slide	Road cutting	Part of NH-109 washed away, forest land affected
Rudraprayag	5 km before Sonprayag on NH-109, right bank of kaldungi nala	79.015	30.612	100	200	70	Debris slide	Toe erosion by nala	150 m stretch of NH-109 damaged
Rudraprayag	Near Sersi village on NH-109, left bank of nala	79.017	30.606	35	80	25	Debris slide	Cut slope	Helipad and 2 to 4 buildings partially damaged
Rudraprayag	7.2 km north of Phata village along NH-109, near Badalpur village	79.018	30.609	35	50	25	Rock cum debris slide	Road cutting	Blockade of NH-109
Rudraprayag	Badasu village	79.022	30.601	225	175	200	Debris slide	Toe erosion by river	Part of NH-109 damaged
Rudraprayag	Between Khat and Phata village, right bank of Mandakini River	79.043	30.578	250	110	150	Debris slide	Toe erosion by river	100 m of NH-109 badly damaged
Rudraprayag	Located just above NH-109 at Khat village	79.046	30.562	8	50	5	Debris slide	Natural failure	Helipad and agricultural land partially damaged
Rudraprayag	Khat village	79.050	30.576	9	30	5	Debris slide	Natural failure	A small building and part of agricultural land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Maikhanda village	79.054	30.574	50	100	30	Debris slide	Natural failure	Helipad premises and 50 m stretch of NH-109 badly affected
Rudraprayag	Near Shak-ti-punj Hotel, Byung village, below NH-109	79.062	30.563	150	15	125	Rock fall	Natural failure	Forest land affected
Rudraprayag	Near the adit of Byung Phata HEP	79.062	30.566	60	100	40	Rock cum debris slide	Natural failure	Part of NH-109 and forest affected
Rudraprayag	Semi village	79.085	30.516	450	700	150	Subsidence	Toe erosion by river	House and commercial buildings damaged
Rudraprayag	Right abutment of Kund girder bridge	79.088	30.504	175	120	150	Debris slide	Toe erosion by river	Partial damage to right abutment of Kund bridge and NH-109
Rudraprayag	Above Semi village, on Gupt-kashi-Mayali road, left bank of Rawan ganga river	79.079	30.515	80	130	60	Debris slide	Road cutting	150 m stretch of Guptkashi-Mayali road affected
Rudraprayag	Opposite to Lawara village, on Guptkashi-Mayali road, left bank of Rawan ganga river	79.067	30.514	220	50	190	Rock fall	Road cutting	70 m stretch of Guptkashi-Mayali road affected
Rudraprayag	1 km before Andrawari village of Guptkashi-Mayali road, right bank of Rawan ganga river	79.057	30.508	200	150	175	Debris slide	Bank and rill erosion	100 m stretch of Guptkashi-Mayali road affected

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Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Left bank of Mandakini river and 1.2 km south of Kund bridge along NH-109	79.088	30.499	40	25	30	Rock slide	Bank erosion	30 m stretch of NH-109 road damaged
Rudraprayag	Left bank of Mandakini river and 1.5 km south of Kund bridge along NH-109	79.088	30.493	80	130	50	Debris slide	Toe erosion by river and road cutting	100 m stretch of NH-109 road damaged
Rudraprayag	80 m downstream of confluence of Mandakini and Kakra gad, left bank of Mandakini river	79.085	30.488	225	100	60	Debris slide	Toe erosion by river and road cutting	200 m stretch of NH-109 road damaged
Rudraprayag	1.5 km north of Bhiri village, left bank of Mandakini village	79.086	30.483	200	175	70	Debris slide	Toe erosion by river	150 m stretch of NH-109 road damaged
Rudraprayag	Near bridge connecting Bhiri and Temriya village, right bank of Mandakini	79.083	30.478	80	100	50	Debris slide	Natural failure	Forest land affected
Rudraprayag	Downstream of bridge connecting Bhiri and Temriya village, right bank of Mandakini	79.082	30.476	75	40	60	Rock cum debris slide	Toe erosion by river	Foot track completely destroyed

