GEOLOGICAL INVESTIGATION OF LAND INSTABILITY IN KOHIMA TOWN, NAGALAND

BY

TEMSULEMBA WALLING

GEOLOGY DEPARTMENT

SUBMITTED

IN PARTIAL FULFILMENT OF THE REQUIREMENT OF THE DEGREE OF DOCTOR OF PHILOSOPHY IN GEOLOGY OF NAGALAND UNIVERSITY

For

Mum & Dad

NAGALAND UNIVERSITY

Dr. Glenn T. Thong
Reader & Head
Department of Geology
☎: 0370 2240515 (R), 2224330/2245341 (O)
Telefax: 2245474
Mobile: 9436000479
E-mail: glen2t03@yahoo.com
nagalandslide@yahoo.com

Dated Kohima the
16th April 2005

CERTIFICATE

The thesis presented by Mr. Temsulemba Walling, M.Sc., embodies the results of investigations carried out by him under my supervision and guidance.

I certify that this work has not been presented for any degree elsewhere and that the candidate has fulfilled all conditions laid down by the University.

Forwarded
16/04/05
HEAD
Department of Geology
Nagaland University, Kohima

(G.T. THONG)
Supervisor

NAGALAND UNIVERSITY
April 2005

DECLARATION

I, Shri Temsulemba Walling, hereby declare that the subject matter of this thesis is the record of work done by me, that the contents of this thesis did not form basis of the award of any previous degree to me or to the best of my knowledge to anybody else, and that the thesis has not been submitted by me for any research degree in any other University/Institute.

This is being submitted to the Nagaland University for the Degree of Doctor of Philosophy in Geology.

16/04/05
Candidate

16/04/05
Head/Supervisor
HEAD
Department of Geology
Nagaland University, Kohima

ACKNOWLEDGEMENT

I am greatly indebted to my Supervisor Dr. Glenn T. Thong, Reader and Head of the Department of Geology, Nagaland University, Kohima for his constant guidance throughout this work. My sincere thanks go to Dr. Imtiwapang Aier, Project Assistant (DST) and Dr. (Ms) V. Rino, Research Associate (CSIR) of the Department of Geology, Nagaland University, Dr. (Ms) Nestalü Hiese, Research Associate (DST), Government of Nagaland, and Mr. Kaihe Kemas, Geologist (ONGC) for their immense contribution. I am forever indebted to my friends Wati, Abemo, and Lima for all their help during my fieldwork. The computer and software facilities and use of satellite data of the Indian Space Research Organisation (ISRO) are gratefully acknowledged.

Kohima: 16th April 2005

(TEMSULEMBA WALLING)
Research Scholar
Department of Geology
Nagaland University
Kohima Campus
797 002

LIST OF TABLES

(Tables follow relevant pages)

1	Stratigraphy of Nagaland
2	Drainage basin parameters
4	Rainfall data
5.1.1a	Slope and Drainage parameters (Segment 1)
5.1.1b	Slope and Drainage parameters (Segment 2)
5.1.2a	Lithology and Land use/Land cover (Segment 1)
5.1.2b	Lithology and Land use/Land cover (Segment 2)
5.2a	LHEF and TEHD (Segment 1)
5.2b	LHEF and TEHD (Segment 2)
7	Subsidiary landslides: Causes and remedial measures

LIST OF FIGURES

(Figures follow relevant pages)

1.1	Location map
1.2	Tectonic map of Northeast India
1.3	Map of Belt of Schuppen
1.4	Geological map of study area
2.1.1	Facet map (Segment 1)
2.1.2	Facet map (Segment 2)
2.2	Drainage basin map
3.1	Subset of study area
3.2	Digital Elevation Model
5.1.1	Slope map (Segment 1)
5.1.2	Slope map (Segment 2)
5.2.1	Relative relief map (Segment 1)
5.2.2	Relative relief map (Segment 2)
5.3.1	Lithologic map (Segment 1)
5.3.2	Lithologic map (Segment 2)
5.4.1	Structural map (Segment 1)
5.4.2	Structural map (Segment 2)
5.5.1	Drainage density map (Segment 1)
5.5.2	Drainage density map (Segment 2)
5.6.1	Land use/Land cover map (Segment 1)
5.6.2	Land use/Land cover map (Segment 2)
6.1	Landslide Hazard Zonation map (Segment 1)
6.2	Landslide Hazard Zonation map (Segment 2)
7.1	Chiepfütsiepfe slide map
7.2	Keziekie slide map
7.3	Lerie slide map
7.4	Paramedical slide map
7.5	Midland slide map
7a	Plan for Filter fabric trench diagram
7b	Plan for Ballie/Bamboo stakes and runners

