R7815

Landslide Risk Assessment in the Rural Access Sector

Report on Project Activities Undertaken in Nepal

November 2000 – March 2003

April 2003

Scott Wilson
DFID Department for International Development

R7815 - Landslide Risk Assessment in the Rural Access Sector

Report on Project Activities Undertaken in Nepal

November 2000 – March 2003

This document is an output from a project funded by the UK Department for International Development (DFID) for the benefit of developing countries. The views expressed are not necessarily those of the DFID.

Version/Revision	Dated	Prepared By	Reviewed By
Draft	March 2003	AB Hart	GJ Hearn
Final	April 2003	AB Hart	GJ Hearn

Scott Wilson Kirkpatrick & Co Ltd

Scott House, Basing View, Basingstoke, RG21 4JG, UK

Tel: +44 (0)1256 461161 / E-mail: gareth.hearn@scottwilson.com

Report on Project Activities undertaken in Nepal
November 2000 – March 2003

Contents

Appendices

List of Tables:

Report on Project Activities Undertaken in Nepal
November 2000 – March 2003

1 Introduction

The project entitled 'Landslide Risk Assessment in the Rural Access Sector' (Landslide Risk Assessment – LRA) is sponsored by the UK Department for International Development (DFID) as part of its Knowledge and Research Programme. The project aim is to develop and test rapid means of landslide susceptibility mapping for road alignment purposes in remote rural areas in hilly or mountainous terrain. The project has also produced guidelines on how best to apply the techniques as well as recommendations for the management of road corridors in landslide-prone areas. The project has been implemented in Nepal in association with the Ministry of Local Development and in Bhutan in conjunction with the Department of Roads.

The principal activities and outputs of the project are as follows:

- Establishment of a Geographical Information System (GIS) within Department of Local Infrastructure Development and Agricultural Roads (DoLIDAR) Nepal and Department of Roads (DoR) Bhutan
- Procurement and interpretation of satellite imagery and aerial photography for landslide assessment
- Development of GIS datasets for the selected study areas (three in Nepal and three in Bhutan) covering *inter alia* geology, topography, land use and landslide distributions
- Confirmation of landslide locations and geology through field mapping
- Development and testing of landslide susceptibility maps for the study areas
- Field surveys to assess engineering and land use management practices with respect to landslide problems in road corridors
- Development of best practice guidelines in remote sensing, landslide hazard mapping, route corridor planning and route corridor engineering
- Training, knowledge transfer and dissemination through secondment and workshops.

This report briefly summarises the LRA Project within Nepal. It is important to note that these achievements would not have been possible without the support and commitment of the DoLIDAR. The Central Departments of Geology and Geography, Tribhuvan University, the Department of Mines and Geology and the Department of Survey also provided assistance with data and part-time expert staff, in the case of Tribhuvan University.

2 Programme of Activities

Table 1 shows a brief summary of the project activities undertaken in Nepal since November 2000, when the LRA Project started:

Table 1: Summary of Project Activities in Nepal (November 2000 – March 2003)

Date	Project Activity
3rd November 2000	Introductory Seminar held in Kathmandu*
18th & 19th December 2000	GIS, SII & API workshop held at TU, Kathmandu*
November 2000 – January 2001	Remote sensing & field mapping for Baglung study area*
February – April 2001	Remote sensing & field mapping for Arghakhanchi study area*
9th – 14th April 2001	International Seminar, Kathmandu*
2nd & 3rd May 2001	API workshop held in Sandhikharka, Arghakhanchi*
10th & 11th May 2001	GIS, SII & API workshop held at TU, Kathmandu*
30th July – 1st August 2001	GIS, SII & API workshop held at TU, Kathmandu*
July – September 2001	Remote sensing & field mapping for Ilam study area*
29th & 30th August 2001	Field Workshop held in Arghakhanchi*
14th October 2001	API workshop held in Baglung*
17th – 19th October 2001	Interim Results Seminar, Kathmandu*
November 2001	Start of data collection for Nepal newspaper-derived landslide database & landslide runout analysis
March – April 2002	API study for Pyuthan and Arun Valley areas*
March – May 2002	Kathmandu Valley fieldwork*
8th, 9th 22nd &23rd August 2002	GIS & API workshops held at TU, Kathmandu*
August – October 2002	Application & testing of LRA techniques for RAP area (Bhojpur)*
18th to 23rd November 2002	Final International Seminar, Kathmandu*
25th to 30th November 2002	Three 2-day workshops, held at TU, Kathmandu covering API, GIS, landslide causes and identification and engineering along road corridors*
December 2002 – January 2003	Kathmandu Valley fieldwork, continued
27th January 2003	Attendance and presentation at the EU-funded Land-Man Project Seminar, TU, Kathmandu
16th – 18th February 2003	Regional Workshop – Pokhara*
16th & 17th March 2003	Regional Workshop – Ilam*
February – March 2003	Resurvey of landslides in Baglung and Arghakhanchi study areas
26th & 27th March 2003	Presentation of four papers at the PIARC Conference in Kathmandu
January to March 2003	Finalisation of results and report writing

* These activities are described in separate, self-contained reports issued in Kathmandu that are listed at the end of this report (Appendix A).

Table 2 shows a brief summary of the project activities undertaken in Bhutan during the period May to October 2002: Mr Sushil Tiwari (seconded engineer from DoLIDAR) was in Bhutan for most of this period, assisting in the satellite image interpretation work, fieldwork, landslide susceptibility analysis and training. Mr Chalise (DG DoLIDAR), Mr Upadhyaya (Senior Divisional Engineer, DoLIDAR) and Mr Tiwari were also involved in the Concluding Results Seminar that was held in Thimphu, 27 September 2002 (see Report on Project Activities Undertaken in Bhutan-January 2003 for details).

Table 2: Summary of Project Activities in Bhutan (May 2002 – October 2002)

Date	Project Activity
12th May 2002	Introductory seminar held in Thimphu, Bhutan
June – July 2002	Remote sensing & field mapping for Mongar – Trashigang study area
17th – 19th June 2002	GIS, SII & API workshop held in Thimphu*
July 2002	Remote sensing & field mapping for Chhukha – Damchu study area
August 2002	Remote sensing & field mapping for Sunkosh – Daga study area
22nd & 23rd August 2002	API workshop held in Thimphu*
27th September 2002	Concluding Results Seminar held in Thimphu, Bhutan*
7th – 9th October 2002	GIS, SII & API workshop held in Thimphu*

* These activities are described in separate, self-contained reports issued in Kathmandu that are listed at the end of this report (Appendix A).

3 Study Team

The study team has consisted of both local Nepali staff as well as a number of expatriate staff. Details of the study team, their roles and responsibilities are given in the tables below (Tables 3, 4 and 5).

Table 3: Expatriate Staff

Name	Position	Responsibility	Time in Nepal
Gareth Hearn	Project Manager	Project management, QA & Engineering input	Nov & Dec 2000, April, Sept & Oct 2001, May, Sept & Nov 2002 & March 2003
David Petley	Research Manager	Office/field QA and Risk Assessment, Global Review of Landslide Risk Mapping	Jan, April, August & Oct 2001, August & Nov 2002 & March 2003
Andrew Hart	Local Team Leader & Principal Researcher	Full time Technical Co-ordination, field mapping, GIS & training	April to Nov 2001 May 2002 to March 2003 (May 2002 to Oct 2002 – Bhutan)
Ivan Hodgson	API Specialist	Landslide mapping from air photos, API training	Nov to Dec 2000 April to May 2001
Will Crick	Remote Sensing Specialist	Interpretation of satellite imagery, RS/GIS training	Nov to Dec 2000 April to May 2001
Philip Ward	Geologist	Field Mapping & literature review	Nov to Dec 2000
John Henley	Highway Specialist	Literature review	Nov 2000 to March 2001
Chris Massey	Geologist	GIS Analysis & November 2002 Seminar	November 2002

Table 4: Full-Time Nepali Staff

Name	Position	Responsibility
Sushil Tiwari	Seconded Engineer, DoLIDAR, MLD, Nepal	Social surveys, remote sensing, GIS and training (Nepal & Bhutan)
Shuva Sharma	In-country Manager, SW Nepal	Project management in Nepal
Prakash Lamichhane	Local Project Co-ordinator, SW Nepal	Project co-ordination in Nepal
Suman Khadka	Surveyor	Surveying & monitoring of landslides
Prakash Jha	Geologist, SW Nepal	Field mapping of geology
Mamta Subba	Secretary, SW Nepal	Data entry, report compilation, social survey
Saroj GC	Office Assistant, SW Nepal	Office duties

Table 5: Other Nepali Staff

Name	Position	Responsibility
Dr M Dhital	Geologist, TU	Local Peer Review Consultant
Mr A. Bhandari	Geologist	Field mapping of geology
Dr D Paudyal	Sociologist	Social survey
Mr NK Ghimire	Sociologist	Social survey and land use mapping

4 Study Area Locations

Three study areas were selected for landslide susceptibility analysis following discussions with DoLIDAR and Tribhuvan University. The three areas are shown on the map below along with the three study areas in Bhutan. The details for the six areas are shown in the Tables 6 and 7. The data collected from these six areas formed the basis for the landslide susceptibility analysis that was undertaken by the project. A number of additional areas were also used in Nepal.

- Two areas (Pyuthan and Bhojpur) were used for testing the landslide susceptibility scheme that was developed by the project
- Two road sections within the Kathmandu Valley were used to study the impact of road construction on the surrounding area and the local population, and landslide management along road corridors.
- An aerial photograph interpretation (API) exercise was completed in the Arun Valley area looking at landslide frequency over a period of 28 years.

Table 6: Study Area Statistics

Study Areas for susceptibility analysis	Area (Sq. km)	No of mapped landslides
Baglung	528	232
Arghakhanchi	327	389
Ilam	364	226
Mongar – Trashigang	346	229
Sunkosh – Daga	251	219
Chhukha – Damchu	202	41
Total	**2,218**	**1,336**

Table 7: Study Area Information

Attribute	Baglung	Arghakhanchi	Ilam	Pyuthan	Bhojpur – Leguwaghat Road Section	Bungmati & Dakshinkali Road Sections	Arun Valley
Location:	North Central Nepal	South Central Nepal	Eastern Nepal	South Central Nepal	Eastern Nepal	Kathmandu Valley	Eastern Nepal
Used for:	Landslide susceptibility analysis	Landslide susceptibility analysis	Landslide susceptibility analysis	Testing of landslide susceptibility model	Testing of landslide susceptibility model for DFID & RAP	Social impact & engineering review	API-based landslide frequency study
Area (sq kilometres):	528	327	364	302	409	15	145
Topography:	Middle Himalayas – Moderate-steep valley sides	Mixed with variable steepness – Siwalik Hills	Mixed with variable steepness – Siwalik Hills	Mixed with variable steepness – Siwalik Hills	Mixed with variable steepness	Valley floor and side slopes	Midlands-style topography
Land use:	Mixed forest/cultivation	Mixed forest/cultivation	Mixed forest/cultivation & Tea Plantations	Mixed forest/cultivation	Mixed forest/cultivation	Mostly cultivated & 1 limestone quarry	Mixed forest/cultivation
Geology:	Phyllite, quartzite, mica schist, slate, limestone & dolomite	Middle & Lower Siwalik sandstone & mudstone, quartzite, shale & limestone	Mica schist, phyllite, gneiss, quartzite, limestone & dolomite	Middle & Lower Siwalik sandstone & mudstone, quartzite, shale & limestone	Quartzite, schist, gneiss, limestone & phyllite	Lake deposit material, meta sandstone, limestone, quartzite & phyllite,	Middle & Lower Siwalik sandstone, mudstone, siltstone & Lesser Himalayas dolomite & quartzite
Infrastructure:	Rural road	Rural road	Charali to Ilam road	Rural road	Rural road	Rural road	Rural road
Available geological mapping:	Unpublished maps only	Unpublished maps only	Unpublished maps only	Unpublished maps only	Unpublished maps only	Published 1:25,000 map	Unpublished maps only
Available topographical mapping:	Complete coverage at 1:25,000 scale	Complete coverage at 1:25,000 scale	Complete coverage at 1:25,000 scale	Complete coverage at 1:25,000 scale	Complete coverage at 1:25,000 scale	Complete coverage at 1:25,000 scale	Not used
Available air photos:	Complete coverage at 1:50,000 scale	Complete coverage at 1:25,000 scale	Complete coverage at 1:50,000 scale	Complete coverage at 1:50,000 scale	Complete coverage at 1:50,000 scale	Complete coverage at 1:50,000 scale	4 epochs at different scales (1964, 1978, 1979 & 1992
Available satellite imagery:	Landsat, SPOT	Landsat, IKONOS	Landsat, IRS	Landsat, IRS	Not used	Not used	Not used

5 Outline Objectives of the Nepal Study

The outline objectives of the Nepal study were as follows:

- Examine globally the different tools and techniques for assessing landslide susceptibility, hazard and risk
- Examine the use of satellite imagery in the assessment of landslide occurrence in Nepal
- Examine the effectiveness of aerial photograph interpretation techniques for the mapping of landslides, as well as for terrain classification
- Develop a landslide dataset for each of three study areas in Nepal
- Analyse this landslide distribution with respect to geology and topography to determine whether the susceptibility models developed for Nepal are applicable. Carry the analyses further to see how best a susceptibility model can be developed
- Develop a landslide database for Nepal using national newspapers to establish an understanding of the physical, social and economic impact of landslide activity within the country
- Carry out social survey to assess the impact that landslides have on livelihoods and land use in selected road corridors
- Carry out an engineering survey of landslide problems on selected roads
- Carry out training through workshops and on-the-job demonstration
- Development of a set of Best Practice Guidelines on the use of remote sensing and GIS techniques for landslide assessment
- Development of Guidelines for route corridor planning and engineering
- Dissemination of the results

6 Methodology and Results Summary

6.1 Remote Sensing

The remote sensing has involved using a combination of satellite imagery and aerial photographs. The project has sought to examine the effectiveness of the different satellite images that are available in comparison with aerial photograph interpretation and field mapping techniques. The satellite imagery used has included Landsat TM, SPOT, IRS, and IKONOS (black and white).

Aerial photographs were purchased from the Department of Survey and Land Records for each of the three main study areas. A summary of the photography used is given in Table 8.

Table 8: Aerial Photograph Descriptions

Attribute	Baglung	Arghakhanchi	Ilam
Scale	1:50,000	1:25,000	1:50,000
Date	1990's	1990's	1990's
Quality	Fair	Fair	Fair

The aerial photographs were viewed in stereo using a stereoscope and the following details recorded:

- The location and areal extent of landslides
- Terrain classification incorporating rock, residual soil and colluvium
- Structural geology lineations
- A proforma was completed for each landslide identified. This proforma contained data on landslide classification, land use and runout length.

Both the satellite image interpretation and the aerial photograph interpretation were supported by field validation. This allowed comparison between features seen in the field and their appearance in aerial photographs. The final output from the remote sensing was digitised as a separate layer into the GIS.

6.2 Field Mapping and Social Survey

The fieldwork has involved field verification of the remote sensing, as well as primary data collection. The primary data collection has included mapping of landslides, geology, structural geology and geomorphology. In some of the study areas, social and land use mapping has also been completed. This information has been used to gain an understanding of the relationship between land use practices and landslide activity.

6.2.1 Geology

1:50,000 scale geological mapping exists in many parts of Nepal, carried out principally by the Department of Mines and Geology. Unfortunately, this mapping has not always been undertaken in a co-ordinated way, and there are several questions remaining over the exact outcrop patterns in some areas and the differentiation between different geological units. Much of this information remains unpublished.

This mapping was therefore augmented by field survey and was undertaken by project staff. The final mapping for each area was then digitised into the GIS as a separate layer.

6.2.2 Land use and Engineering Surveys

Two surveys have been completed in the Kathmandu Valley. These were along two road sections – the Bungmati and the Dakshinkali roads. The surveys included mapping all slope failures within a specified distance of the road, as well as completing social surveys to assess the impact of the slope failures on the road and the local population. A more detailed description of this database, as well as the results, is given in the Social Survey and Land Use Reports (Report Numbers N11 and N16).

6.3 Compiling the Landslide Database

The three landslide datasets (from satellite imagery interpretation, aerial photograph interpretation and field mapping) were compiled into a single dataset for each of the three main study areas. Table 9 summarises the number of landslides identified from each source in each of the Nepal study areas.

Table 9: Landslide Mapping Statistics

Source of Data	Baglung	Arghakhanchi	Ilam
Satellite Imagery – Landsat/SPOT/IRS	54	134	35
Satellite Imagery – IKONOS	NA	154	NA
Aerial Photography	101	137	48
Field Mapping	127	230	226
Total Number	**231**	**389**	**226**

Note that "Total Number" refers to the number of landslides used in the analysis. It will be less than the sum of the three data sources because some of the landslides were identified from more than one source. The number of landslides identified by either of the remote sensing methods will also differ slightly from the number used in the analysis, because the former number represents the number of landslides mapped prior to field verification.

6.4 GIS Analysis & the Regional Landslide Susceptibility Rating Scheme

ArcView 3.2 was used to store and analyse all of the data that was collected and used by the project. This included the data that was collected during the field visits and the remote sensing stages of the project. Where digital contour or land use data was available it was purchased. This saved a considerable amount of time as it avoided the lengthy operation of manually digitising the data. The project team digitised all other necessary data. This was:

- Published and field mapped geology (including structural geology)
- Landslides
- API and field mapped terrain classification
- The locations of new infrastructure and roads not marked on the published topographic maps
- Any other relevant information.

The data analysis involved comparing the mapped landslide distribution with the other data layers that were collected. The aim was to identify those factors that are involved in controlling the landslide activity that was seen in the study areas. A number of standard statistical techniques were used during this process.