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Between Damar and Temriya village, right bank of Mandakini village	79.070	30.474	700	200	350	Debris slide	Toe erosion by river	Foot track blocked, agriculture and forest land affected
Rudraprayag	Opposite to Banswara, right bank of Mandakini	79.074	30.455	180	150	160	Rock cum debris slide	Toe erosion by river	Forest land affected
Rudraprayag	400 m before Banswara on NH-109	79.079	30.450	75	30	60	Rock cum debris slide	Toe erosion by river and road cutting	30 m stretch of NH-109 road damaged
Rudraprayag	1 km before Banswara opposite to NH-109, below Dewal village	79.076	30.448	150	200	120	Debris slide	Toe erosion by river	-
Rudraprayag	About 2.5 km north of Chandrapuri on NH-109 between Syalsaur and Banswara	79.077	30.442	900	4	5	River bank erosion	Bank erosion	800 m stretch of NH-109 road and agriculture land damaged
Rudraprayag	2 km north of Chandrapuri, right bank of Mandakini	79.072	30.436	30	60	25	Debris slide	Toe erosion by river	Loss of property, agricultural land and forest land
Rudraprayag	North of old Chandrapuri on right bank of Mandakini	79.070	30.428	300	10	3	River bank erosion	Toe erosion by river	Buildings on T1 terrace completely damaged, agricultural land affected
Rudraprayag	South of old Chandrapuri on right bank of Mandakini	79.068	30.428	30	90	25	Debris slide	Toe erosion by river	Agricultural land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	100 m north of New Chandrapuri village Market on left bank of Mandakini	79.066	30.418	300	4	4	Bank erosion	Toe erosion by river	500 m stretch of NH-109 damaged and forest land affected
Rudraprayag	Just south of Chandrapuri village market on left bank of Mandakini	79.068	30.424	200	6	15	River bank erosion	Toe erosion by river	200 m stretch completely washed away and 1 km stretch of NH-109 damaged and agricultural land affected
Rudraprayag	400 m south of New Chandrapuri village along NH-109	79.070	30.423	300	3	4	River bank erosion	Toe erosion by river	200 m stretch of NH-109 road badly damaged and partly swept away
Rudraprayag	1 km before Chandrapuri village, on the right bank of Mandakini river	79.064	30.419	50	60	45	Debris slide	Toe erosion by river	Road damage
Rudraprayag	1 km south of Silli village, on the left bank of Mandakini river	79.001	30.378	700	5	4	River bank erosion	Toe erosion by river	300 m stretch completely washed away and 700 m stretch of NH-109 is badly affected between Gangtal and Silli.
Rudraprayag	Opposite to Hat village located on right bank	79.059	30.409	40	30	35	Debris slide	Toe erosion by river and road cutting	40 m stretch of NH-109 road damaged and forested land affected
Rudraprayag	4 km north of Agastmuni market on left bank of Mandakini	79.054	30.409	700	8	15	River bank erosion	Bank erosion	Property lost and partial damage to NH-109 and substantial loss of agricultural land

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Ganganagar on NH-109	79.046	30.404	25	100	20	Debris slide	Bank erosion	Partial damage to left abutment of steel bridge and 40 m stretch of NH-109
Rudraprayag	2 km north of Agastmuni market	79.044	30.405	500	8	5	River bank erosion	Bank erosion	Heavy loss of property and 100 m stretch of NH-109 damaged
Rudraprayag	300 south of Ganganagar on right bank of Mandakini	79.043	30.403	35	100	30	Debris slide	Bank erosion	10 houses toppled, 60 m foot track swept away
Rudraprayag	Opposite to Agastmuni Degree College, right bank of Mandakini	79.037	30.401	125	100	85	Debris slide	Toe erosion by river	35 m foot track badly affected
Rudraprayag	200 m north of Agastmuni market, left bank of Mandakini	79.031	30.392	350	20	25	River bank erosion	Bank erosion	50 houses on T1/T2 terraces swept away
Rudraprayag	Below East Chaka village on right bank of Mandakini	79.020	30.394	150	130	120	Debris slide	Toe erosion by river	Agricultural and forest land affected
Rudraprayag	300 m south of Sauragad village, left bank of Mandakini	79.019	30.387	250	5	5	River bank erosion	Bank erosion	75 m stretch completely washed away and 350 m stretch of NH-109 damaged and agricultural land affected
Rudraprayag	Back of Silli village, left bank of Mandakini	79.033	30.380	175	15	150	Debris slide	Natural failure	Agricultural land affected
Rudraprayag	Either side of NH-109	79.016	30.394	400	3	6	River bank erosion	Toe erosion by river	80 houses damaged and steel girder bridge swept away
Rudraprayag	South of Silli market	79.010	30.383	200	25	175	Rock cum debris slide	Toe erosion	Forest land affected