LIST OF PLATES

(Plates numbered according to text and follow relevant pages)

7.1.1	Chiepfütsiepfe slide
7.1.2	Chiepfütsiepfe slide
7.2.1	Keziekie slide
7.2.2	Keziekie slide
7.3	Lerie slide
7.4.1	Paramedical slide
7.4.2	Paramedical slide
7.5	Midland slide
7a	New Market slide
7b	Naga Bazaar slide
7c	BRTF slide
7d	Assam Rifles slide

CONTENTS

			PAGE
CHAPTER 1	**INTRODUCTION**		1 - 13
	1.1	Location of the area	2
	1.2	Geology of Nagaland	3
	1.3	Major structural features of Nagaland	7
	1.4	Objectives	9
	1.5	Geology of the area	11
CHAPTER 2	**METHODOLOGY**		14 - 21
	2.1	LHEF Rating Scheme	14
	2.2.1	Slope Morphometry	15
	2.2.2	Relative Relief	16
	2.2.3	Lithology	16
	2.2.4	Structure	16
	2.2.5	Drainage Density	17
	2.2.6	Land use and Land cover	19
	2.3	Total Estimated Hazard	20
	2.4	Landslide Hazard Zonation	20
	2.5	GIS and Remote Sensing	21
CHAPTER 3	**GIS AND REMOTE SENSING**		22 - 26
	Introduction		22
	3.1	Sources of acquisition	24
	3.2	Spatial data creation	24
	3.3	Geocoding, Georeferencing, and Mosiacking	25
	3.4	Digital Elevation Model	25

	3.5	Thematic maps from satellite imageries	25
	3.6	Attribute data creation	26
CHAPTER 4	**LITERATURE REVIEW**		27 - 42
	Introduction		27
	4.1	Slope and Relief	30
	4.2	Lithology	33
	4.3	Structure	34
	4.4	Hydrogeology	36
	4.5	Land use and Land cover	37
	4.6	Rainfall	39
	4.7	Seismicity	40
CHAPTER 5	**THEMATIC MAPPING**		43 - 72
	Introduction		43
	5.1	Slope morphometry	43
	5.2	Relative Relief	52
	5.3	Lithology	61
	5.4	Structure	61
	5.5	Drainage density	70
	5.6	Land use and Land cover	71
CHAPTER 6	**LANDSLIDE HAZARD ZONATION**		73 - 76
	Introduction		73
	Landslide Hazard Zonation Mapping		75