The distribution of landslides was compared systematically with the following factors:

Table 10: Factors Analysed during the Landslide Factor Analysis

Factor	Source
Rock type	Field mapping or published/unpublished geological maps provided by Department for Mines & Geology, Nepal
Geological structure	Field mapping or published/unpublished geological maps provided by Department for Mines & Geology, Nepal
Distance from structural lineaments	Derived using GIS
Terrain classification	Field mapping and/or API
Soil type	Field mapping and/or API
Land use	Published maps and/or field mapping
Elevation	Derived from contour data using GIS
Slope angle	Derived from contour data using GIS
Slope aspect	Derived from contour data using GIS
Distance from drainage lines	Derived using GIS
Earthquake distribution	Downloaded from the United States Geological Survey website. Additional data was obtained from the Department of Mines and Geology, Nepal
Rainfall distribution	Data provided by Department of Hydrology & Meteorology, Nepal

This landslide susceptibility factor analysis was undertaken using the Spatial Analyst extension within ArcView. It was found that when all of the three Nepal study areas were combined only rock type and slope angle were systematically correlated with the distribution of landslides. Consequently, these datasets were combined with those from Bhutan, where a similar conclusion had been reached to yield a regional (Nepal and Bhutan) listing of landslide density according to rock type-slope angle category. Therefore, for any given area containing rock types found in the regional list (this should include most of Nepal) it is possible to derive landslide density and thus a relative susceptibility to landslides once the distribution of rock types and slope angles are known. This has significant advantages for the preliminary assessment of route corridors.

The results from this analysis were used to develop a landslide susceptibility rating scheme. This scheme follows a logic tree approach based on four different slope angle classes and each rock type that has been mapped by the LRA Project (Table 11). The scheme was then tested in each of the LRA Project study areas to see how well it predicted the mapped landslide distribution. The results were very encouraging.

6.5 Testing of the Landslide Susceptibility Scheme

The scheme that is described above has been tested in all six of the Project study areas, as well as a further two test areas – Pyuthan and Bhojpur. For the two test areas, a landslide susceptibility map was produced by using published geological information and the digital contour data for the areas and applying the susceptibility ratings directly from the "Regional List". This map was compared with the landslide distribution mapped independently from aerial photographs. Due to security reasons, neither the map nor the aerial photograph interpretation could be field-verified. Nevertheless, the results of this analysis indicated that the susceptibility scheme was generally applicable, thus vindicating the approach. The Bhojpur analysis is described in more detail in Report that has been submitted to DoLIDAR, RAP and DFID (Report Number N12).

A summary of the results for each of the study areas is given in Table 12.

Table 11: The regional landslide susceptibility rating list

Susceptibility Class	Rock Type	Slope Angle	Indicative landslide density (landslides/Sq km)
Low Landslide Susceptibility (Rating of 1)	Granite	0° - 20°	0.00
	Granite	20° - 30°	0.00
	Granite	30° - 40°	0.00
	Granite	> 40°	0.00
	Limestone/Dolomite with Quartzite, Phyllite &/or shale	0° - 20°	0.00
	Slate/shale with Limestone &/or Quartzite	0° - 20°	0.00
	Quartzite & Phyllite	0° - 20°	0.16
	Mica Schist & Gneiss	0° - 20°	0.20
	Limestone/Dolomite with Quartzite, Phyllite &/or shale	20° - 30°	0.20
	Mica Schist and other minor rock types	0° - 20°	0.22
	Gneiss & Mica Schist	0° - 20°	0.25
	Mica Schist & Phyllite	20° - 30°	0.26
	Mica Schist & Quartzite	0° - 20°	0.27
	Gneiss	0° - 20°	0.30
	Phyllite (with Quartzite &/or Limestone)	0° - 20°	0.30
	Limestone/Dolomite with Quartzite, Phyllite &/or shale	30° - 40°	0.36
	Quartzite & Phyllite	20° - 30°	0.36
Moderate Landslide Susceptibility (Rating of 2)	Limestone/Dolomite with Quartzite, Phyllite &/or shale	> 40°	0.40
	Mica Schist & Phyllite	0° - 20°	0.43
	Phyllite (with Quartzite &/or Limestone)	20° - 30°	0.46
	Mica Schist and other minor rock types	20° - 30°	0.48
	Mica Schist & Gneiss	20° - 30°	0.53
	Quartzite & Phyllite	30° - 40°	0.54
	Gneiss	20° - 30°	0.55
	Mica Schist	0° - 20°	0.56
	Slate/shale with Limestone &/or Quartzite	30° - 40°	0.59
	Mica Schist & Quartzite	20° - 30°	0.60
	Slate/shale with Limestone &/or Quartzite	20° - 30°	0.60
	Quartzite & shale &/or Sandstone	20° - 30°	0.62
	Quartzite & shale &/or Sandstone	0° - 20°	0.65
	Gneiss & Mica Schist	20° - 30°	0.66
	Slate/shale with Limestone &/or Quartzite	> 40°	0.67
High Landslide Susceptibility (Rating of 3)	Quartzite & Phyllite	> 40°	0.72
	Mica Schist	30° - 40°	0.75
	Mica Schist	20° - 30°	0.77
	Fine grained Sandstone (siltstone/mudstone)	0° - 20°	0.78
	Mica Schist	> 40°	0.80
	Mica Schist & Gneiss	> 40°	0.81
	Gneiss	30° - 40°	0.82
	Mica Schist & Phyllite	30° - 40°	0.83
	Phyllite (with Quartzite &/or Limestone)	30° - 40°	0.88
	Mica Schist and other minor rock types	30° - 40°	1.00
	Gneiss & Mica Schist	30° - 40°	1.00
	Mica Schist & Gneiss	30° - 40°	1.02
	Gneiss	> 40°	1.02
	Medium to coarse grained Sandstone	0° - 20°	1.03
	Quartzite & shale &/or Sandstone	30° - 40°	1.15
	Mica Schist & Quartzite	30° - 40°	1.19
	Quartzite & shale &/or Sandstone	> 40°	1.45
	Phyllite (with Quartzite &/or Limestone)	> 40°	1.55
	Mica Schist & Quartzite	> 40°	1.58
	Mica Schist and other minor rock types	> 40°	1.58
	Medium to coarse grained Sandstone	20° - 30°	1.64
	Gneiss & Mica Schist	> 40°	1.89
	Medium to coarse grained Sandstone	> 40°	2.15
	Medium to coarse grained Sandstone	30° - 40°	2.48
	Mica Schist & Phyllite	> 40°	2.62
	Fine grained Sandstone (siltstone/mudstone)	20° - 30°	2.91
	Fine grained Sandstone (siltstone/mudstone)	30° - 40°	3.33
	Fine grained Sandstone (siltstone/mudstone)	> 40°	6.85

Table 12: Summary Statistics for the Landslide Susceptibility Mapping when Applied to the Study and Test Areas

Area	% of Area Covered by each Landslide Susceptibility Class			% of Landslides found in each Landslide Susceptibility Class		
	Low	Moderate	High	Low	Moderate	High
Baglung	36.8	39.2	24.0	14.7	37.9	47.4
Arghakhanchi	29.2	13.4	57.4	9.0	8.7	82.3
Ilam	38.2	40.3	21.4	15.0	35.0	50.0
Puythan	24.2	27.1	48.7	11.1	44.4	44.4
Bhojpur	42.1	35.2	22.7	0.0	35.7	64.3

6.6 Landslide Frequency Analyses

In an attempt to ascertain the frequency of landslide activity in Nepal a study was undertaken in an area where more than one epoch of aerial photographs was available. This study was based on part of the Arun Valley in eastern Nepal, where (according to our information) the longest period of air photographic record is present. The landslide distribution was mapped using four epochs of aerial photographs covering a time period of 28 years (1964, 1978, 1979 and 1992). A comparison was then made between each of the landslide distributions mapped to see how frequently existing landslides became enlarged and with what recurrence new landslides were generated. Unfortunately, the coverage of the aerial photography in the earlier epochs was limited and no firm conclusions could be drawn from this investigation. As the air photograph coverage is amongst the best in the country, it is concluded that frequency analysis cannot be reliably undertaken using this technique. A more detailed description of this investigation is given in the Arun Valley API Study Report (Report Number N21).

Given the rather disappointing results from the Arun Valley analysis, it was decided to adopt a pragmatic approach in assigning probability. As the main objective of the LRA project is to provide tools for rural road management, it was decided to take the nominal design life of a low cost road as the 'design' period for the study. Thus, it was assumed that there would be a hundred percent probability that a landslide would occur from a High susceptibility area during a 20 year period (see Overseas Road Note 16 for discussion), a 50% probability that a landslide would occur in a Moderate susceptibility area in 20 years, and a 25% probability that a landslide would occur from a Low susceptibility area during the same period.

6.7 Landslide Runout Analyses

Using the landslide proforma data that was collected during the remote sensing and field mapping parts of the project, it has been possible to analyse the distances travelled by each of the landslides mapped. Potentially, this data could be very useful in estimating how far a potential landslide could travel. Therefore, a detailed analysis has been carried out of the relationships between the area of the mapped landslide sources, underlying rock type, slope angle and failure mechanism. The data was plotted up as a series of graphs, which have been used to calculate a series of best-fit curves for the data. These curves enable the preparation of an outline landslide hazard map, as they portray predicted runout distance from any potential landslide source area. It is emphasised that, while this runout analysis has been comparatively successful, there are many factors involved in the determination of landslide runout length, and practitioners should always err on the side of caution. A more detailed description of this database, as well as the results, is given in the Landslide Runout Analysis Report (Report Number N22).

6.8 Landslide Hazard Assessment

A landslide susceptibility map provides an indication of which areas are most prone to landslide activity. However, it does not provide any indication of the probability or frequency of the landslide activity or which areas that landslide activity might affect (i.e. landslide runout). Therefore a landslide hazard map requires the combination of landslide susceptibility, probability of occurrence and an assessment of the runout from any potential landslide.

6.8.1 Probability

Table 13 shows the levels of probability that have been assigned to each of the hazard classes used by this project. These values are based on a pragmatic assessment combined with the results of a landslide frequency analysis that was carried out for part of the Arun Valley where four epochs of aerial photographs are available covering a period of 28 years (see Section 7.7 and associated report for justification of these probabilities).

Table 13: Probabilities of Landslide Occurrence Assigned to each of the Landslide Hazard Classes

Level of Hazard	Description	Hazard Rating
Low	Probability of **25%** that a landslide will occur in a 20 year period	0.25
Moderate	Probability of **50%** that a landslide will occur in a 20 year period	0.50
High	Probability of **100%** that a landslide will occur in a 20 year period	1.00

6.8.2 Runout

To ascertain the potential runout from any given susceptible area an analysis of the runout data collected from the landslide mapping was undertaken (see Section 7.8 and associated report). Therefore, the following criteria were used while undertaking an assessment of the runout for each potential landslide source area identified in the landslide susceptibility map:

Upslope to account for the retrogression of the landslide:	15 m
Across the slope to account for lateral growth of the landslide:	15mm
The runout travel distance of the landslide downslope:	Use the best fit line for the relevant slope material involved in the landslide and the area of the potential landslide source area (Section 7.8)

The process of producing the landslide hazard map requires manually digitising the different hazards areas, and making a number of judgemental decisions regarding most likely runout paths. These are:

- The effect of the topography, including the slope angle
- The effect of a landslide reaching a drainage line (the landslide was assumed to stop or turn into a flood problem when it reached a major or third order drainage line

- Any changes in the slope material that could be entrained into the landslide debris and therefore affect the runout
- Any changes in land use that may affect the runout (i.e. thick forest may slow down or stop a small landslide)

Existing landslides are included in the areas of high hazard, even if they did not occur in an area of high landslide susceptibility. However, given the general success of the susceptibility modelling, such cases were few.

6.9 Landslide Risk Assessment

A landslide risk map provides an indication of the level of economic risk that is posed by potential and existing landslides. It is based upon the overlay between the landslide hazard map and the economic value/asset map of any given area. The economic values that have been used in this landslide risk assessment are given below (Table 14). Following consultation with the Nepalese authorities it was decided not to include the cost of potential loss of human life in this risk assessment.

Table 14: Costs of Land Use and Infrastructure used during the Landslide Risk Assessment

Infrastructure		**Cost (20 year period) in NRs**
House (rural area)	(Structure Only)	15,000
House (town area)	(Structure Only)	400,000
School	(Structure Only)	150,000
Rural suspension bridge		100,000
Black top road (per 10m length)		11,500
District road (per 10m length)		4,500
Earthen track (per 10m length)		150
Earthen canal (per 10m length)		250
Land Use	**Cost per Ropani (NRs)**	**Cost per 10 sq m (NRs)**
Settlement	100,000	1,965
Tea Estate	60,000	1,180
Khet	35,000	690
Sand	50,000	980
Bush	12,000	235
Forest	20,000	390

Landslide risk is calculated by multiplying the landslide hazard ratings by the cost of the infrastructure and land use listed above. To do this requires the following steps:

1. Create an economic map for the land use of the study area
2. Create an economic map for the infrastructure of the study area
3. Add these two maps together to produce a map showing the economic value for every 10 square meters of the study area
4. Create a map showing the hazard ratings
5. Multiply this map by the economic value map for the study area to produce the final risk map

The economic risk attributed to each of the landslide risk classes is given in Table 15.

Table 15: Economic Values Assigned to each of the Landslide Risk Classes

Level of Risk	Cost per 10 square meters (NRs)
Low	Up to 28,620
Moderate	Between 28,620 and 85,860
High	Between 85,860 and 200,344

Thus, for example, in a 20 year period it is calculated that between Rs 85,860 and Rs 200,344 worth of damage will occur as a result of landslides. This estimate does not include allowance for loss of life, and is subject to the assumptions and uncertainties outlined above.

6.10 Landslide Monitoring

During February and March 2003 a visit was made to the Baglung and Arghakhanchi study areas to record the locations of any new landslides that had been initiated since the initial mapping in 2001. These landslides were entered into the GIS and compared with the landslide susceptibility map for the study area (Table 16).

Table 16: Landslides that have occurred since Spring 2001

Study Area	Susceptibility Class	No. of New Landslides
Baglung	Low	2
	Moderate	4
	High	6
Arghakhanchi	Low	4
	Moderate	0
	High	12

The above table shows that there is good correspondence between the new landslides and the susceptibility rating of the areas in which they have occurred. The relationship is especially good for Baglung, thus vindicating further the application of the susceptibility scheme. It should be pointed out however, that such a small dataset of new landslides is not necessarily statistically significant.

6.11 Newspaper-Derived Landslide Database for Nepal

To gain a better understanding of the impact of landslide activity on the population and infrastructure in Nepal a database of reported landslide activity was created. The main data source for the database has been the published newspapers dating back to 1968. This data has been incorporated into a GIS database, along with data obtained from the Department of Roads, the Department of Mines and Geology, the Department of Hydrology and Metrology and the Central Departments of Geology and Geography, Tribhuvan University.

The data collected shows that for the period 1968 to 2002, a total of 733 landslides have been reported in the national press, resulting in over 2400 fatalities, 500 people injured and an estimated NRs 345 million of damage. A more detailed description of this database is given in a separate report (Report Number 22 and a paper presented at the PIARC Conference in Kathmandu).

6.12 Quality Assurance

At every possible opportunity QA practices have been applied to check data collection and analysis. This has usually involved senior project staff checking the work of others following a sampled procedure. Dr Gareth Hearn of Scott Wilson, Dr David Petley from the University of Durham and Dr Megh Dhital of Tribhuvan University have undertaken much of this QA of the Nepal work.

7 Outputs

The principal outputs of the project in Nepal are listed below:

- GIS database, remaining with DoLIDAR
- GIS Output maps (Appendix B)
- Satellite imagery for the study areas, remaining with DoLIDAR
- Topographical, geological, landslide distribution and landslide susceptibility maps of the three study areas, remaining digitally with DoLIDAR and reproduced as Appendix A of this report
- Training Manual Report (compilation of handouts used during workshops)
- Reports on:
  - Remote sensing
  - Land use/engineering review in route corridors
  - Workshop reports
  - Landslide database
- Best Practice Guidelines in the following subjects:
  - Remote Sensing for Landslide Studies in the Rural Access Sector
  - Landslide Hazard and Risk Mapping
  - Rural Access Corridor Management and Land use Planning
  - Route Corridor Engineering
- Summary Guidance Notes on Satellite Image Interpretation, Aerial Photograph Interpretation, Field Assessments and Regional and Small Scale Susceptibility Mapping
- Papers and presentation given at the PIARC Conference, that was held in Kathmandu 25^{th} to 28^{th} March 2003

The draft Best Practice Guidance Notes have been commented upon by DoLIDAR, Department of Roads, Nepal and DFID and will be finalised later in 2003. The Summary Guidance Notes were issued at the November 2002 international seminar in Kathmandu.

8 Training & Dissemination

Training has comprised on the job training through secondment and workshops held at regular intervals. Project secondment has involved principally one member of DoLIDAR staff (Mr S Tiwari), devoting approximately 90% of his time to the project. He has been trained in the following subjects:

- Geographical Information Systems
- Remote sensing, including satellite image interpretation but mostly aerial photograph interpretation
- Field recognition and mapping of landslides and geology
- Factor analysis and susceptibility analysis
- Hazard and risk assessment.

A more detailed description of the topics covered by the training is given in Table 17. Other DoLIDAR staff members have been trained through field and laboratory workshops, though not on a continuous basis.

This training has progressed as the project has proceeded. Over the project duration, and with the exception of Mr S Tiwari in some subjects, it has not been possible to train DoLIDAR staff as experts, and indeed this was never the intention. However, sufficient exposure and practice has been provided to allow those staff involved to proceed with the application of the techniques. They will require further training as their depth of involvement increases. To aid in this a Report has been prepared that contains a compilation of the handouts that have been used during the workshops (Report Number N24).

Workshops have been held in satellite image interpretation, aerial photograph interpretation, GIS and landslide susceptibility analysis (Table 18). These workshops have been attended by DoLIDAR staff, together with other officers from the public sector, especially those in the Department of Roads, Department of Mines and Geology, the Department of Survey, Department of Water Induced Disaster Prevention, Ministry of Home, Department of Soil Conservation, Department of Forestry, Department of Irrigation, Department of Water Supply and Sewerage, Department of Soil and various private consultants, and Tribhuvan University. Questionnaires have been distributed at the end of these workshops to gauge the response of delegates to the content and value of the workshops, and without exception delegates' responses were very positive. A collection of workshop reports and questionnaires has been prepared separately. The schedule of workshops given in Nepal under this project is summarised below.

As part of the dissemination process, a number of seminars and meetings have been held in Kathmandu and Bhutan (Table 19). A wide selection of participants has contributed to these seminars and meetings, representing different government departments, academic institutions, donor agencies, and private consultants. Their involvement has been through either giving presentations and/or being involved in the numerous discussion sessions that have taken place. The schedule of seminars held in Nepal under this project is summarised below.