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Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	150 m before Silli village on NH-109	79.010	30.381	130	150	90	Debris slide	Bank erosion	125 m of NH-109 completely washed away
Rudraprayag	250 m south of Silli village on NH-109	79.006	30.380	150	3	3	Bank erosion	Bank erosion	200 m of NH-109 completely washed away and forest land affected
Rudraprayag	500 m before Silli village on right bank of Mandakini river	79.003	30.379	70	90	50	Debris slide	Toe erosion by river	30 m foot track badly affected
Rudraprayag	1 km south of Silli village on the left bank of Mandakini river	79.001	30.378	700	5	4	Bank erosion	Bank erosion	300 m stretch completely washed away and 700 m stretch of NH-109 badly affected between Gangtal and Silli and forest land affected
Rudraprayag	Near Phalti village on right bank of Mandakini river	78.999	30.376	50	75	40	Debris slide	Toe erosion by river	Forest land affected
Rudraprayag	Near Gangatal village on right bank of Mandakini river	78.995	30.372	70	90	60	Debris slide	Toe erosion by river	Blockade of NH-109
Rudraprayag	300 m south of Gangatal village on the left bank of Mandakini river	78.994	30.367	70	200	55	Rock cum debris slide	Toe erosion by river	Forest land affected
Rudraprayag	At Rampur village near kilometer stone	78.982	30.364	50	4	12	River bank erosion	Toe erosion by river	30 m stretch of NH-109 road damaged and barren land affected
Rudraprayag	1 km south of Rampur village on the left bank of Mandakini river	78.980	30.359	300	4	15	River bank erosion	Bank erosion	300 m stretch of NH intermittently damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Opposite to Tilwara near Tilwara-Mayali road right bank of Mandakini river	78.975	30.346	350	8	12	River bank erosion	Bank erosion	30 houses damaged, 10 m stretch of Tilwara-Mayali road damaged and agricultural land affected
Rudraprayag	On Tiwara-Saurakhal road right bank of Mandakini river	78.970	30.344	250	150	200	Debris slide	Toe erosion by river	15 houses badly damaged, 60 m stretch of Tilwara-Saurakhal road damaged, agricultural and forest land affected
Rudraprayag	500 m before Tilwara, near petrol pump on left bank of Mandakini river	78.969	30.341	50	4	15	Bank erosion	Bank erosion	25 m stretch of NH-109 road damaged
Rudraprayag	7.4 km from Rudraprayag along NH-109	78.969	30.327	20	180	12	Rock cum debris slide	Toe erosion by river	100 m stretch of NH-109 road damaged
Rudraprayag	6.6 km from Rudraprayag near bifurcation for Nari village road	78.969	30.319	30	50	20	Rock cum debris slide	Gully erosion	50 m stretch of NH-109 road damaged and forest affected
Rudraprayag	3 km from Tilwara on Tilwara-Mayali road on right bank of Lastar Gad	78.964	30.340	40	30	25	Debris slide	Rill erosion	Partial blockade of SH-15 and damage to forest land
Rudraprayag	Right bank of Helaun Gad on Tilwara-Mayali road near Regar village	78.907	30.361	175	20	60	Debris slide	Gully erosion	Partial blockade of SH-15 and damage to forest land
Rudraprayag	On tilwara-Mayali road on right bank of Helaun Gad near Launga village	78.901	30.364	10	15	8	Debris slide	Gully erosion	Partial blockade of SH-15 and damage to forest land