CHAPTER 7 **CASE STUDIES** 77 - 94

Introduction 77

7.1 Chiepfütsiepfe slide 77

7.1.1 Introduction 77

7.1.2 Geology of the area 78

7.1.3 Structure 78

7.1.4 Causes 78

7.1.5 Effects 78

7.1.6 Previous works 79

7.1.7 Recommendations 79

7.2 Keziekie slide 80

7.2.1 Introduction 80

7.2.2 Geology of the area 80

7.2.3 Structure 80

7.2.4 Causes 81

7.2.5 Effects 81

7.2.6 Previous works 82

7.2.7 Recommendations 82

7.3 Lerie slide 83

7.3.1 Introduction 83

7.3.2 Geology of the area 83

7.3.3 Structure 83

7.3.4 Causes 84

7.3.5 Effects 84

7.3.6 Previous works 84

7.3.7 Recommendations 84

7.4 Paramedical slide 86

7.4.1 Introduction 86

7.4.2 Geology of the area 86

7.4.3 Structure 86

7.4.4 Causes 87

7.4.5 Effects 87

7.4.6 Previous works 87

7.4.7 Recommendations 87

7.5 Midland slide 89

7.5.1 Introduction 89

7.5.2 Geology of the area 89

7.5.3 Structure 89

7.5.4 Causes 89

7.5.5 Effects 90

7.5.6 Previous works 91

7.5.7 Recommendations 91

7.6 Description of proposed remedial measures 92

7.6.1 Water control methods 92

7.6.1.1 Catch water drain 92

7.6.1.2 Deep trench drain 93

7.6.2 Bamboo/wooden nail reinforcement 93

7.6.3 Retaining walls 93

7.6.4 Vegetation 94

CHAPTER 8 DISCUSSION AND CONCLUSION 95 - 105

BIBLIOGRAPHY 106 - 117

CHAPTER 1

INTRODUCTION

Nagaland is part of a mobile belt that is highly dissected and represents a relatively immature young mountainous terrain. The area of investigation lying at the central-south region of Nagaland may be divided into two broad topographic units. These include the highly mountainous terrain fringing the south of Kohima town and the comparatively low denuded hills of the rest of the town. The southern fringe of high mountains is the area covered by the Barail sediments which are dominantly made up of sandstones. This is a thickly forested area that occupies a very small portion of the area of investigation. The lower hills are made up of the Disang sediments that are composed mostly of shales and their weathered products. These hills are more or less devoid of vegetation, the area being primarily used for human inhabitation.

Tectonism has caused large scale folding and faulting that has resulted in severe fracturing and crumpling of the rocks. Folding is responsible for the tight anticlines and synclines at places in the rocks of the area which have been further altered by the geomorphic processes. The erosional processes that dissect geologic structures help loosen rock masses on slopes of present topography. Fracture zones and systems of joints and faults display different orientations along slopes and ridges. Failure planes in jointed rocks mainly depend on the attitude, spacing, and number of sets of joints present in the rock.

Slope instability is common in this fragile and geodynamically sensitive zone which is subjected to very intense tectonic activity. Neotectonic activity has left its signature in some ways in this township and its surroundings. Evidence is the thick deposits of black clays that seem to appear everywhere faults are suspected to be active. It is along these fault planes that water accumulation is tremendous. It is also at these faulted areas that most landslide activity is concentrated. Neotectonism is also responsible for causing the collapse of rock material and engineering structures at a number of localities. The phenomenon has also caused certain portions of the township to continuously sink. The sinking is attributed to the development of shear zones within very recent times.

Instability in the form of slumps, rockslides, rock falls, gully erosion, creep, and subsidence are recognized in this township. These landslides of varying magnitudes commonly occur during heavy and prolonged rains. Cloud burst is another natural phenomenon that is responsible for landslides in some localities. In this area some of the debris slides, debris falls, and rock falls are road-induced. Besides natural environmental factors, excavations of rocks and slope modification have made the environment unfavourable, thus initiating instability in the area.

In the area of investigation, lower order streams such as first, second, and third are prevalent. Low order streams are more active in their erosive activity. Erosion is commonly high in areas that are tectonically disturbed. Like landslides found in other parts of the world the slides in this area too have been caused due to diverse factors. Some of the landslides in this area have occurred at the sites of ancient landslides which have been reactivated. Investigations have revealed that in the Disang dominated areas of the town a number of landslides have occurred in the past.

1.1 LOCATION OF THE AREA

The area of investigation is Kohima Town, the capital of Nagaland (Fig. 1.1). The urban area of this town covers approximately 11.06 sq kms and includes parts of the National Highways 39 and 61. This also serves as the headquarters for Kohima District and Nagaland. The study area is incorporated in the Survey of India Toposheet no. 83 K/2 and lies between north latitudes 25°51'37" & 25°48'37" and east longitudes 94°03'40" & 94°06'24".