Table 17: Summary of the Topics Covered by the on-the-job Training and Workshops

Subject	Description	When, Where & Trainer
Field mapping	• Landslides • Geology • Geomorphology • Terrain Classification • Field Verification of API and SII • Use of GPS	• On site with LRA and at the workshops • GJH, ABH, CM, WC, DNP, and Geologists
Social Data Field Mapping	• Social data • Land use data • Use of GPS	• On site with LRA
Aerial Photographic Interpretation	• Aerial photographic interpretation principles and techniques • Identification of landslides • Identification of geology and geomorphology	• In the LRA office and at the workshops • GJH, ABH, CM, WC, IH, DNP, and Geologists
Satellite Image Interpretation	• Identification of landslides • Identification of geology and geomorphology • Geo-rectification of satellite and scanned images • Automatic classification • Satellite image processing principles and techniques	• In the LRA office and at the workshops • WC
Basic GIS concepts	• Different GIS data types • GIS database structure and design • GIS file naming structures	• In the LRA office and at the workshops • ABH, CM, WC
Data capture, acquisition & input into GIS. Data conversion techniques	• Map projections and conversion • On-screen digitising • Digitising with tablet • Data conversion process • Probable sources of errors	• In the LRA office and at the workshops • WC, ABH, CM
Attribute data in GIS	• Importing attribute data • Linking spatial and attribute data • Editing and querying attribute data	• In the LRA office and at the workshops • WC, ABH, CM

DTM concepts & application	• To gain an understanding of TIN Models and their uses for deriving slope angle and slope aspect data • Use of 3D-Analyst GIS extension software	• In the LRA office and at the workshops • WC, ABH, CM
GIS data analysis	• Data retrieval, re-classification, overlay functions, measurement options • Data querying • Statistical data analysis techniques	• In the LRA office and at the workshops • ABH, CM
Landslide Factor Analysis	• Comparison of landslide distribution with other factor layers held in the GIS • Single and multi factor analysis techniques • Use of Spatial Analysis GIS extension software • Statistical data analysis techniques	• In the LRA office and at the workshops • ABH, CM
Landslide Susceptibility Analysis	• Creation of the LRA Regional Landslide Susceptibility Scheme • Data requirements • Comparison with other landslide susceptibility schemes • Application of the LRA Scheme	• In the LRA office and at the workshops • ABH, CM, GJH
Landslide Hazard and Risk Assessment	• Data required for hazard and risk assessment • Frequency of landslide occurrence • Landslide run out • Vulnerability assessment of infrastructure	• In the LRA office and at the workshops • ABH, CM, GJH

GJH = Gareth Hearn   ABH = Andrew Hart   DNP = David Petley   CM = Chris Massey
WC = Will Crick   IH = Ivan Hodgson

Table 18: Workshops that have been organised by the LRA Project

Type of Workshop	Date	Number of Delegates
API, GIS, SII workshop at TU	18th & 19th December, 2000	17
Air Photo Interpretation Workshop in Sandhikharka	2nd & 3rd May, 2001	21
Remote sensing & GIS workshop in TU	10th & 11th May, 2001	18
Geomorphology by Remote sensing and GIS, TU	30th July – 1st August 2001	31
Field workshop in Arghakhanchi	29th & 30th August 2001	7
Workshop on API & field validation for road engineering and rural development proposes	14th October, 2001	12
GIS, SII & API workshop, Thimphu	17th – 19th June 2002	20
API Workshop, TU	8th & 9th August 2002	10
GIS Workshop, TU	22nd & 23rd August 2002	9
API Workshop, Thimphu	22nd & 23rd August 2002	10
GIS Workshop, Thimphu	7th – 9th October 2002	10
Kathmandu Workshop, TU	25th & 26th November 2003	22
Kathmandu Workshop, TU	27th & 28th November 2003	23
Kathmandu Workshop, TU	29th & 30th November 2003	21
Regional Workshop – Pokhara	16th to 18th February 2003	40
Regional Workshop – Ilam	March 2003	20
	Approximate number of participants:	**300**

Table 19: Seminars that have been organised as part of the LRA Project Dissemination

Type of Seminar	Date	Number of Delegates
Introductory Seminar, Nepal	3rd November 2000	12
International Seminar, Nepal	9th – 14th April 2001	88
Interim Results Seminar, Nepal	17th – 19th October 2001	62
Introductory Seminar, Bhutan	12th May 2002	50
Concluding Seminar, Bhutan	27th September 2002	50*
Final International Seminar, Nepal	18th – 23rd November 2002	106

* Mr NP Chalise, Mr B Upadhyaya and Mr SC Tiwari of DoLIDAR attended the seminar in Bhutan

9 Recommendations for the Future Application of Landslide Studies in Nepal

The value of the Landslide Risk Assessment Project for the planning of rural roads in Nepal is not only technical. It has also helped bring together a number of government departments who are involved and concerned with a) the management and analysis of geo-environmental data by GIS and b) the assessment of landslide potential for rural development and conservation purposes. Furthermore, staff within DoLIDAR have been given a good introduction to remote sensing, field mapping, GIS development and landslide susceptibility mapping for route corridor evaluation.

It is important that this process is taken forward in the future. DoLIDAR needs to progressively build up its database of topography, geology, land use and landslides, while at the same time acquiring copies of aerial photographs for specific areas on a project needs basis. DoLIDAR also needs to strengthen its staff capabilities in the application of LRA techniques, so that it is not dependent on one or two individuals. Those trained under LRA are in a position to train others, though some assistance will be required externally from time to time.

It is important that DoLIDAR does not work in isolation. It needs to strengthen its links with DoR, Tribhuvan University, DMG and Department of Survey. It can do this through sending selected officers for training at the various GIS workshops organised by other government departments or organisations such as ICIMOD. Also, if the techniques and procedures developed and tested under LRA in Nepal are formalised within DoLIDAR/DoR then it will become mandatory to follow up links through the acquisition of aerial photography, topographical and geological mapping.

Finally, DoLIDAR needs to strengthen its capability in geotechnical engineering: landslide recognition, investigation, analysis and design. Again, it is unwise to invest expertise in only one or two officers.

The above recommendations relate primarily to capacity building within DoLIDAR. A number of recommendations can be made that should benefit the wider public sector in Nepal as well as DoLIDAR. These are listed below:

- There is a critical need for up to date, medium scale (1:25,000) and small scale (1:50,000) good quality black and white aerial photography for the entire country outside the High Himalayas
- A country-wide terrain classification at 1:50,000 scale would greatly assist with the assessment of terrain for development purposes
- Comprehensive and field-verified geological mapping should be made available for the entire country
- A procedural framework for incorporating LRA procedures into an Environmentally Friendly Roads Policy needs to be established and put into operation, in conjunction with the DoR
- A central GIS Unit needs to be established that is able to acquire all GIS and geographically referenced digital data from government departments and consequently make this data available within the public sector, free of charge
- DoLIDAR and DoR should consider institutionalising LRA through the establishment of a joint Unit
- Experimentation is required with new satellite technology to determine how well it can assist with the above, especially with respect to the geo-referencing of datasets.

10 Acknowledgements

Scott Wilson would like to thank the Department for International Development, UK for sponsoring this research. The commitment and contributions to the study made by the Department of Local Infrastructure and Agricultural Roads, Nepal is also gratefully acknowledged along with the personal commitments of Mr NP Chalise, Mr ML Chaudhary, Mr B Upadhyaya and Mr SC Tiwari, Engineer.

- Mr N.P. Chalise, former Director General, DoLIDAR
- Mr. M.L. Chaudary, Director General, DoLIDAR
- Mr B. Upadhyaya, Senior Divisional Engineer, DoLIDAR
- Mr S.C. Tiwari, Seconded Engineer to LRA Project, DoLIDAR
- Dr M. Dhital, Central Department of Geology, Tribhuvan University
- Prof. Dr. V. B. S. Kansakar, Central Department of Geography, Tribhuvan University
- Mr. N.R. Khanal Central Department of Geography, Tribhuvan University
- Dr D. Paudyal, Consultant Sociologist
- Mr A. Bhandari, Consultant Geologist
- Mr S. Khadka, Surveyor
- Mr N.K. Ghimire, Sociologist
- Mr Y.R. Poudel, Assistant Sociologist
- Mr A.P. Gajurel, Geologist
- Mr R.P. Shrestha, Geologist
- Mr M.P. Kharel, Geologist

- The Department of Roads
- The Department of Mines and Geology
- The Department of Hydrology and Metrology
- The Department of Survey
- The National Planning Commission
- The Department of Disaster Management, Ministry of Home Affairs
- The District DoLIDAR Engineers, District Development Committees (DDC's), and Village Development Committees (VDC's) of Baglung, Arghakhanchi, Ilam and Pokhara

The commitment and hard work of the LRA Project Team is gratefully acknowledged. Without this the Project would not have achieved what it has in the last two and half years.

- Mr Shuva Sharma, In-country manager for Scott Wilson, Nepal
- Mr Prakash Lamichhane, Local Project Coordinator, LRA Project, Scott Wilson, Nepal
- Mr Prakash Jha, Geologist, LRA Project, Scott Wilson, Nepal
- Ms Mamta Subba, Secretary, LRA Project, Scott Wilson, Nepal
- Mr Saroj GC, Office Assistant, LRA Project, Scott Wilson, Nepal

11 References

Overseas Road Note 16. 1997. Principles of low cost road engineering in mountainous regions. Transport Research Laboratory.

Appendix A
LRA Project Reports

The following is a list of all the reports that have been prepared by the LRA Project in Kathmandu:

Nepal 2000 - 2003

Report No.:	Report Title:	Issued:
N1	Landslide Risk Assessment Project Inception Report	December 2000
N2	Report on the Mountain Hazard Research & Risk Minimisation Seminar, 9th – 13th April 2001, Kathmandu, Nepal	
N3	Internal Project Reports Prepared between October 2000 and April 2001.	May 2001
N4	Report on Social Economic Assessment for the Arghakhanchi Study Area	November 2001
N5	Report on the Geomorphology by Remote Sensing and GIS Workshop, TU, Kathmandu, 30th July to 1st August 2001	November 2001
N6	Report on the Field Workshop held in Arghakhanchi, 29th to 30th August 2001	November 2001
N7	Report on the API Workshop held in Baglung, 14th October 2001	November 2001
N8	Report on the Preliminary Findings Technical Meeting, 18th – 19th October 2001, Kathmandu, Nepal	November 2001
N9	Internal Project Reports Prepared between May 2001 and October 2001.	November 2001
N10	Draft Guidance Notes on Best Practice	May 2002
N11	Report on Brief Report on Landuse and other Social Aspects for Landslide Management in Rural Access Corridor	September 2002
N12	Summary of results obtained from the desk study evaluation of the Bhojpur – Leguwaghat Alignment	September 2002
N13	Report on the August 2002 GIS Workshop, Nepal	October 2002
N14	Report on the August 2002 API Workshop, Nepal	October 2002
N15	Draft Best Practice Guidelines for Landslide Risk Assessment	November 2002
N16	Proceedings of the Mountain Hazards Research and Risk Minimisation Seminar, Kathmandu, November 2002.	January 2003
N17	Report on the Landslide and other Social Aspects for Landslide Management in Rural Access Corridors	January 2003
N18	Report on the API, Terrain Assessment & Engineering Application Workshops, TU, Kathmandu, Nepal, November 2002	February 2003
N19	Report on the Pokhara Regional Workshop, February 2003	March 2003
N20	Report on the Ilam Regional Workshop, March 2003	March 2003
N21	Report on the Arun Valley API Study, March 2003	March 2003
N22	Report on the Landslide Database for Nepal, March 2003	March 2003
N23	Report on Landslide Runout Analysis, March 2003	April 2003
N24	Workshop Handouts	April 2003
N25	Report on Project Activities Undertaken in Nepal, March 2003	April 2003

Bhutan 2002

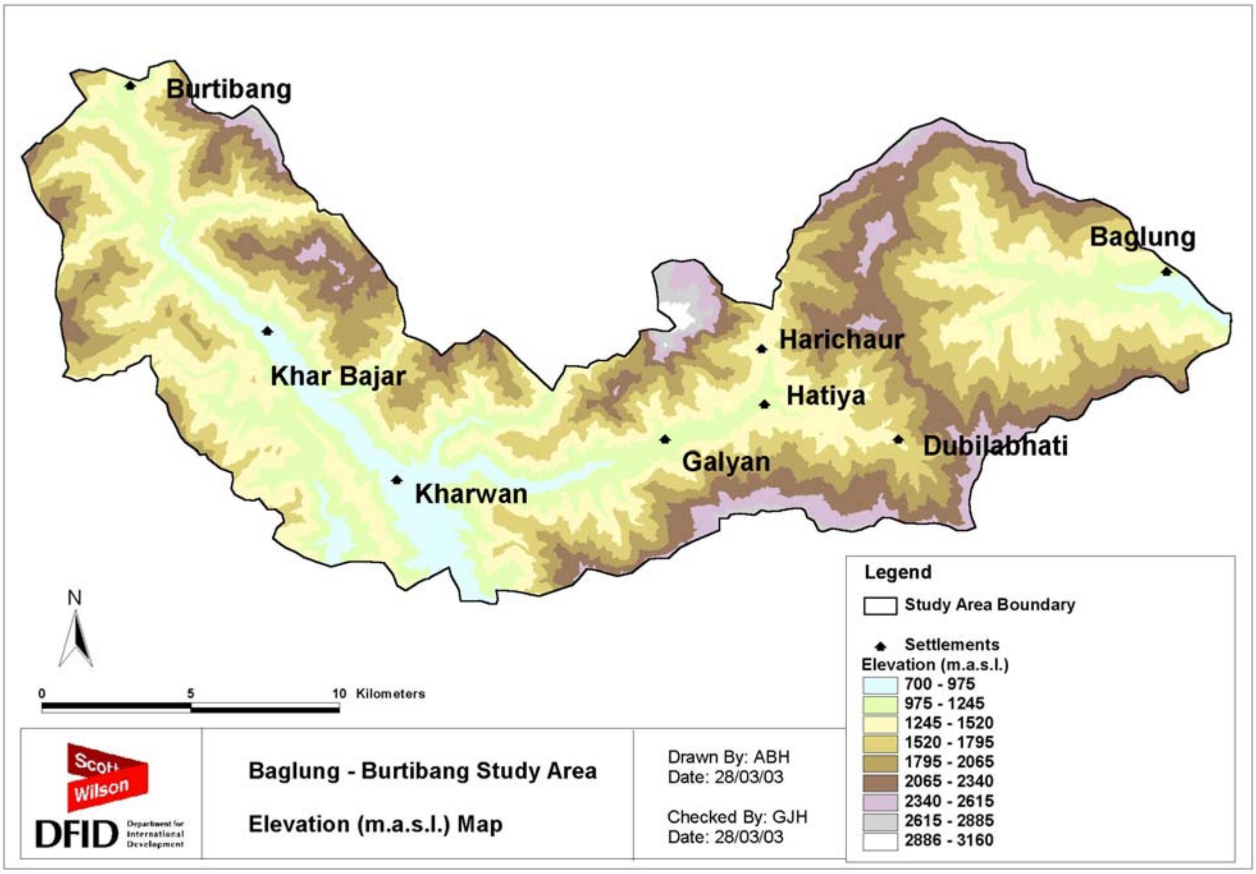
Report No.:	Report Title:	Issued:
B1	Results of the Use of Satellite Image Interpretation in Bhutan	January 2003
B2	Report on Workshops undertaken in Bhutan	January 2003
B3	Report on the Final Seminar held in Thimphu, Bhutan, September 2002	January 2003
B4	Report on project activities undertaken in Bhutan	January 2003