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	Right bank of Mandakini river, 500 m downstream of confluence of Kali ganga and Mandakini river	79.083	30.548	130	200	100	Debris slide	Bank erosion	Agricultural land washed away
Rudraprayag	Below Narayan-koti village on right bank of Mandakini river	79.086	30.546	200	150	175	Debris slide	Bank erosion	Forest land affected
Rudraprayag	Left bank of Mandakini river opposite to Narayankoti village	79.094	30.544	40	25	40	Debris slide	Rill erosion	Blockade of road
Rudraprayag	Left bank of the Mandakini river	79.085	30.546	150	100	120	Rock cum debris slide	Bank erosion	Road damage and forest land affected
Rudraprayag	500 m north of iron bridge on right bank of Mandakini river	79.092	30.540	100	700	80	Debris slide	Toe erosion by river	Forest land affected
Rudraprayag	Right bank of Mandakini river, 500 m south of its confluence with Madh-maheshwar ganga	79.091	30.531	300	200	275	Debris slide	Toe erosion by river	700 m road damaged at different levels
Rudraprayag	1.5 km north of Kund iron bridge on Kund-Okhi-math road	79.088	30.511	130	50	100	Debris slide	Toe erosion by river	50 m stretch of SH-36 completely damaged and forest land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	3.5 km north of Kund iron bridge on Kund-Okhimath road near power corporation building, Chunni village	79.096	30.524	700	50	600	Debris slide	Bank erosion by nala and toe erosion by Mandakini river	Buildings, agriculture, forest land and part of SH-36 road damaged
Rudraprayag	4 km north of Kund iron bridge on Kund Okhimath road below Chunni village	79.093	30.529	250	30	200	Debris slide	Toe erosion by river	30 m stretch of SH-36 completely washed away and forest land affected
Rudraprayag	Left bank of Madhmaheshwar ganga, 300 m upstream of its confluence with Mandakini river	79.099	30.537	200	150	175	Rock cum debris slide	Toe erosion by river	Forest land affected
Rudraprayag	1.5 km before Mansuna village below road, opposite to Jaggi slide, on the left bank of Madhmaheshwar Ganga	79.115	30.548	100	200	200	Rock cum debris slide	Toe erosion by river	Forest land affected
Rudraprayag	Right bank of Madhmaheshwar ganga, 300 m north east of Jaggi-Bedula village	79.111	30.549	700	500	450	Debris slide	Toe erosion by river	300 m road stretch completely damaged and agriculture land near river bank washed away
Rudraprayag	Near Mansuna village	79.126	30.551	10	20	7	Debris slide	Cut slope	Road partly damaged and forest land partly affected
Rudraprayag	Near steel girder bridge on Madhmaeshwar ganga	79.135	30.569	400	5	8	River bank erosion	Bank erosion	Buildings and agricultural land washed away (Jagga and Mansuna village), road stretch between km 14 and 15 damaged completely

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Rudraprayag	500 m before Chhaji village	79.125	30.570	35	25	20	Rock cum debris slide	Cut slope	10 m stretch of road damage & forest affected
Rudraprayag	400 m south of Ransi village	79.142	30.586	30	100	20	Debris slide	Cut slope	Road damage and agricultural land affected
Rudraprayag	7.5 km from Okhmath near Korkhi	79.129	30.505	120	100	100	Debris slide	Natural failure	50 m stretch of SH-36 damaged, barren, agriculture and forest land affected
Rudraprayag	50 m before Mastura village on SH-36	79.142	30.513	150	60	100	Debris slide	Natural failure	Stretch of SH-36 damaged, barren, agriculture land affected
Rudraprayag	11 km from Okhmath on Okhmath-Chopta road, right bank of Siot Gad	79.162	30.510	500	400	-	Subsidence	Toe erosion by river	Buildings affected and 100 m stretch of SH-36 at Usara village damaged
Pithoragarh	-	79.918	29.709	35	35	25	Rock fall	wedge failure	State highway damaged
Pithoragarh	-	79.922	29.714	25	35	15	Debris slide	Natural failure	Road damaged and forest affected
Pithoragarh	-	80.117	29.826	15	45	15	Debris slide	Natural failure	State highway damaged
Pithoragarh	-	80.120	29.827	40	25	30	Debris slide	Road widening	State highway damaged
Pithoragarh	Lodia-bagar	80.148	29.933	120	200	80	Rock cum debris slide	Toe erosion by Ramganga river	Road damaged and forest affected above crown
Pithoragarh	-	80.146	30.004	140	50	80	Rock cum debris slide	Natural failure	Agricultural land affected
Pithoragarh	Major slide on opposite bank of present location	80.151	30.016	80	30	50	Rock cum debris slide	Toe erosion by river and road widening	Road blockade