LOCATION MAP

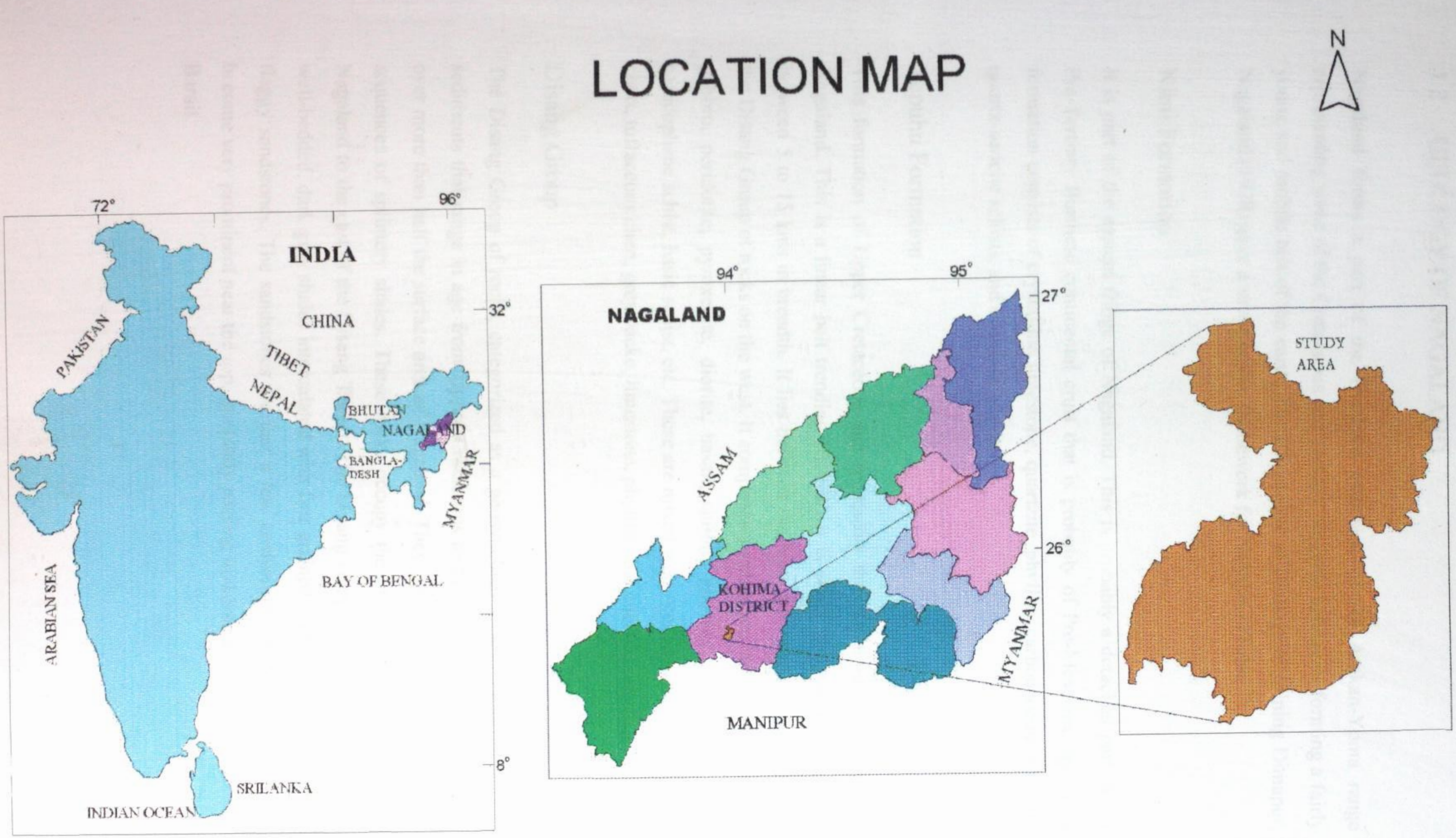


Fig. 1.1

1.2 GEOLOGY OF NAGALAND

Nagaland forms a part of the Northern extension of the Arakan-Yoma range representing some of the Cretaceous and Tertiary orogenic upheavals forming a fairly young and mobile belt of the earth. The Directorate of Geology & Mining Dimapur, Nagaland (1978) gave a stratigraphic framework for Nagaland (Table 1).

Nimi Formation

It is part of the eastern fringe of Nagaland. This is probably a detached part of the Pre-Tertiary Burmese continental crust that is probably of Pre-Mesozoic age. This formation consists of crystalline limestone, quartzite, phyllite, carbonaceous phyllite, quartz-sericite schists, and schistose granites.

Zepuhu Formation

This formation of Upper Cretaceous age represents the "Ophiolite Complex" of Nagaland. This is a linear belt trending NE-SW. It is about 90 kms in length and between 5 to 15 kms in breadth. It lies between the Nimi Formation in the east and the Disang Group of rocks on the west. It comprises amphibolite, dunite, serpentinite, gabbro, peridotite, pyroxenite, diorite, basalt, spillite, andesite, agglomerate tuff, glaucophane schist, basic schist, etc. These are mixed with oceanic sediments such as chert, tuffaceous chert, greywacke, limestone, phyllite, and cherty quartzite.