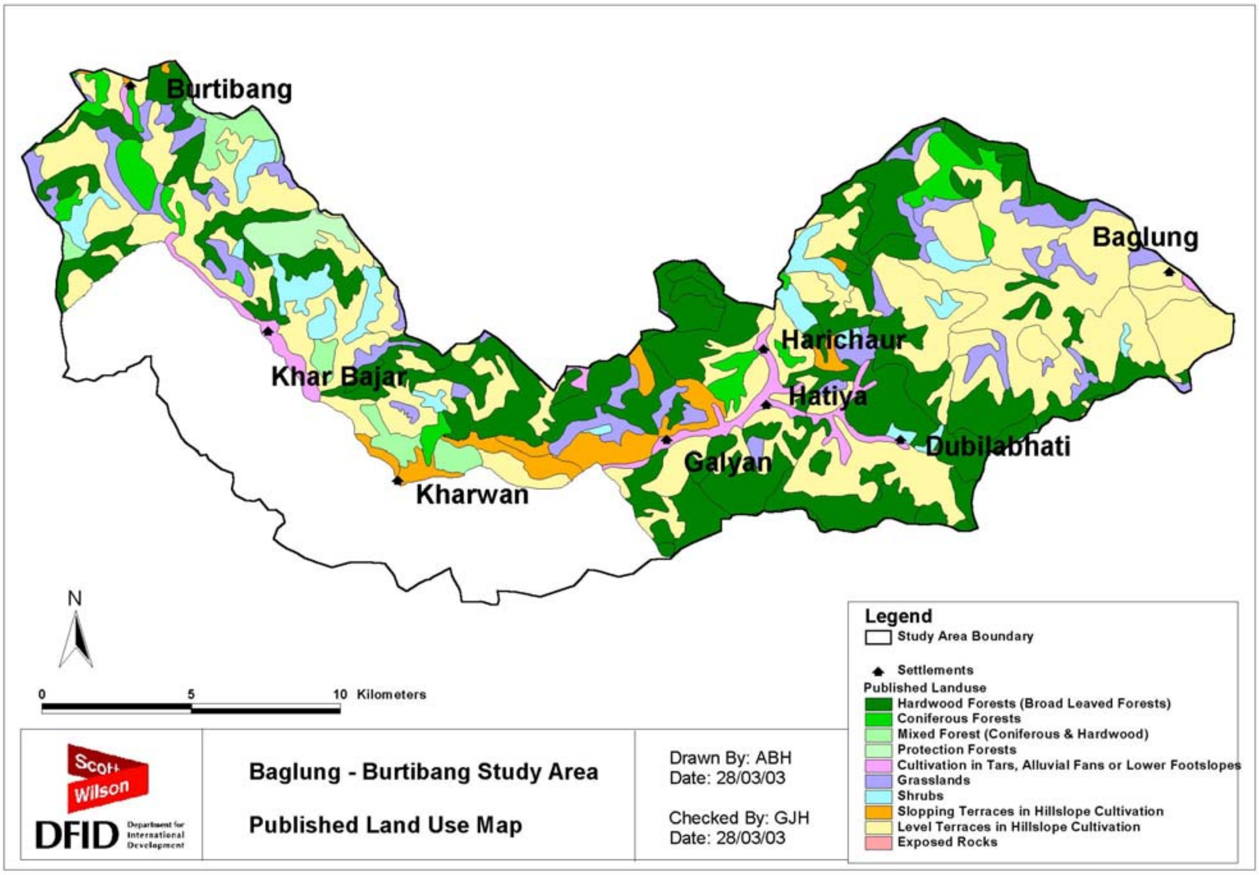
Appendix B
LRA Project GIS Output Maps

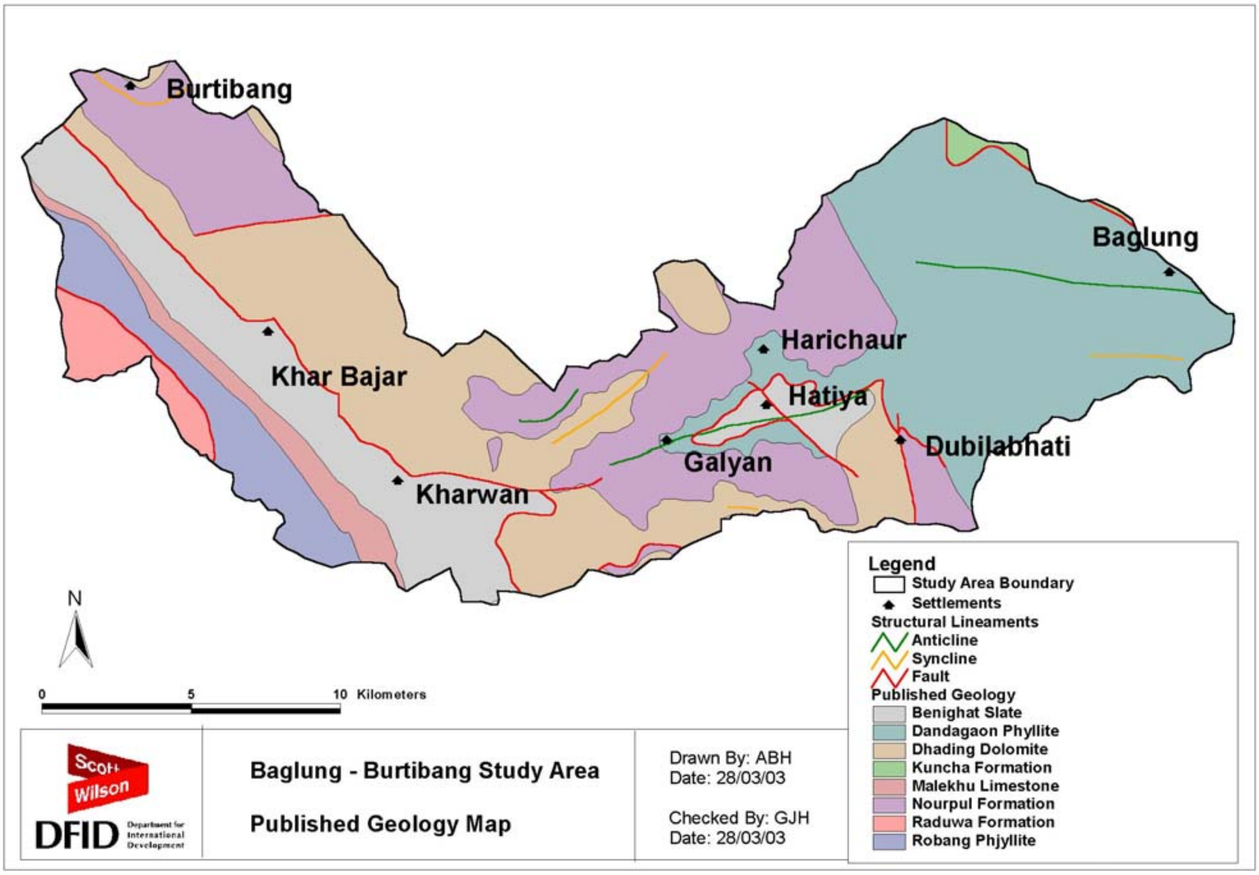
The following output maps are included in this Appendix:

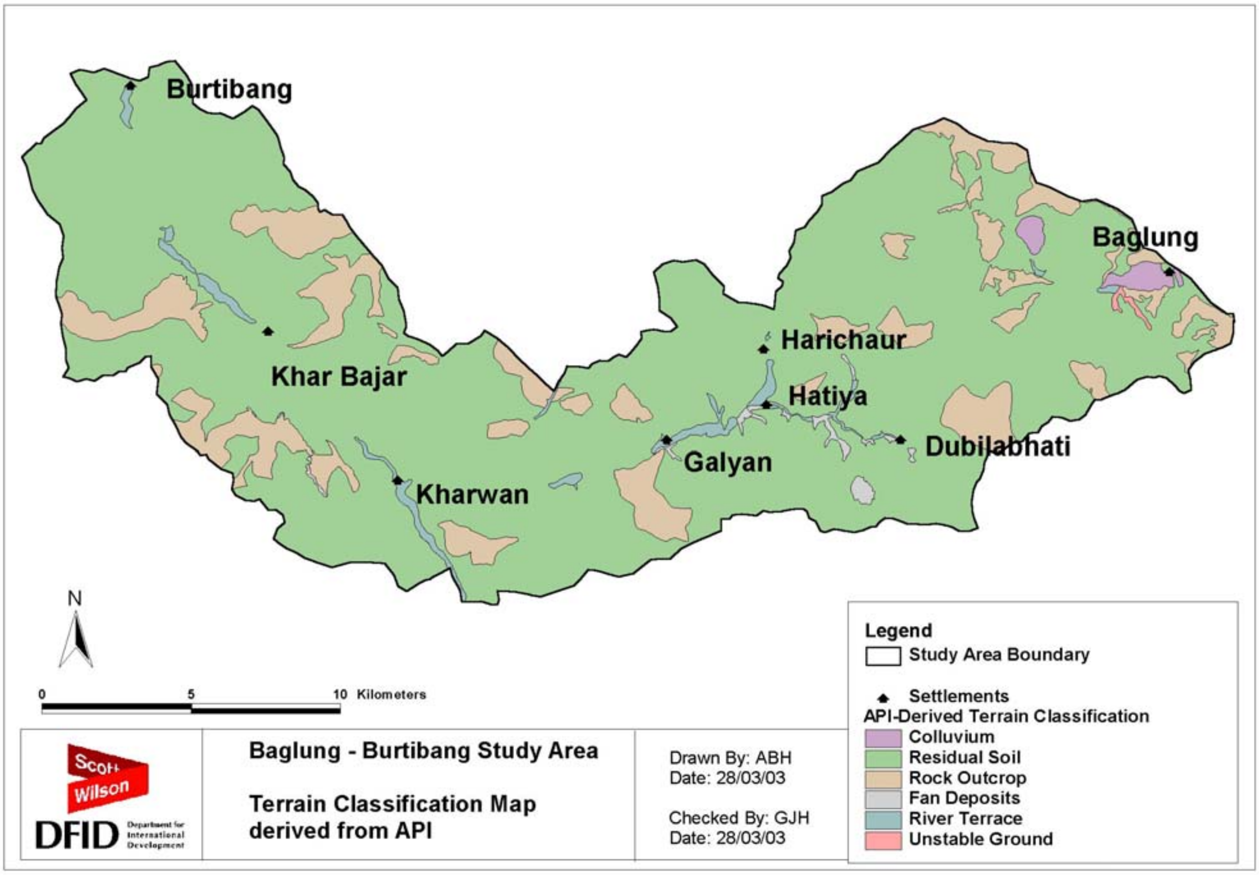
AREA	**GIS OUTPUT MAP**
Baglung	Landslide distribution
	Unpublished Geology Verified in the Field
	Terrain Classification
	Land Use
	Elevation
	Regional Scale Landslide Susceptibility
	Regional Scale Landslide Susceptibility & landslide distribution
Arghakhanchi	Landslide distribution
	Field Geology
	Terrain Classification
	Land Use
	Elevation
	Regional Scale Landslide Susceptibility
	Regional Scale Landslide Susceptibility & landslide distribution
Ilam	Landslide distribution
	Unpublished Geology
	Land Use
	Elevation
	Regional Scale Landslide Susceptibility
	Regional Scale Landslide Susceptibility & landslide distribution
	Landslide Distribution with Enlarged Area Marked
	Land Use, Infrastructure and Landslides for the Enlarged Area
	Landslide Susceptibility with Landslides and Infrastructure for the Enlarged Area
	Landslide Hazard Assessment with Landslides and Infrastructure for the Enlarged Area
	Landslide Risk Assessment with landslides for the enlarged area

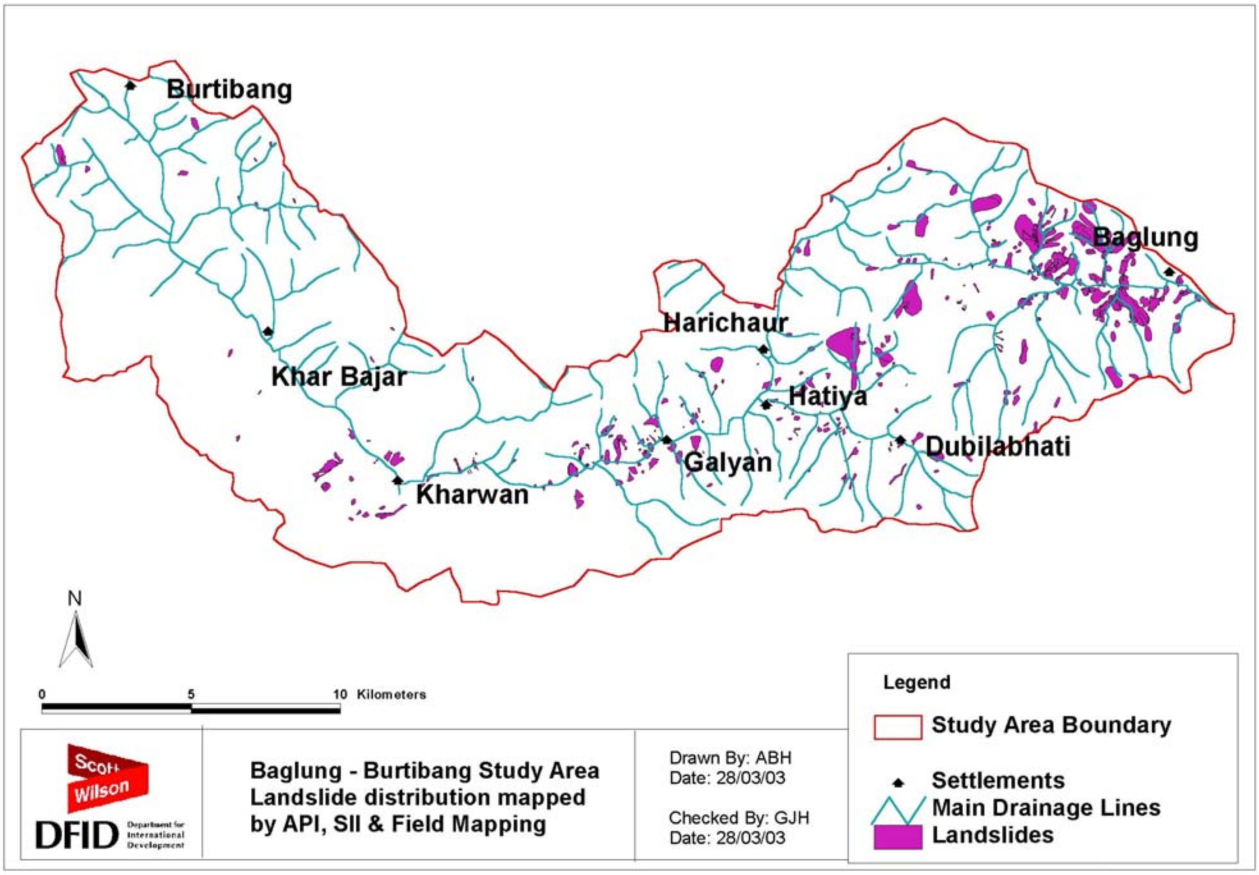
Baglung Study Area, Nepal

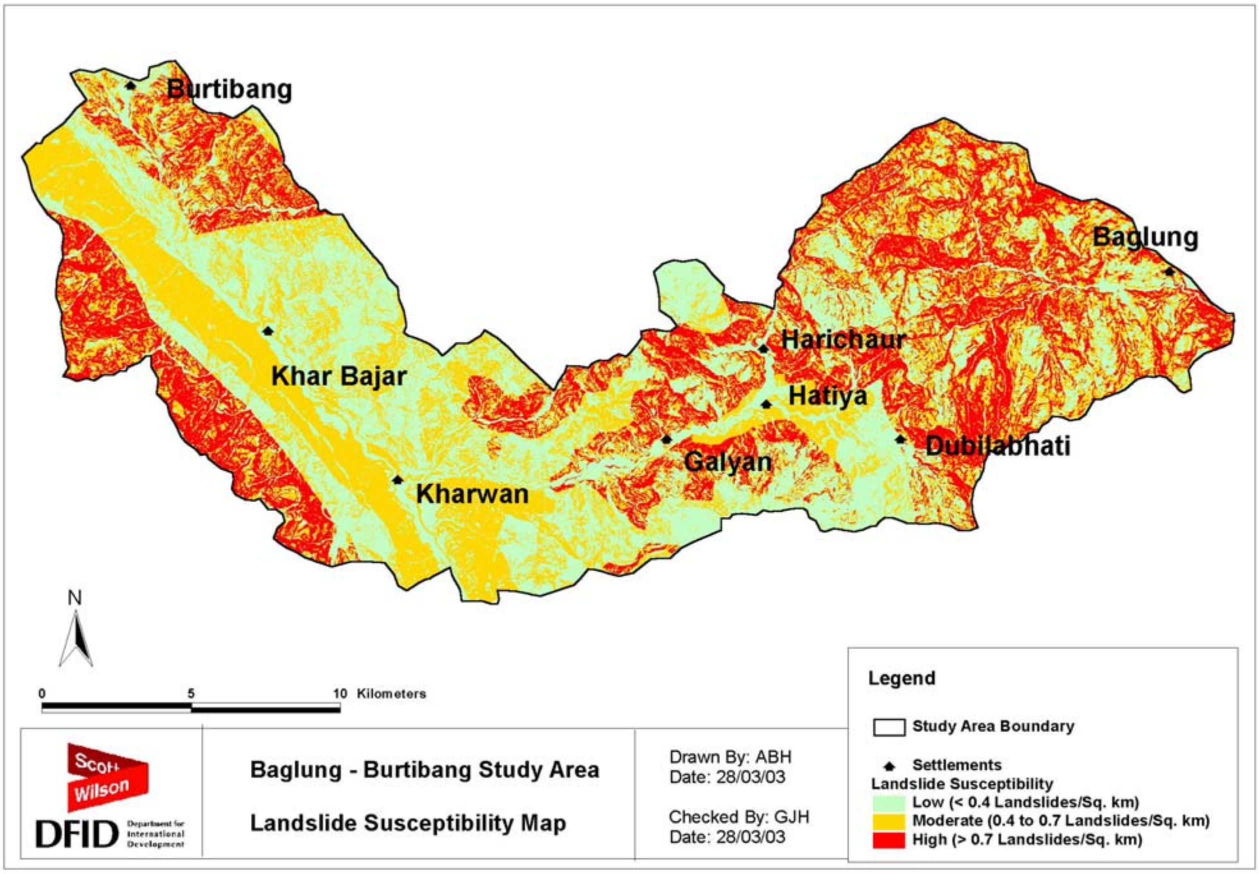


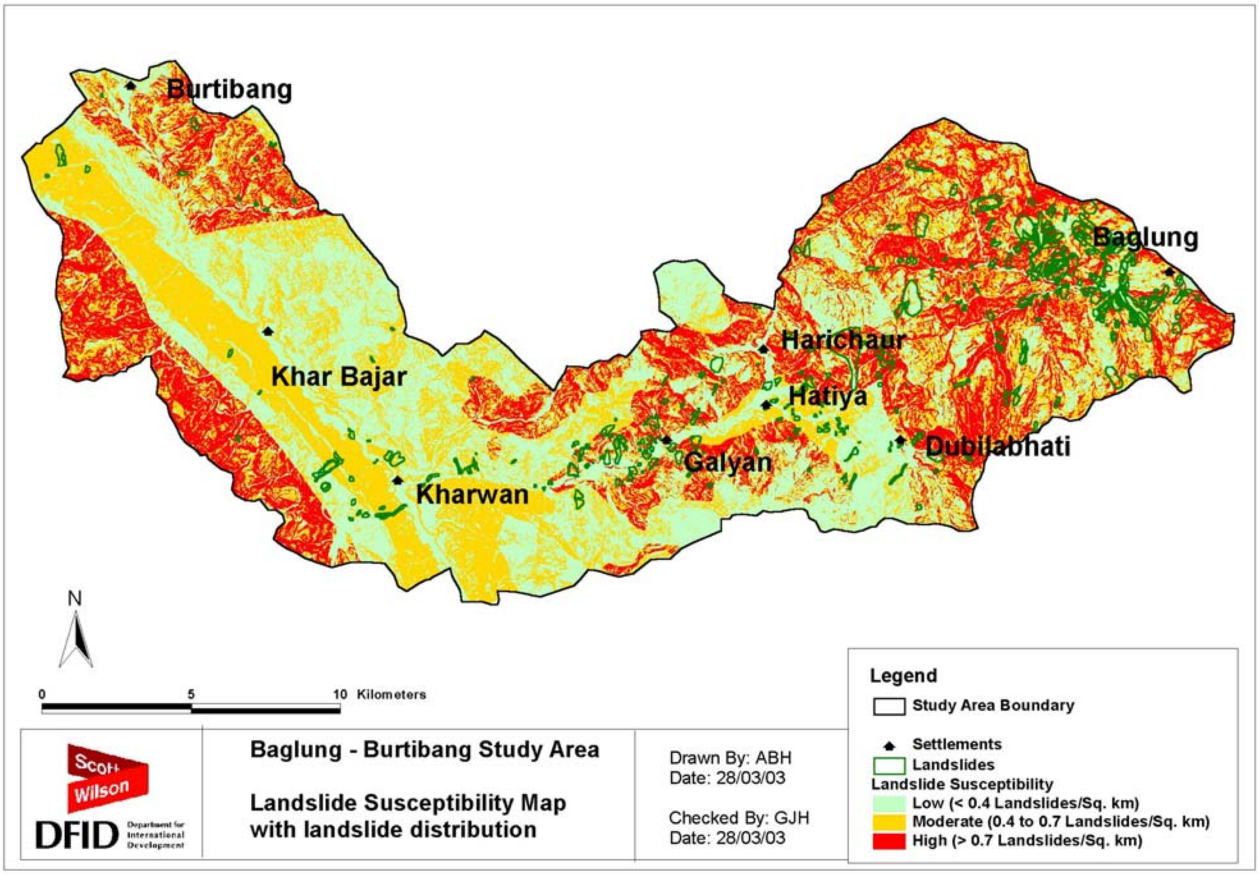



Burtibang
Baglung
Harichaur
Khar Bajar
Hatiya
Dubilabhati
Galyan
Kharwan
N
0
5
10 Kilometers
Legend
Study Area Boundary
Settlements
Structural Lineaments
Anticline
Syncline
Fault
Published Geology
Benighat Slate
Dandagaon Phyllite
Dhading Dolomite
Kuncha Formation
Malekhu Limestone
Nourpul Formation
Raduwa Formation
Robang Phjyllite
Scott Wilson
DFID Department for International Development
Baglung - Burtibang Study Area
Published Geology Map
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