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	-	80.150	30.022	80	210	50	Rock cum debris slide	Gully erosion	Road blockade and subsidence
Pithoragarh	-	80.157	30.021	70	150	110	Debris slide	Gully erosion	10 houses damaged, agriculture land affected
Pithoragarh	-	80.217	30.054	35	40	20	Debris slide	Gully erosion	70 m of road sub-sided
Pithoragarh	Opposite to Dhapa village	80.256	30.122	700	500	500	Debris slide	Gully erosion	6 houses damaged completely, 35 people affected and 5 live stock lost
Pithoragarh	Left bank of Senar gad just near steel bridge	80.236	30.108	80	150	60	Debris slide	Gully erosion	150 m stretch of road and forest land affected
Pithoragarh	Left bank of Senar gad	80.230	30.107	600	250	400	Debris slide	Gully erosion	One house damaged each at Senar and Pyangti village; 24 & 14 families affected at Senar and Pyangti village respectively
Pithoragarh	-	80.240	30.114	100	60	60	Debris slide	Gully erosion	6 houses damaged, 20 people affected
Pithoragarh	Above Jimi tok village	80.246	30.132	40	125	25	Debris slide	Gully erosion & road widening	Road and forest land affected
Pithoragarh	Right bank of Goriganga river, confluence of Jimi nala	80.250	30.134	25	350	6	Bank erosion	Toe erosion by river and gully erosion	Agricultural land affected
Pithoragarh	Opposite to Dhapa village	80.256	30.122	700	500	500	Debris slide	Natural failure	6 houses completely damaged, about 35 people affected and 5 nos. of live stock lost

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Right bank of Goriganga river	80.251	30.108	270	1500	200	Debris slide	Gully erosion	5 houses and foot track completely damaged, UJVNL power house washed away and about 20 people affected
Pithoragarh	Near steel bridge	80.253	30.086	45	45	35	Debris slide	Gully erosion	45 m of road stretch damaged and forest land affected
Pithoragarh	Right bank of Goriganga river	80.271	30.081	1000	1100	800	Debris slide	Gully erosion	15 houses in Kainthi village completely damaged, 15 families of the village affected
Pithoragarh	Bhadel village on right bank of Goriganga river	80.279	30.074	1300	30	20	Bank erosion	Toe erosion by river and gully erosion	3 houses in Bhadel Tok village completely damaged, 3 families of the village affected, 1200 m road stretch affected and 400 m road stretch and 2 nali agricultural land washed away
Pithoragarh	Right bank of Goriganga river	80.289	30.069	40	120	30	Debris slide	Toe erosion by river and gully erosion	150 m stretch of road and forest land affected
Pithoragarh	Madkot village, left bank of Goriganga river	80.292	30.058	20	500	60	Bank erosion	Toe erosion by river and gully erosion	17 nos. of buildings, 350 m road stretch completely washed away and 4 families affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Near temple and Walthi village on left bank of Goriganga river	80.304	30.048	20	600	15	Bank erosion	Toe erosion by river and gully erosion	2 houses damaged. agricultural land washed away and 4 families affected
Pithoragarh	-	80.319	30.014	90	200	75	Debris slide	Toe erosion by river and gully erosion	Road network and forest land affected
Pithoragarh	Confluence of Goriganga river with Palna gad	80.320	30.009	150	30	20	Bank erosion	Toe erosion by river and gully erosion	Powerhouse of Himalayan Hydro damaged, road network and agricultural land affected
Pithoragarh	Left flank of Goriganga river	80.318	29.986	60	250	45	Debris slide	Toe erosion by river and gully erosion	250 m road stretch washed away and forest land affected
Pithoragarh	Electric poles (4 nos.) on left bank of Goriganga river	80.315	29.978	200	700	150	Rock cum debris slide	Toe erosion by river and road widening	700 m road stretch washed away and forest land affected
Pithoragarh	Left flank of Goriganga river	80.312	29.970	70	400	40	Bank erosion	Gully erosion	08 houses completely damaged, 04 houses partially damaged, 14 families affected and 150 nali agricultural land lost
Pithoragarh	Left flank of Goriganga river	80.314	29.965	80	10	40	Rock cum debris slide	Gully erosion	Road network and forest land affected
Pithoragarh	Suspension bridge over Goriganga river	80.306	30.961	60	800	60	Bank erosion	Gully erosion	02 houses including Patwari Chowki partially damaged and agricultural land lost