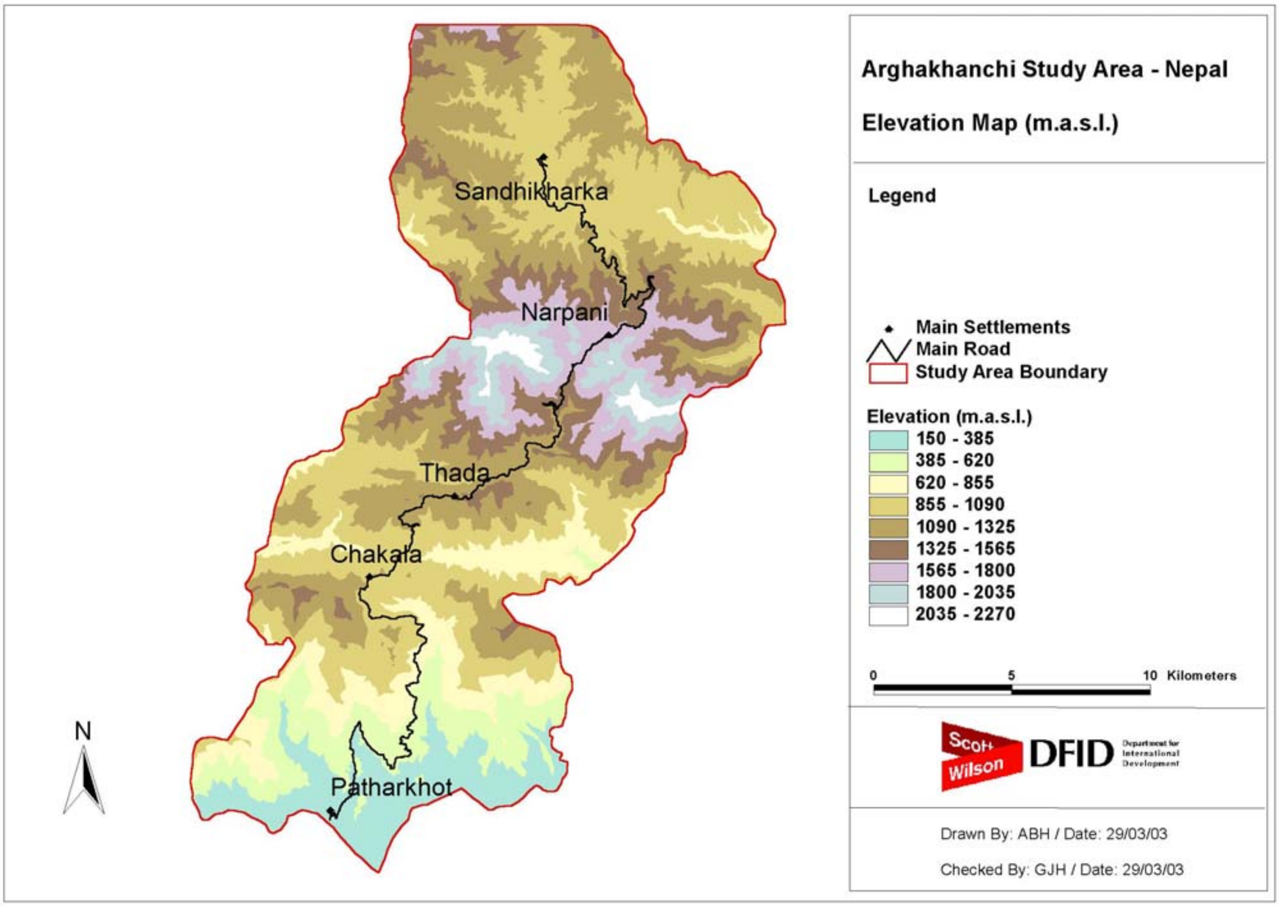

Burtibang
Baglung
Harichaur
Khar Bajar
Hatiya
Dubilabhati
Galyan
Kharwan
N
0
5
10 Kilometers
Legend
Study Area Boundary
Settlements
API-Derived Terrain Classification
Colluvium
Residual Soil
Rock Outcrop
Fan Deposits
River Terrace
Unstable Ground
Scott Wilson
DFID Department for International Development
Baglung - Burtibang Study Area
Terrain Classification Map
derived from API
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

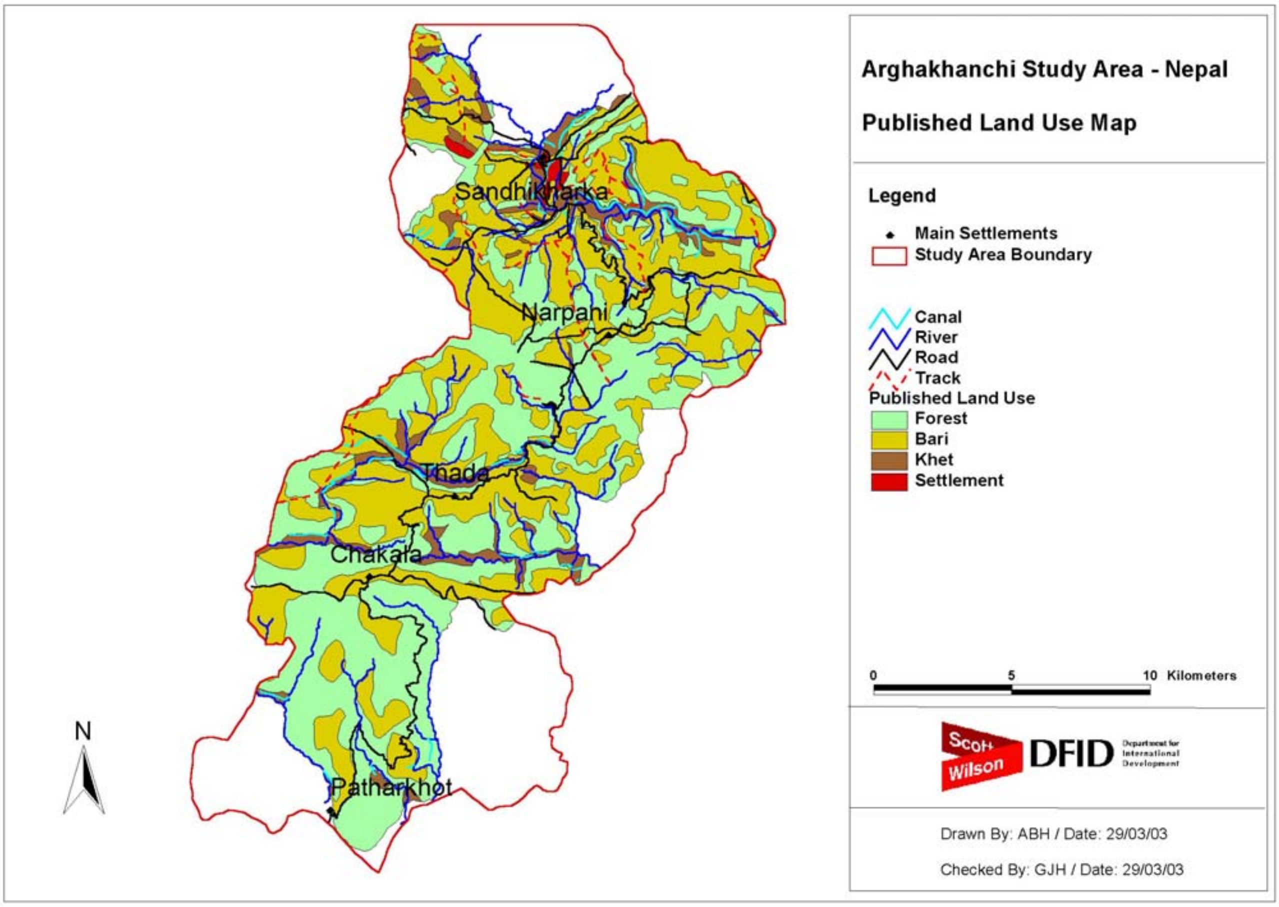

Burtibang
Baglung
Harichaur
Khar Bajar
Hatiya
Galyan
Dubilabhati
Kharwan
N
0
5
10 Kilometers
Legend
Study Area Boundary
Settlements
Main Drainage Lines
Landslides
Scott Wilson
DFID Department for International Development
Baglung - Burtibang Study Area
Landslide distribution mapped
by API, SII & Field Mapping
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

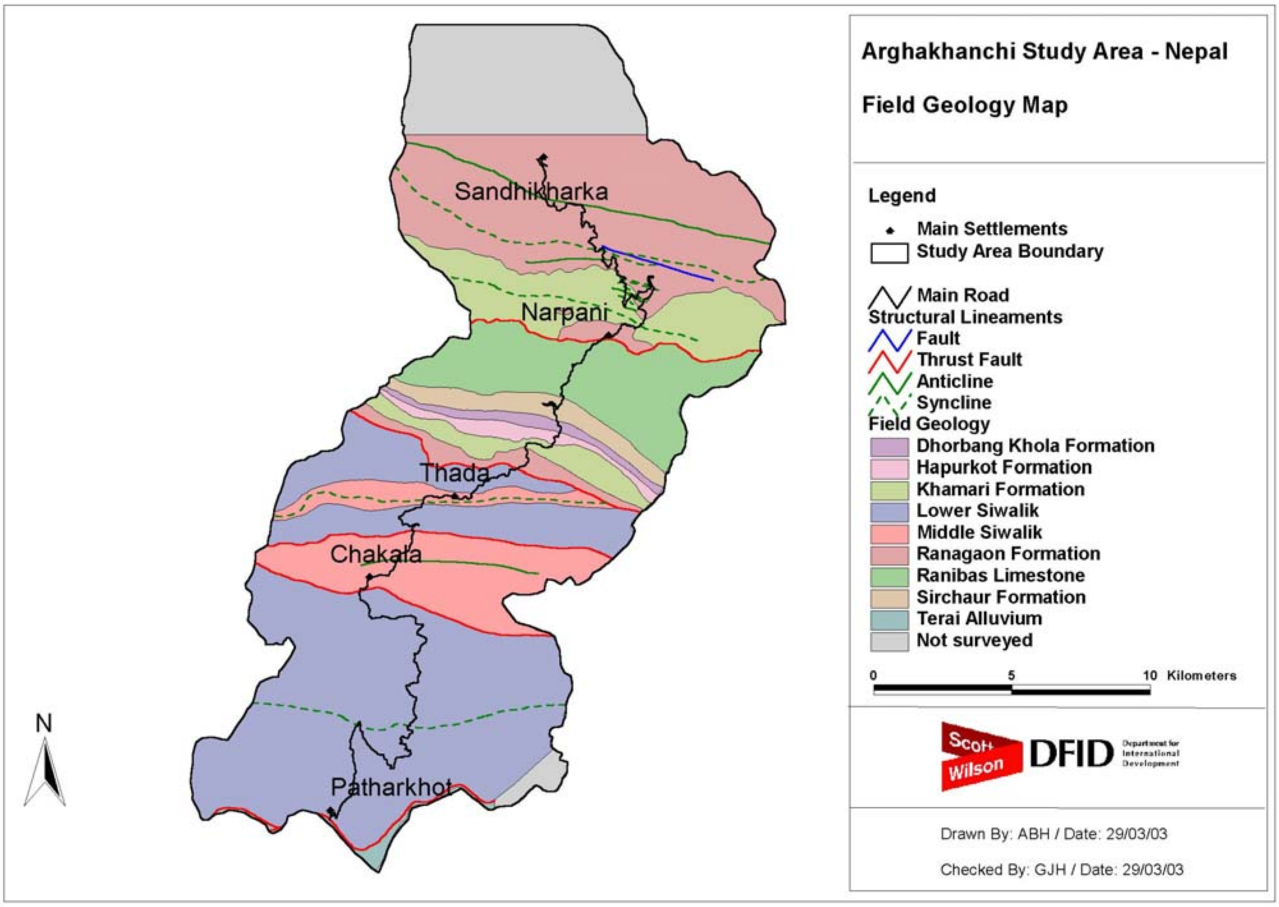

Burtibang
Baglung
Harichaur
Khar Bajar
Hatiya
Galyan
Dubilabhati
Kharwan
N
0
5
10 Kilometers
Legend
Study Area Boundary
Settlements
Landslide Susceptibility
Low (< 0.4 Landslides/Sq. km)
Moderate (0.4 to 0.7 Landslides/Sq. km)
High (> 0.7 Landslides/Sq. km)
Scott Wilson
DFID Department for International Development
Baglung - Burtibang Study Area
Landslide Susceptibility Map
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