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Suspension bridge over Goriganga river	80.305	29.958	40	35	25	Debris slide	Gully erosion	50 m road stretch damaged and forest land affected
Pithoragarh	Suspension bridge over Goriganga river	80.305	29.958	20	1000	20	Bank erosion	Gully erosion	03 houses damaged, caving of support of suspension bridge, road network and agricultural land affected
Pithoragarh	Left bank of Goriganga river	80.302	29.948	35	1500	20	Bank erosion	Gully erosion	08 houses completely damaged, 04 families affected, 1.5 km road stretch washed away and 200 nali agricultural land lost
Pithoragarh	Left bank of Goriganga river	80.304	29.931	40	160	22	Rock cum debris slide	Toe erosion by river and road widening	150 m stretch of road and forest land affected
Pithoragarh	Left bank of Goriganga river	80.313	29.905	80	250	15	Bank erosion	Gully erosion	Agricultural land affected
Pithoragarh	Left bank of Goriganga river	80.315	29.903	200	220	160	Debris slide	Gully erosion	Road and forest land affected
Pithoragarh	Left bank of Goriganga river	80.318	29.893	80	250	20	Bank erosion	Gully erosion	06 houses and 250 m road stretch completely washed away, 05 nali agricultural land lost
Pithoragarh	Dogri/Chami Nala intersection, left bank of Goriganga river	80.326	29.881	60	325	40	Debris slide	Gully erosion	300 m road stretch damaged