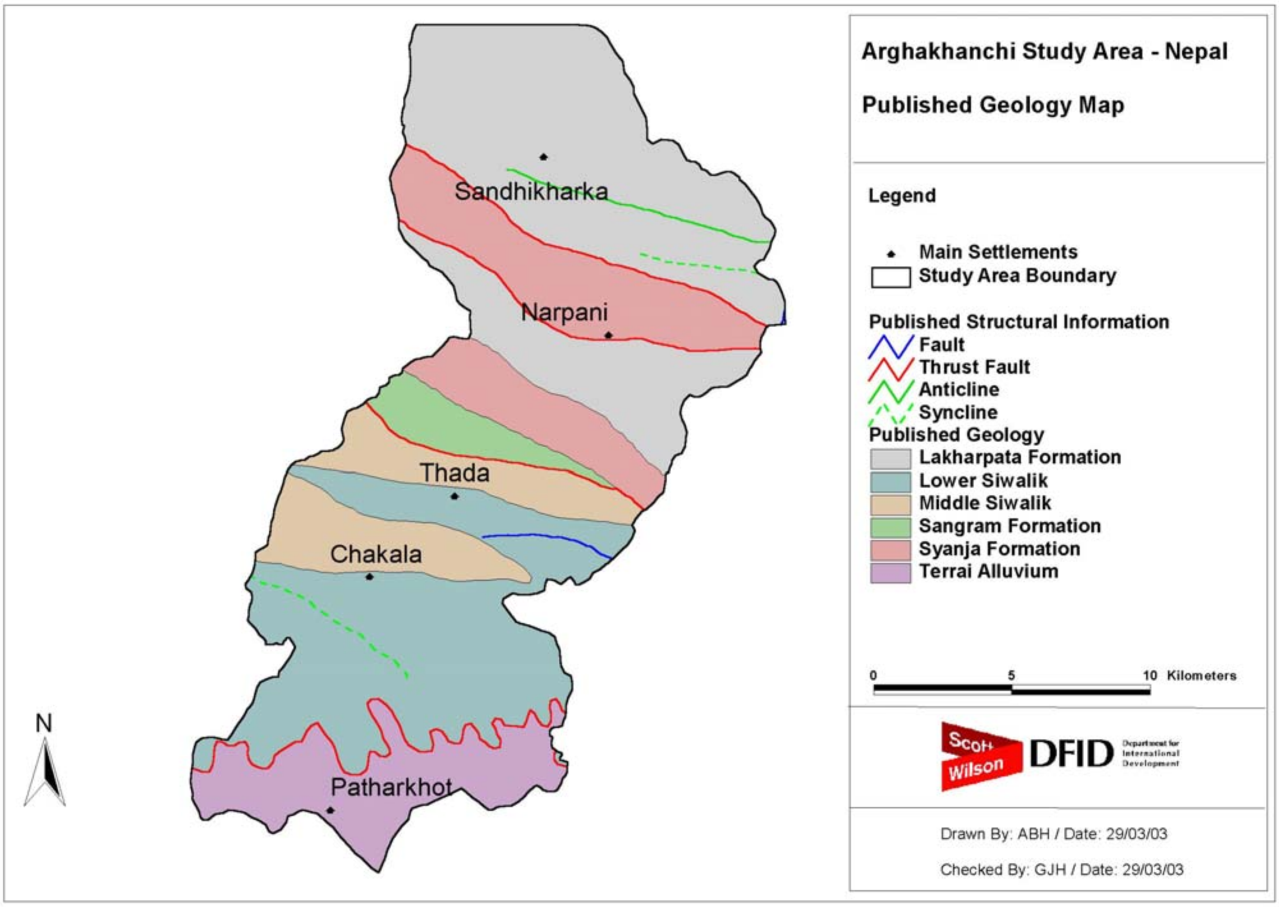


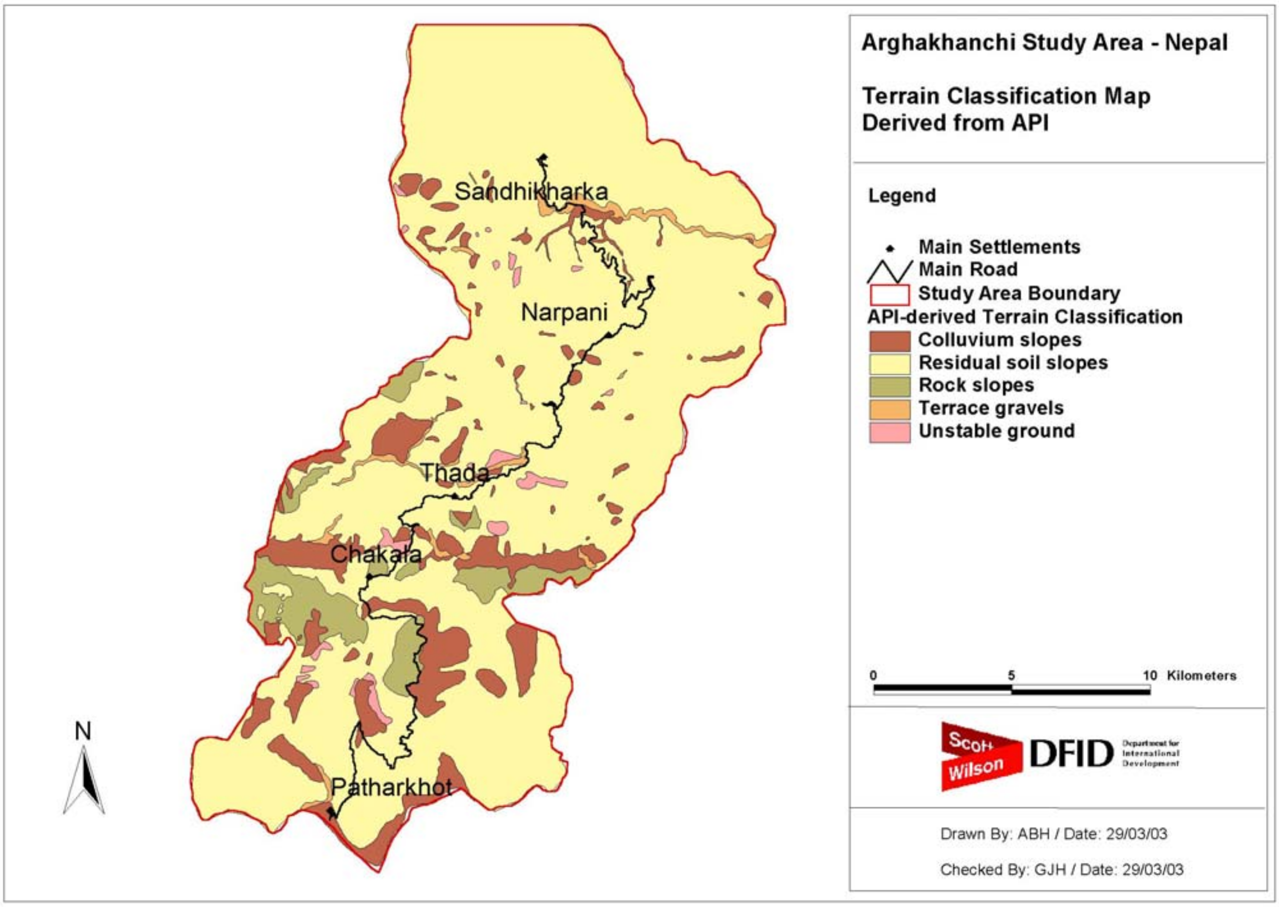
Arghakhanchi Study Area, Nepal

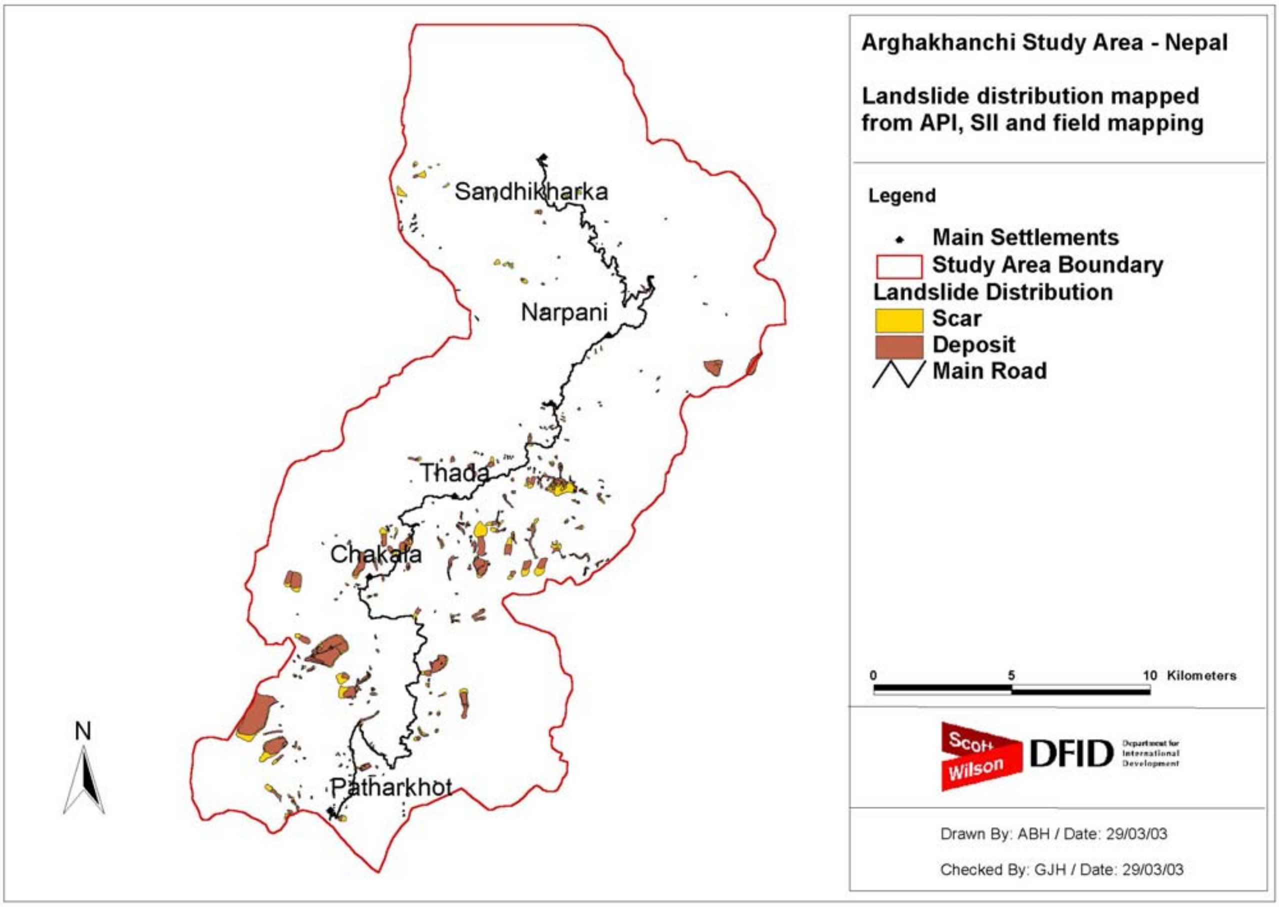


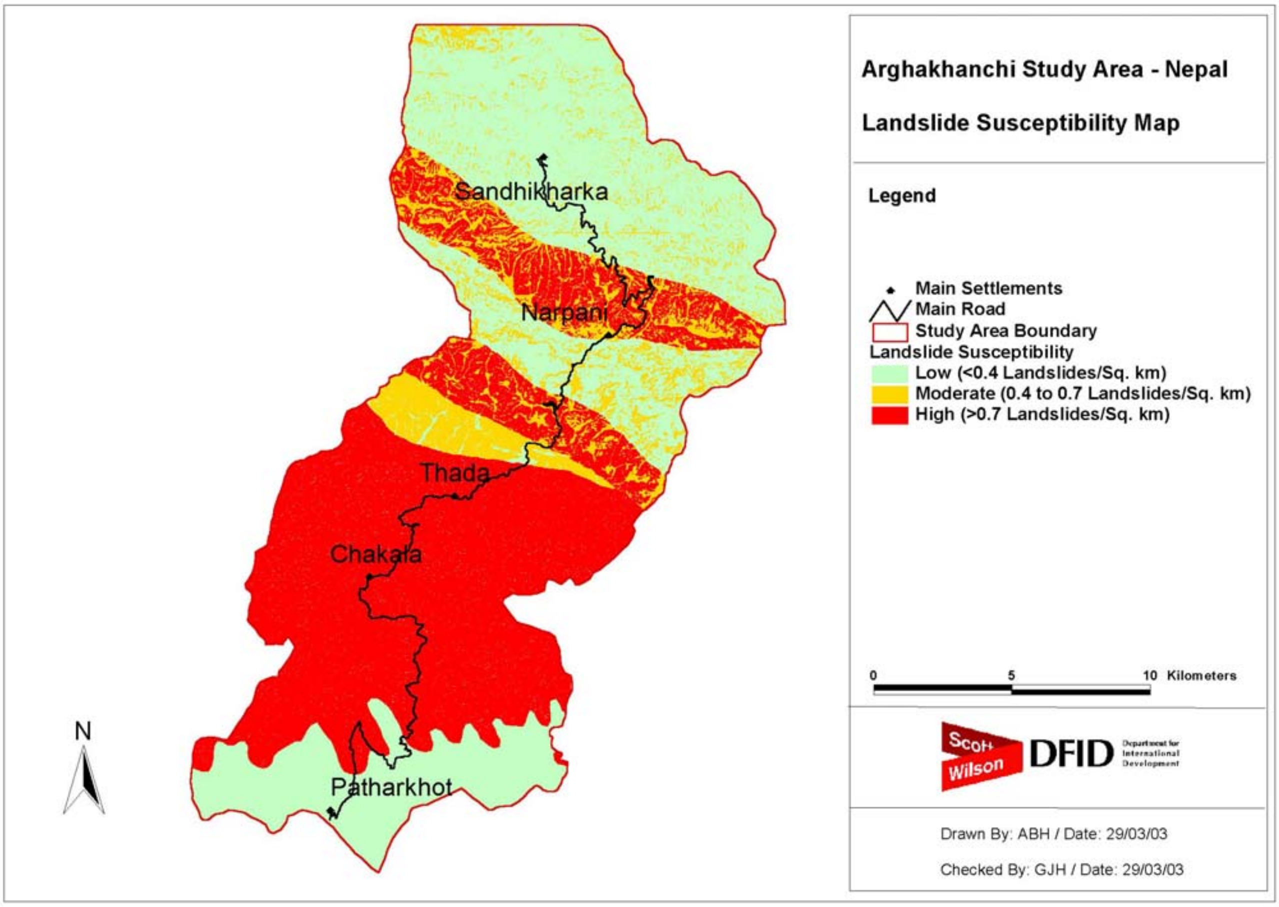

Arghakhanchi Study Area - Nepal
Published Land Use Map
Legend
Main Settlements
Study Area Boundary
Canal
River
Road
Track
Published Land Use
Forest
Bari
Khet
Settlement
0
5
10 Kilometers
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
N

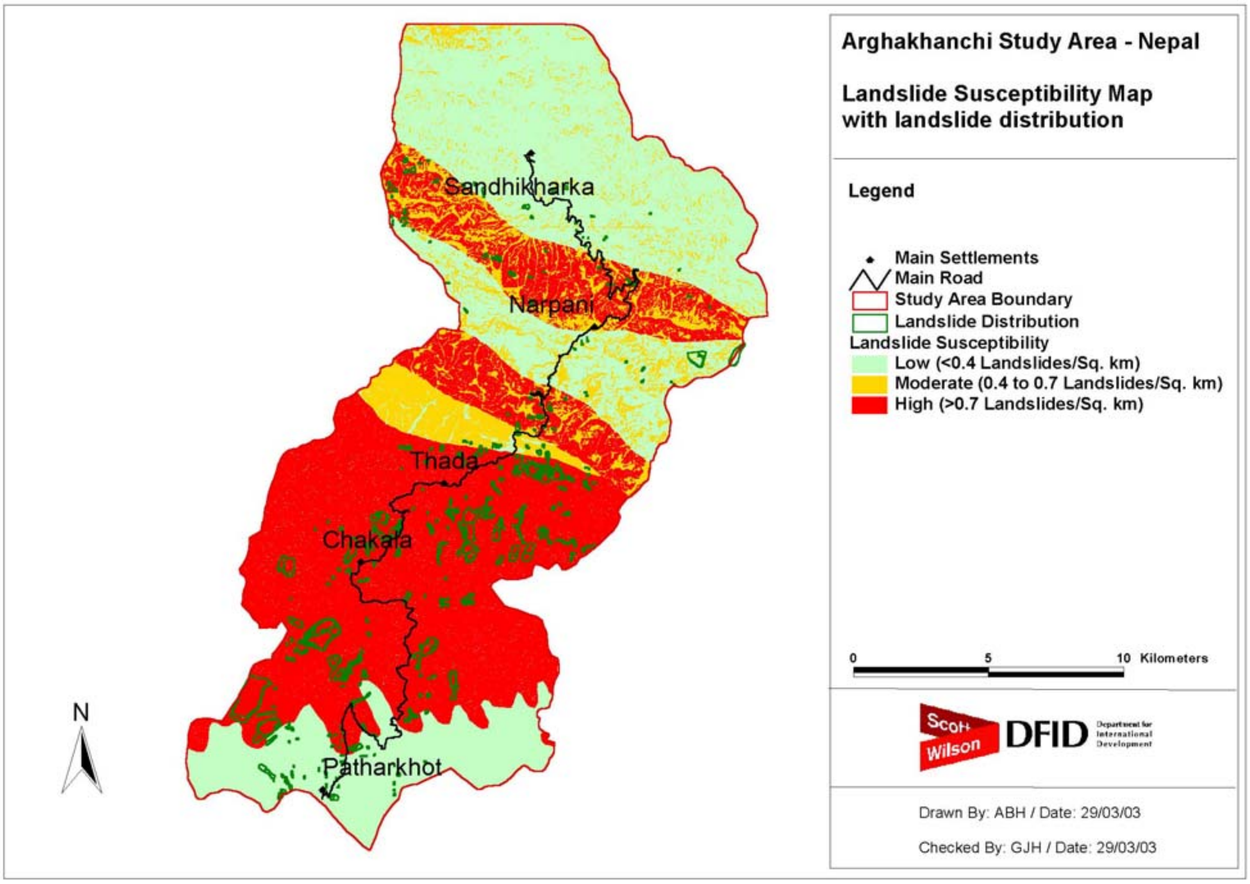

Arghakhanchi Study Area - Nepal
Field Geology Map
Legend
Main Settlements
Study Area Boundary
Main Road
Structural Lineaments
Fault
Thrust Fault
Anticline
Syncline
Field Geology
Dhorbang Khola Formation
Hapurkot Formation
Khamari Formation
Lower Siwalik
Middle Siwalik
Ranagaon Formation
Ranibas Limestone
Sirchaur Formation
Terai Alluvium
Not surveyed
0
5
10 Kilometers
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
N


Arghakhanchi Study Area - Nepal
Published Geology Map
Legend
Main Settlements
Study Area Boundary
Published Structural Information
Fault
Thrust Fault
Anticline
Syncline
Published Geology
Lakharpata Formation
Lower Siwalik
Middle Siwalik
Sangram Formation
Syanja Formation
Terrai Alluvium
0
5
10 Kilometers
N
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03

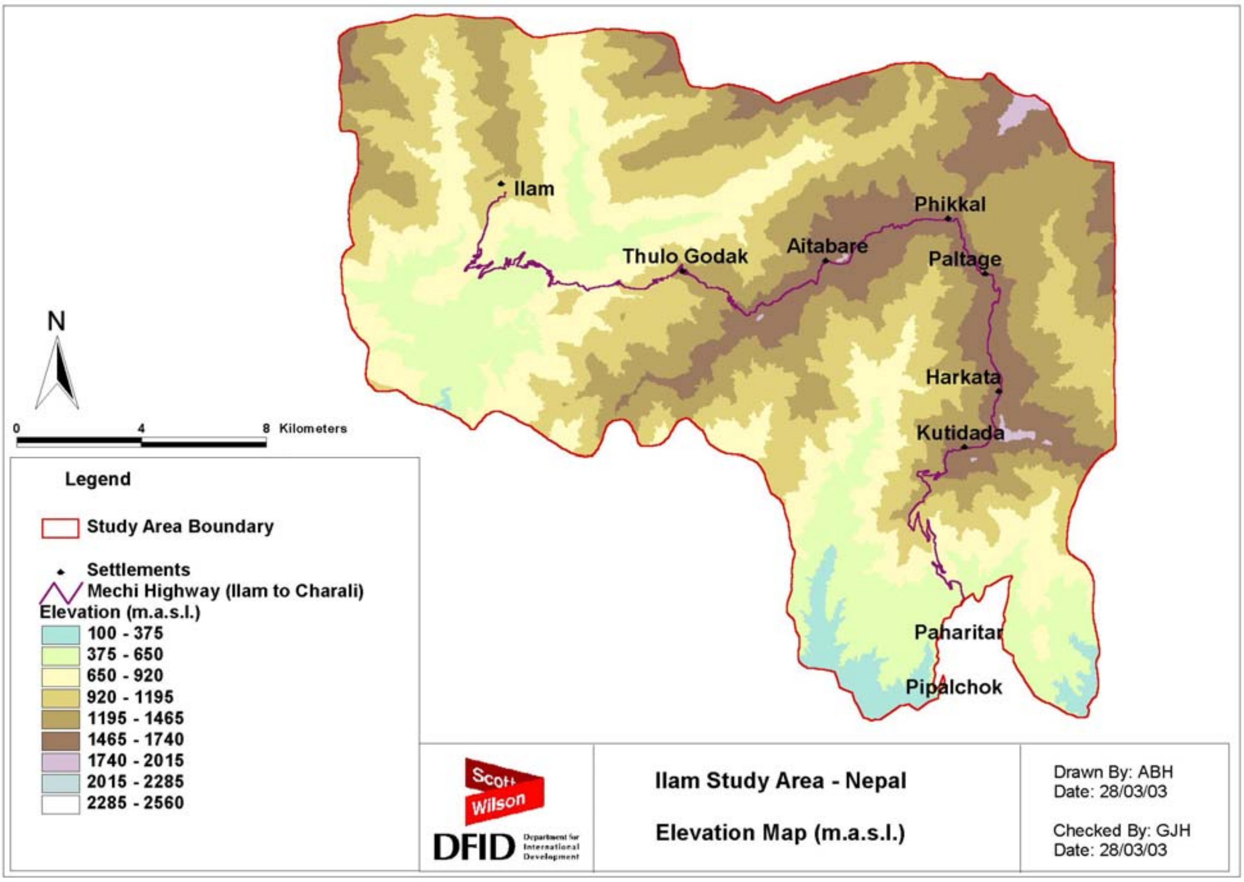

Arghakhanchi Study Area - Nepal
Terrain Classification Map
Derived from API
Legend
Main Settlements
Main Road
Study Area Boundary
API-derived Terrain Classification
Colluvium slopes
Residual soil slopes
Rock slopes
Terrace gravels
Unstable ground
0
5
10 Kilometers
N
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03