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Left bank of Goriganga river	80.366	29.829	1200	70	60	Bank erosion	Gully erosion	36 houses and road network affected, 1.5 nali agriculture land lost
Pithoragarh	Left bank of Goriganga river, near Toli village	80.373	29.818	50	350	30	Rock cum debris slide	Gully erosion and road widening	300 m road stretch damaged and agricultural land affected
Pithoragarh	Nala intersection, left bank of Goriganga river	80.370	29.809	40	125	25	Debris slide	Gully erosion and road widening	150 m stretch of road and forest land affected
Pithoragarh	Confluence of Kali and Dhauliganga river	80.601	29.958	-	1000 (along road)	15	Bank erosion	Gully erosion	52 houses completely damaged, 1 person died and about 100 people affected; motorable bridge on Dhauliganga river connecting Dharchula with Garbhyang through Tawaghat washed away, also 350 m road stretch along right bank of Dhauliganga river from Tawaghat to Dar washed away
Pithoragarh	Right bank of Kali river	80.594	29.952	45	30	30	Debris slide	Gully erosion & road widening	150 m stretch of road affected
Pithoragarh	Confluence of Elagad and Kali river	80.570	29.923	-	500	20	Bank erosion	Gully erosion	10 nos of State highway bailey bridge on Elagad, MAT portal of NHPC's HEP u/s of confluence washed away, UJVNL powerhouse damaged and 1 km road stretch affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Right bank of Kali river	80.570	29.902	70	150	50	Debris slide	Gully erosion	About 90 m stretch of road washed away
Pithoragarh	Near Electric tower line, right bank of Kali river	80.567	29.885	18	600	20	Bank erosion	Gully erosion	About 600 m stretch of road damaged
Pithoragarh	Dobat village on right bank of Kali river	80.563	29.877	20	400	40	Bank erosion	Gully erosion	08 houses, 24 people and 1 nali of agriculture land affected
Pithoragarh	Downstream of Dobat village, right bank of Kali river	80.561	29.872	120	100	80	Debris slide	Gully erosion	120 m road stretch affected
Pithoragarh	NHPC (administrative colony), on right bank of Kali river	80.556	29.870	25	350	10	Bank erosion	Gully erosion	11 houses and store of NHPC colony, hot spring location and temple washed away and 60 people affected
Pithoragarh	Right bank of Kali river	80.549	29.854	15	400	10	Bank erosion	Gully erosion	02 houses affected and 25 nali agricultural land washed away
Pithoragarh	Suspension bridge connecting to Nepal	80.536	29.847	45	300	5	Bank erosion	Gully erosion	About 30 barracks of Indian Army and flood protection wall completely washed away, 40 nali agricultural land washed away
Pithoragarh	Baluwakot village	80.430	29.801	50	500	20	Bank erosion	Gully erosion	43 houses and families, 100 m stretch of State highway damaged, 30 nali agricultural land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Right bank of Kali river	80.381	29.751	60	300	7	Bank erosion	Gully erosion	01 room in school, 01 check-post of SSB and 01 community stage washed away; foot-suspension bridge across Kali river connecting Indian Territory with Nepal washed away
Pithoragarh	-	80.348	29.758	25	60	20	Rock cum debris slide	Natural failure and gully erosion	Road and forest land affected
Pithoragarh	Downslope of Askot village	80.331	29.764	30	200	20	Rock cum debris slide	Natural failure and gully erosion	Road and forest land affected
Pithoragarh	-	80.235	29.754	300	450	220	Debris slide	Natural failure	45 houses partially damaged; 50 families, road and forest land affected
Pithoragarh	Opposite to Didihat village	80.245	29.794	250	220	210	Debris slide	Natural failure	03 house partially damaged, one family, agricultural and forest land affected
Pithoragarh	-	80.162	29.709	40	25	20	Rock cum debris slide	Gully erosion	Road and forest land affected
Pithoragarh	-	80.081	29.581	40	35	25	Rock cum debris slide	Gully erosion	State highway affected
Pithoragarh	Suspension bridge on Kali river connecting Nepal	80.383	29.571	50	15	25	Bank erosion	Natural failure	37 houses damaged, 120 people, 03 livestock and 25 nali agricultural land affected
Pithoragarh	-	80.316	29.761	40	60	22	Debris slide	Road widening	State highway affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Right bank of Ramganga river	80.136	29.823	200	80	150	Debris slide	Gully erosion	20 houses, 100 people, State highway affected
Pithoragarh	Near steel bridge	80.041	29.884	120	120	35	Debris slide	Gully erosion	07 houses sink, 06 families and State highway affected
Pithoragarh	-	80.038	29.887	80	40	35	Debris slide	Gully erosion	03 families, State highway and forestland affected
Pithoragarh	Left bank of Ramganga river	80.119	29.958	180	105	125	Rock cum debris slide	Gully erosion	State highway affected
Pithoragarh	Just over Raton village, left bank of Ramganga river	80.086	29.984	100	60	70	Rock cum debris slide	Gully erosion and road widening	Road and forest land affected
Pithoragarh	Right bank of Dhauliganga river	80.590	29.977	200	100	90	Debris slide	Gully erosion	100 m road stretch damaged
Pithoragarh	Immediate d/s of NHPC Dam	80.584	29.978	80	120	50	Debris slide	Gully erosion	02 families, 02 house affected, 100 m road stretch damaged and 17 nali agricultural land affected
Pithoragarh	Immediate d/s of NHPC Dam	80.584	29.978	100	120	-	Rock cum debris slide	Gully erosion	03 km stretch of road damaged, temporary hutments, NHPC dam and spillway structure damaged
Pithoragarh	U/s of NHPC dam-site, right bank of Dhauliganga river	80.566	29.992	170	70	110	Rock cum debris slide	Gully erosion	100 m road stretch damaged and forest land affected
Pithoragarh	Khet village	80.566	29.997	30	1500	80	Bank erosion	Natural failure	1.2 km road stretch damaged, agricultural and forest land affected

contd.

Annexure - II (contd.)

District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	Along right and left bank of Dhauliganga river	80.572	30.018	25	1000	30	Bank erosion	Natural failure	02 people died, 40 houses and 40 families each in Khimtal and Kanchuti village affected, 01 km road stretch damaged; steel bridges on Kanchuti nala and Dhauliganga river, Kanchuti Micro-Hydel power house washed away, 200 nali agricultural land affected
Pithoragarh	Along right and left bank of Dhauliganga river	80.573	30.021	150	600	100	Debris slide	Gully erosion	600 m road stretch damaged
Pithoragarh	50 m d/s of confluence of Dhauliganga with Suwagad	80.583	30.034	130	150	100	Debris slide	Gully erosion	150 m road stretch damaged
Pithoragarh	Jhimargaon village	80.586	30.039	15	130	15	Bank erosion	Natural failure	06 nos livestock lost
Pithoragarh	D/s of confluence of Dhauliganga river and Thari nala	80.588	30.053	50	700	20	Bank erosion	Gully erosion	45 houses and shops, suspension bridge partially damaged; 45 families and 250 nali agricultural land affected
Pithoragarh	Dhauliganga-Thari nala confluence	80.587	30.059	35	1000	20	Bank erosion	Gully erosion	190 houses in Sobala and 23 houses in Thari village, ITBP barracks, army transit camps, bridge on Thadi Gad, Sobala Micro-hydel powerhouse area completely washed away; 450 people and 250 nali agricultural land affected

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Annexure - II (contd.)

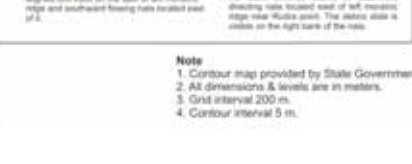
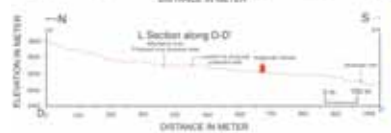
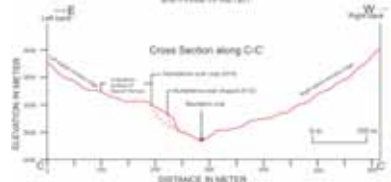
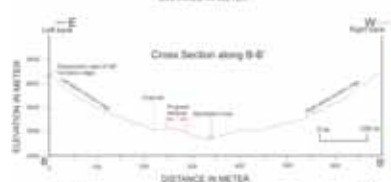
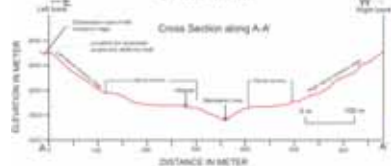
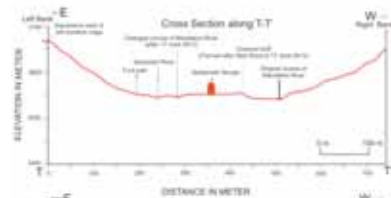
District	Location/Name of landslide	Long.	Lat.	L	W	H	Type of landslide	Cause	Damage detail
Pithoragarh	U/s of Dhauli-ganga-Thari nala confluence	80.603	30.071		1000	80	Bank erosion	Gully erosion	Subsidence in re-spective village
Pithoragarh	U/s of Dhauli-ganga-Thari nala confluence, helipad at Tijam	80.571	30.064	40	2000	60	Bank erosion	Gully erosion	09 houses, UJVNL projects weir washed away, 02 people died, 08 families, 03 livestock, 02 nali agricultural land affected
Pithoragarh	-	80.615	29.961	70	60	40	Debris slide	Gully erosion	Road affected
Pithoragarh	Right bank of Kali river	80.633	29.965	50	215	30	Debris slide	Gully erosion	Road affected
Pithoragarh	Right bank of Kali river	80.636	29.964	45	110	20	Debris slide	Gully erosion	Road and forest land affected
Pithoragarh	-	80.649	29.959	70	70	45	Rock cum debris slide	Gully erosion & road widening	Road affected
Pithoragarh	-	80.669	29.958	45	220	30	Debris slide	Natural failure	220 m road stretch affected
Pithoragarh	-	80.679	29.961	30	80	20	Debris slide	Natural failure	Road affected
Pithoragarh	Near Mangti village	80.717	29.998	100	90	70	Debris slide	Natural failure & gully erosion	100 m road stretch damaged
Pithoragarh	150 m d/s of Mangti steel bridge on Symkhola Gad	80.719	30.003	130	140	80	Rock cum debris slide	Gully erosion	150 m road stretch damaged

L is Length of landslide in meter; W is Width of landslide in meter and H is height of landslide in meter.



GEOLOGICAL SURVEY OF INDIA

DETAILED GEOLOGICAL AND GEOMORPHOLOGICAL MAP FOR PROPOSED TREATMENT MEASURES IN THE KEDARNATH AREA, RUDRAPRAYAG DISTRICT, UTTARAKHAND



Note
1. Contour map provided by State Government
2. All dimensions & levels are in meters.
3. Grid interval 200 m.
4. Contour interval 5 m.

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Back Cover photo : Landslide at Aungi Village, Bhatwari, Uttarkashi district, Uttarkhand.