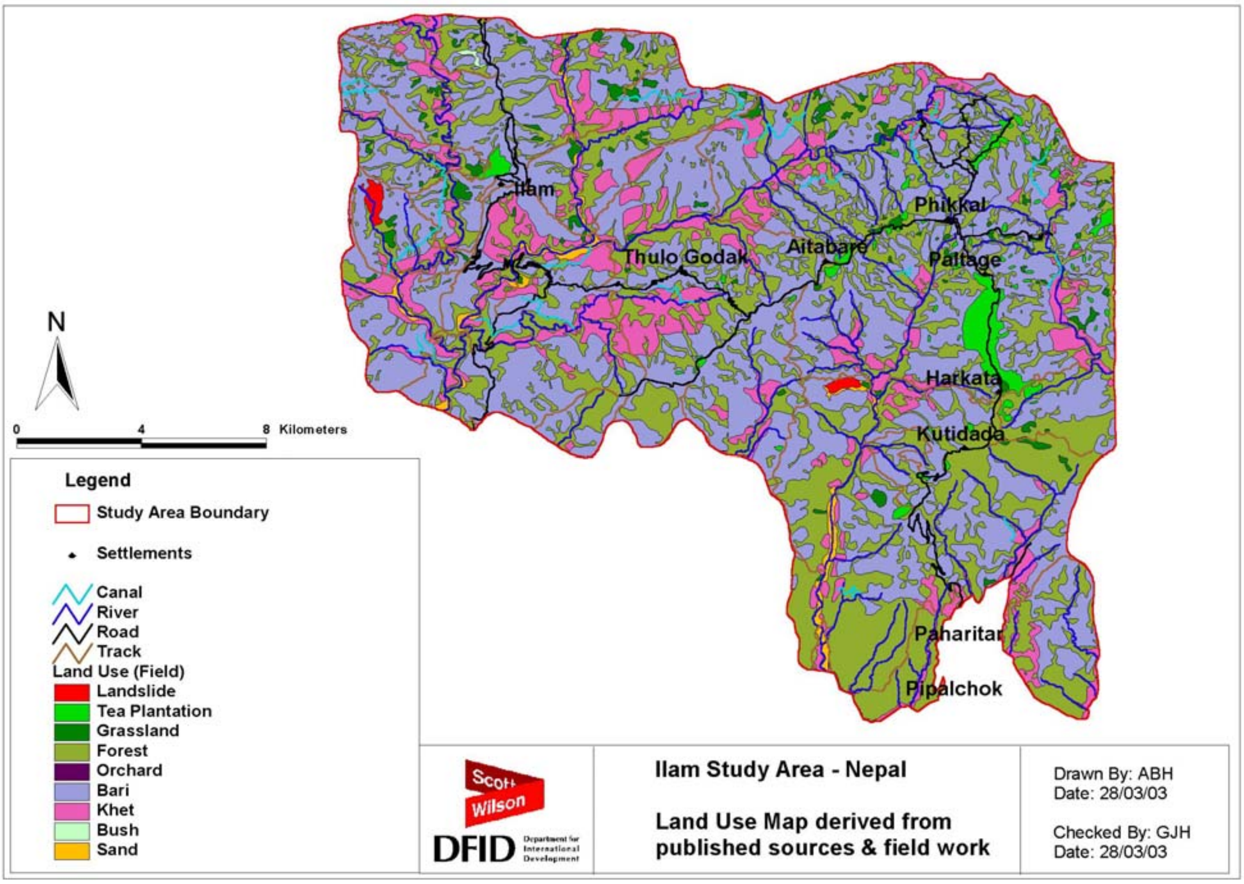

Arghakhanchi Study Area - Nepal
Landslide distribution mapped from API, SII and field mapping
Legend
Main Settlements
Study Area Boundary
Landslide Distribution
Scar
Deposit
Main Road
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
N
0
5
10 Kilometers
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03

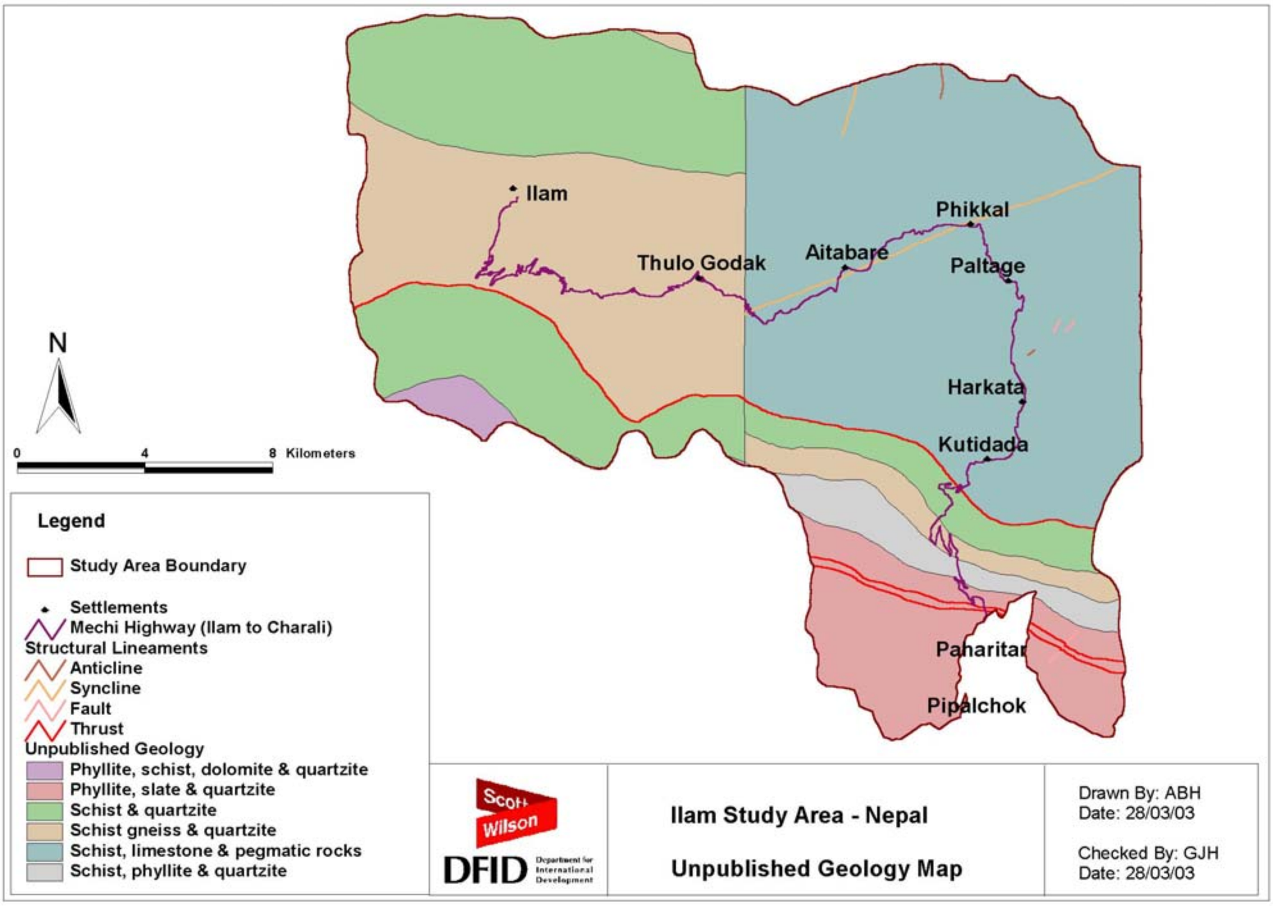

Arghakhanchi Study Area - Nepal
Landslide Susceptibility Map
Legend
Main Settlements
Main Road
Study Area Boundary
Landslide Susceptibility
Low (<0.4 Landslides/Sq. km)
Moderate (0.4 to 0.7 Landslides/Sq. km)
High (>0.7 Landslides/Sq. km)
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
N
0
5
10 Kilometers
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03

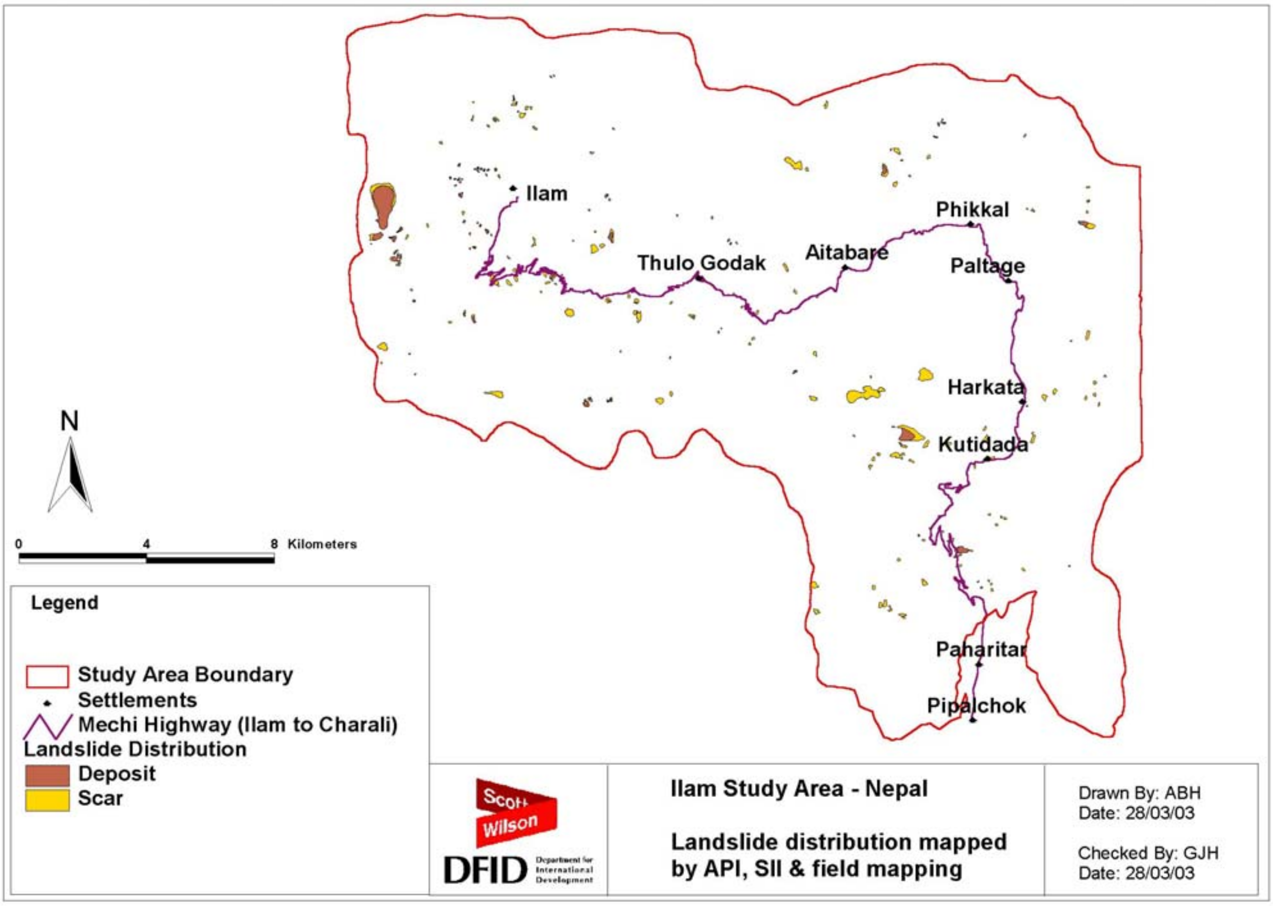

Arghakhanchi Study Area - Nepal
Landslide Susceptibility Map
with landslide distribution
Legend
Main Settlements
Main Road
Study Area Boundary
Landslide Distribution
Landslide Susceptibility
Low (<0.4 Landslides/Sq. km)
Moderate (0.4 to 0.7 Landslides/Sq. km)
High (>0.7 Landslides/Sq. km)
0
5
10 Kilometers
Sandhikharka
Narpani
Thada
Chakala
Patharkhot
N
Scott Wilson
DFID
Department for International Development
Drawn By: ABH / Date: 29/03/03
Checked By: GJH / Date: 29/03/03

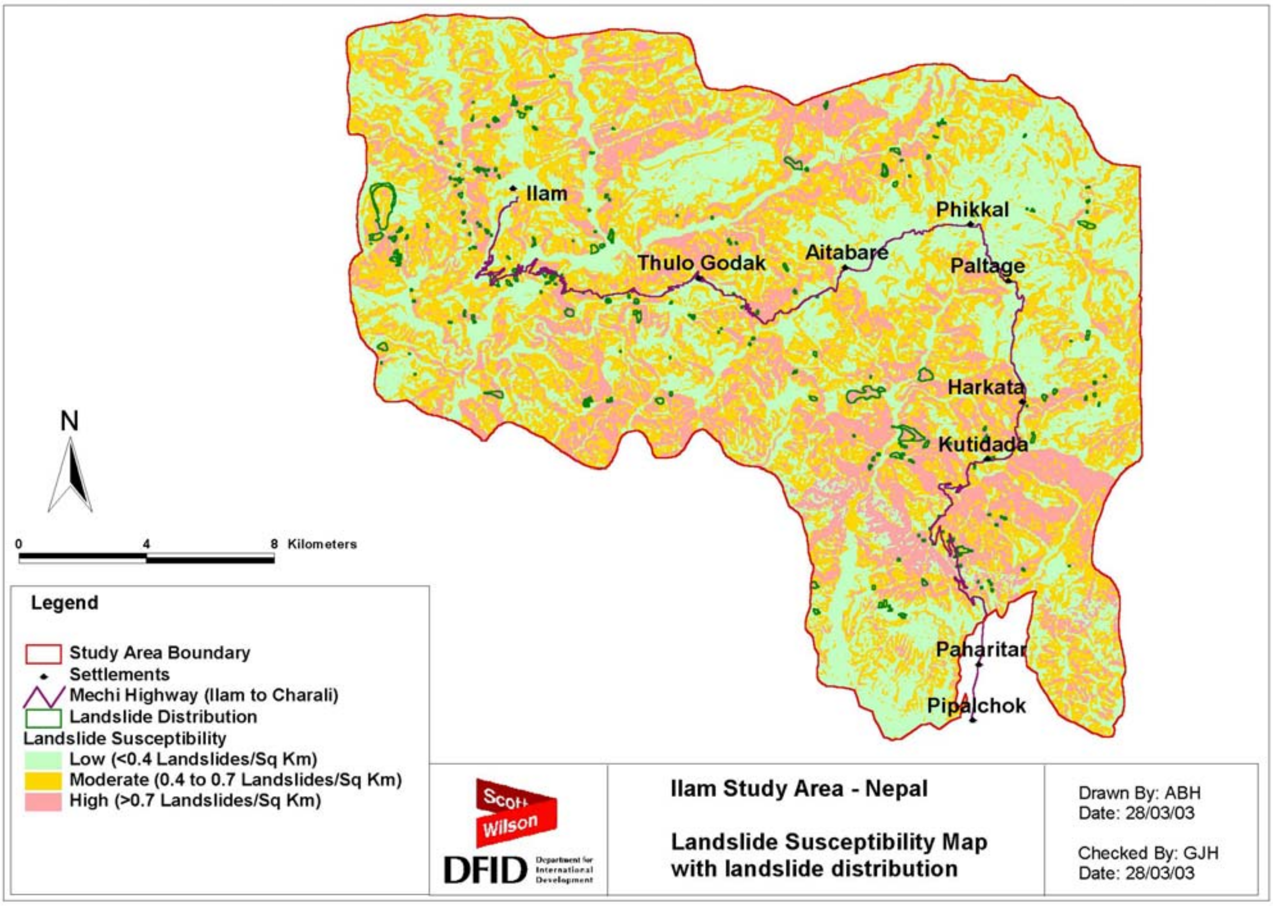
Ilam Study Area, Nepal

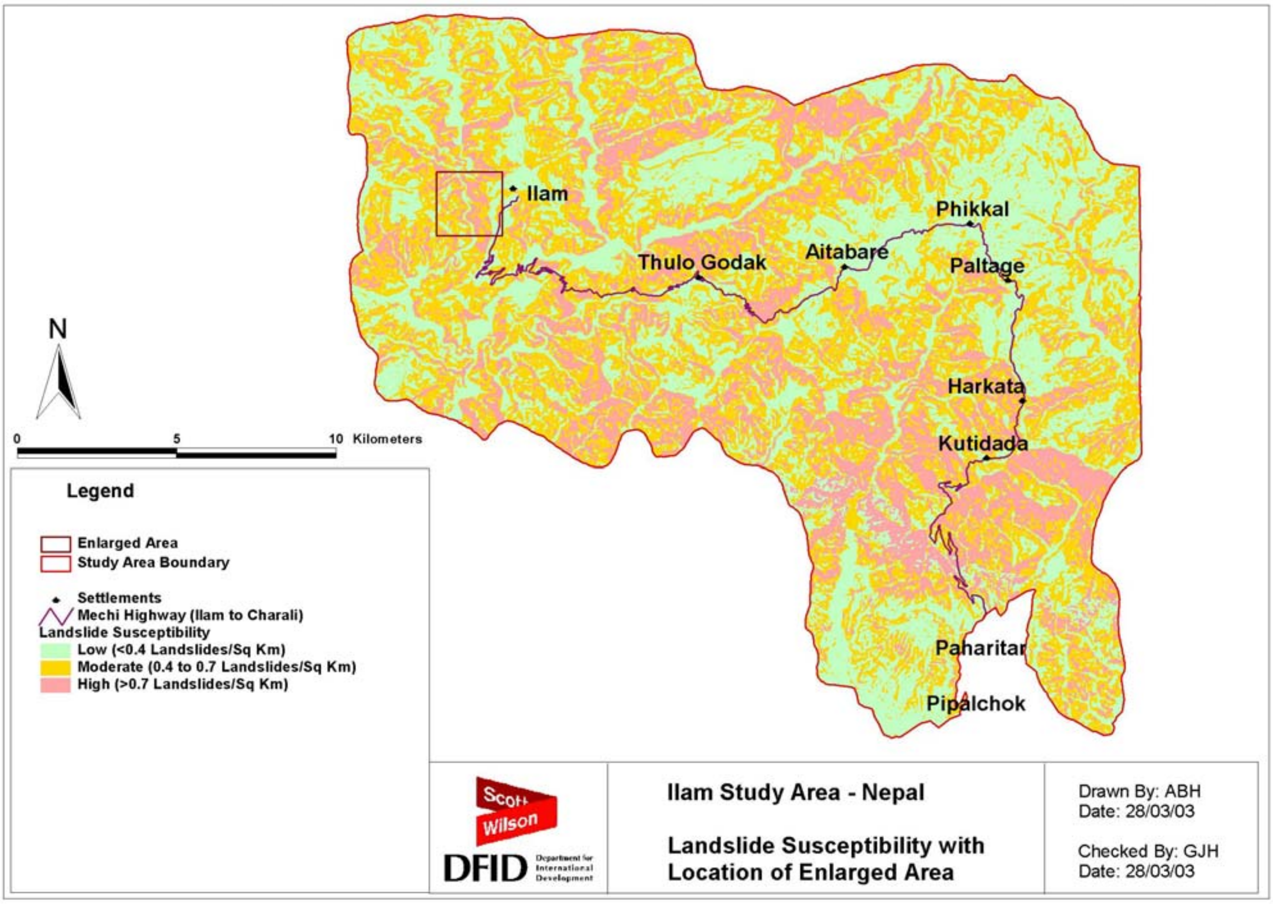


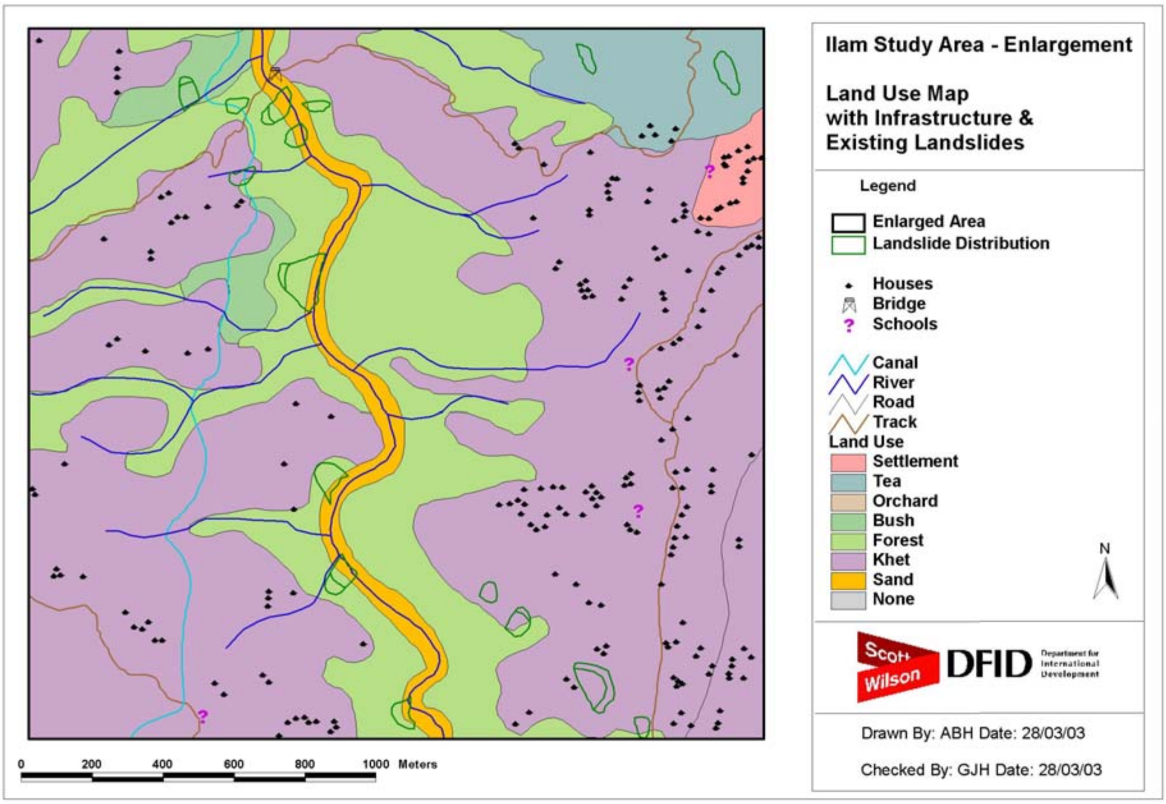


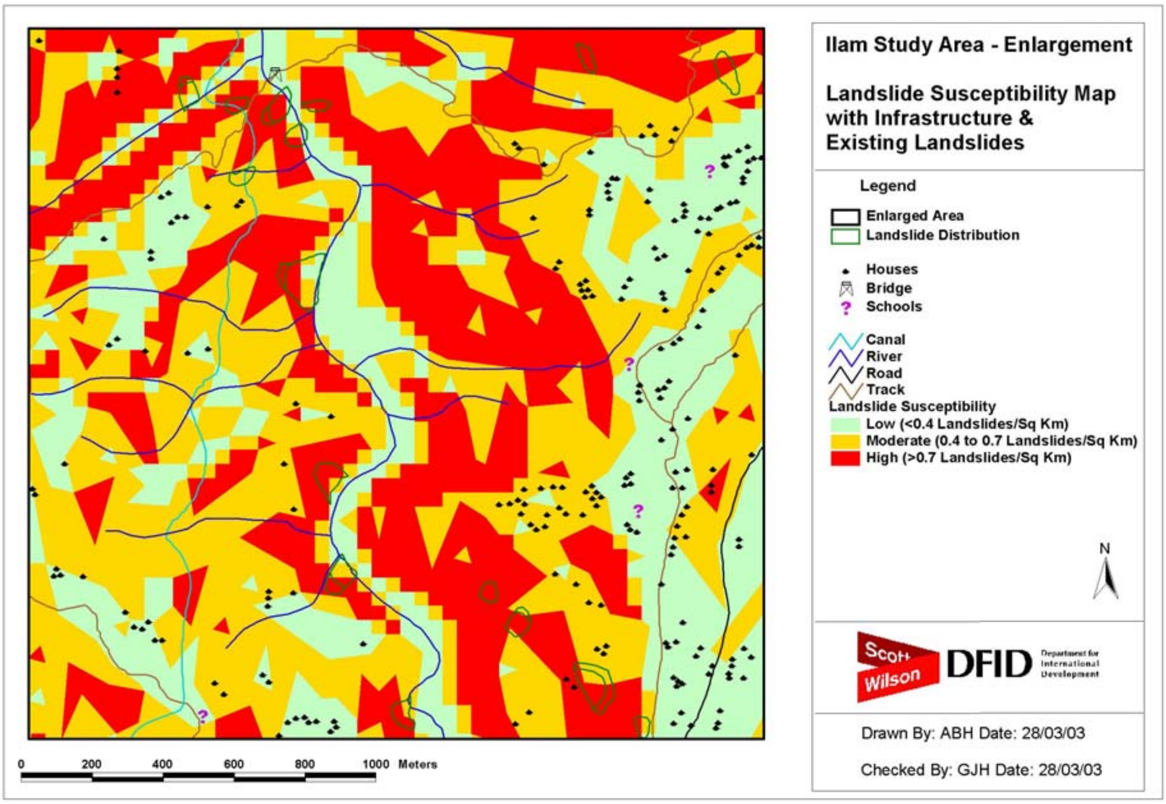

Ilam
Thulo Godak
Aitabare
Phikkal
Paltage
Harkata
Kutidada
Paharitar
Pipalchok
N
0 4 8 Kilometers
Legend
Study Area Boundary
Settlements
Mechi Highway (Ilam to Charali)
Structural Lineaments
Anticline
Syncline
Fault
Thrust
Unpublished Geology
Phyllite, schist, dolomite & quartzite
Phyllite, slate & quartzite
Schist & quartzite
Schist gneiss & quartzite
Schist, limestone & pegmatic rocks
Schist, phyllite & quartzite
Scott Wilson
DFID Department for International Development
Ilam Study Area - Nepal
Unpublished Geology Map
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

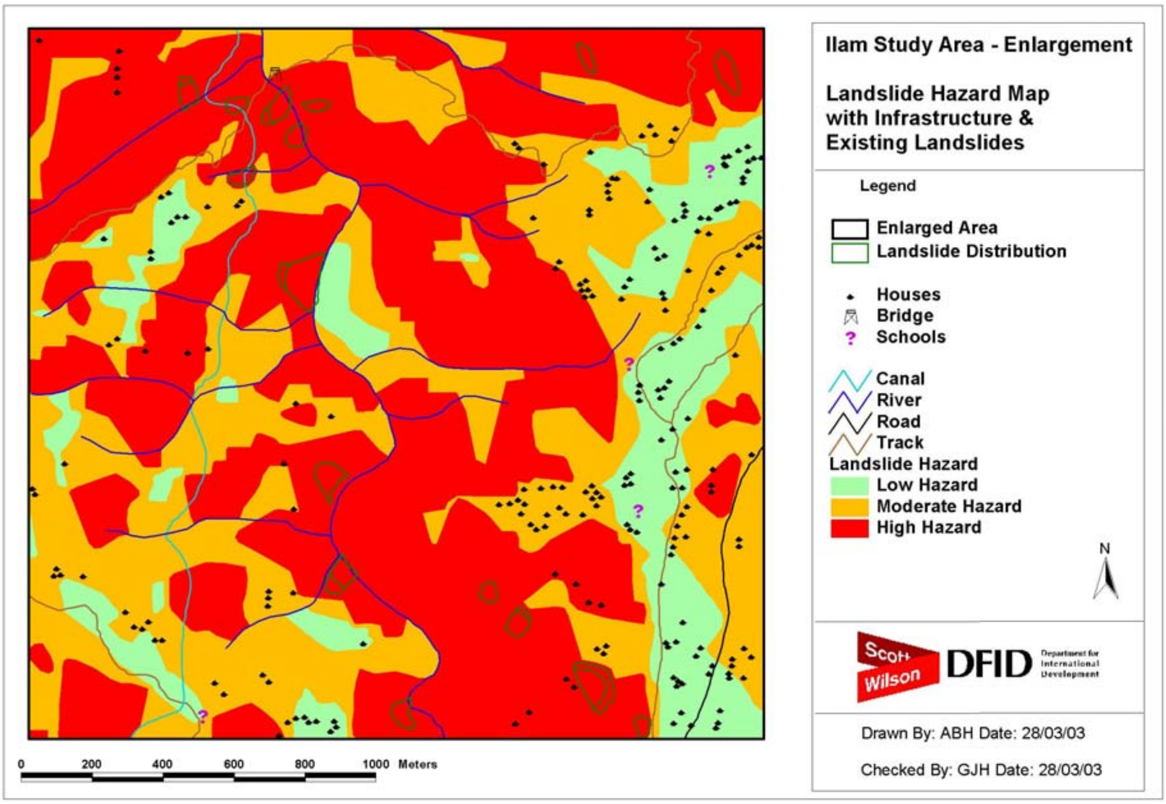

Ilam
Thulo Godak
Aitabare
Phikkal
Paltage
Harkata
Kutidada
Paharitar
Pipalchok
N
0 4 8 Kilometers
Legend
Study Area Boundary
Settlements
Mechi Highway (Ilam to Charali)
Landslide Distribution
Deposit
Scar
Scott Wilson
DFID Department for International Development
Ilam Study Area - Nepal
Landslide distribution mapped by API, SII & field mapping
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03

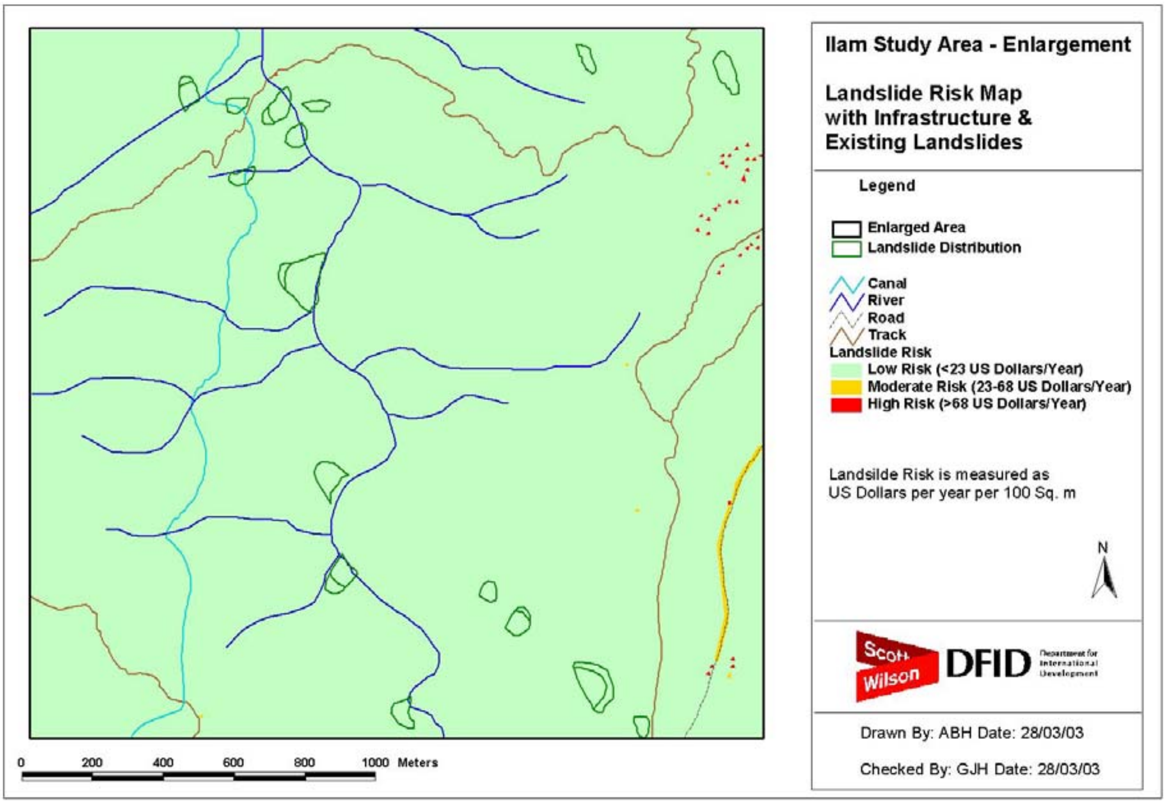

Ilam
Thulo Godak
Aitabare
Phikkal
Paltage
Harkata
Kutidada
Paharitar
Pipalchok
N
0
4
8 Kilometers
Legend
Study Area Boundary
Settlements
Mechi Highway (Ilam to Charali)
Landslide Distribution
Landslide Susceptibility
Low (<0.4 Landslides/Sq Km)
Moderate (0.4 to 0.7 Landslides/Sq Km)
High (>0.7 Landslides/Sq Km)
Scott Wilson
DFID Department for International Development
Ilam Study Area - Nepal
Landslide Susceptibility Map
with landslide distribution
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03


Ilam
Thulo Godak
Aitabare
Phikkal
Paltage
Harkata
Kutidada
Paharitar
Pipalchok
N
0
5
10 Kilometers
Legend
Enlarged Area
Study Area Boundary
Settlements
Mechi Highway (Ilam to Charali)
Landslide Susceptibility
Low (<0.4 Landslides/Sq Km)
Moderate (0.4 to 0.7 Landslides/Sq Km)
High (>0.7 Landslides/Sq Km)
Scott Wilson
DFID Department for International Development
Ilam Study Area - Nepal
Landslide Susceptibility with
Location of Enlarged Area
Drawn By: ABH
Date: 28/03/03
Checked By: GJH
Date: 28/03/03


Ilam Study Area - Enlargement
Land Use Map
with Infrastructure &
Existing Landslides
Legend
Enlarged Area
Landslide Distribution
Houses
Bridge
Schools
Canal
River
Road
Track
Land Use
Settlement
Tea
Orchard
Bush
Forest
Khet
Sand
None
N
Scott Wilson
DFID
Department for International Development
Drawn By: ABH Date: 28/03/03
Checked By: GJH Date: 28/03/03
0 200 400 600 800 1000 Meters


Ilam Study Area - Enlargement
Landslide Susceptibility Map
with Infrastructure &
Existing Landslides
Legend
Enlarged Area
Landslide Distribution
Houses
Bridge
Schools
Canal
River
Road
Track
Landslide Susceptibility
Low (<0.4 Landslides/Sq Km)
Moderate (0.4 to 0.7 Landslides/Sq Km)
High (>0.7 Landslides/Sq Km)
N
Scott Wilson
DFID
Department for International Development
Drawn By: ABH Date: 28/03/03
Checked By: GJH Date: 28/03/03
0 200 400 600 800 1000 Meters


Ilam Study Area - Enlargement
Landslide Hazard Map with Infrastructure & Existing Landslides
Legend
Enlarged Area
Landslide Distribution
Houses
Bridge
Schools
Canal
River
Road
Track
Landslide Hazard
Low Hazard
Moderate Hazard
High Hazard
N
0 200 400 600 800 1000 Meters
Scott Wilson
DFID
Department for International Development
Drawn By: ABH Date: 28/03/03
Checked By: GJH Date: 28/03/03


Ilam Study Area - Enlargement
Landslide Risk Map with Infrastructure & Existing Landslides
Legend
Enlarged Area
Landslide Distribution
Canal
River
Road
Track
Landslide Risk
Low Risk (<23 US Dollars/Year)
Moderate Risk (23-68 US Dollars/Year)
High Risk (>68 US Dollars/Year)
Landsilde Risk is measured as US Dollars per year per 100 Sq. m
N
0 200 400 600 800 1000 Meters
Scott Wilson
DFID
Department for International Development
Drawn By: ABH Date: 28/03/03
Checked By: GJH Date: 28/03/03