Disang Group

The Disang Group of rocks, categorized as a geosynclinal facies, comprises flysch sediments that range in age from Upper Cretaceous to Eocene. The Disang spreads over more than half the surface area of Nagaland. They consist of thick monotonous sequences of splintery shales. These rocks occupy the intermediate hill region of Nagaland to the east of the Disang Thrust. The Disang comprises thick sequences of well-bedded, dark gray shales intercalated with fine grained, well cemented, and thin flaggy sandstones. The sandstones are just a few centimeters thick at the base but become very prominent near the top, gradually passing upwards and laterally into the Barail.

TABLE 1

Stratigraphy of Nagaland
(Directorate of Geology & Mining, Nagaland, 1978)

Age (approx)	Litho-formations in Belt of Schuppen & Intermediate Hills			Litho-formations in Eastern High Hills
	Tipam	Girujan Clay Tipam Sandstone	Girujan Clay Tipam Sandstone	Jopi Formation Conglomeratic greywacke and arkose with plant fossils
	Surma			
---------- Unconformity ----------				
Upper Eocene - Oligocene (molassic sediments)	Barail		Tikak Parbat Baragolai Naogaon	Lower Barail Fine to medium grained sandstones with plant fossils
Upper Cretaceous - Eocene (flysch sediments)	Disang			Disang Shale, slate, and phyllite with calcareous lenses in basal sections and invertebrate and plant fossils in upper sections with brine springs
				______ Fault/Thrust ______
Upper Cretaceous - Lower Eocene (Ophiolite Complex)				Zepuhu Formation 1. Chert, quartzites, limestone, greywacke, tuffs, basic volcanics, basic schists, blue schists with ultramafites and other suites noted under 2 2. Gabbro, diorite, quartz diorite, and ultramafites with minor lenses/bodies of rock types noted under 1
				______ Fault/Thrust ______
Pre-Mesozoic (?)				Nimi Formation Phyllites, quartz-chlorite-sericite schist, other schists, feldspathic quartzite, orthoquartzite, limestone, and cataclastic granite

The Disang shales are finely laminated and commonly exhibit curved or concentric surfaces. Carbonaceous shales intercalated with massive shales and occasionally fine grained sandstones also occur in certain areas, especially at the junction of faults within the Disang. The Disang beds are commonly crumpled and squeezed. Ferruginous concretionary structures and nodules are common, especially in areas of red ferruginous soil. Pyrites and brine and sulphur springs are also common.

Barail Group

The Barail is an arenaceous suite of rocks that conformably overlie the Disang. They comprise thick sequences of sandstones intercalated with very thin papery shales. These rocks range in age from Upper Eocene to Oligocene and are found scattered in patches in Nagaland. They are exposed in southern Kohima, the eastern parts of Nagaland, and all along the western margin of the state.

The Barail may be divided into three formations in the south and south-west of Nagaland including Laisong, Jenam, and Renji. In the intermediate hills of Nagaland they are recognized as the Tikak Parbat, Baragolai, and Naogaon Formations. The Laisong Formation consists of very hard, gray, thin bedded sandstones alternating with hard, silty and sandy shales. Occasionally massive sandstones with intercalations of carbonaceous shales and thin streaks of coal are also encountered. The Jenam Formation is made up of massive sandstones with intercalations of shale, sandy shale, and calcareous and iron stained shales. The youngest member of the Barail is the Renji Formation which extends toward the south-west of Nagaland and beyond into Assam and south into Manipur. They are massive, hard, ferruginous, and very thick bedded and are intercalated with minor shales. They form a very thick forested range with high peaks such as Japfü (3015 m) just south of Kohima.

The Naogaon Formation is exposed in the eastern parts of Nagaland where they form high ranges and cover extensive areas. Towards the south they branch out into strips, one such branch extending into northern Manipur. Sandstones of this formation are hard, gray, thin bedded, and fine to medium grained. Some shales and carbonaceous shales are intercalated with these sandstones. Concretionary structures are noted in some areas. The sandstones are thick and massive with occasional thin shale partings towards the southern border of Nagaland. The Naogaon sandstones are indistinguishable from those of the Laisong of the intermediate hills.

Surma Group

These rocks unconformably overlie the Barail sediments. They consist of Lower Miocene molasse and comprise alternations of well-bedded sandstones, shaly sandstones, mudstones, sandy shales, and thin beds of conglomerate. The rocks are exposed in the Belt of Schuppen in the form of a number of long narrow strips running along almost the entire length of Nagaland on the western margin. They gradually thin out toward the north. The Surma are subdivided into the Bhuban and Boka Bil Formations, the former characterised by the presence of some conglomerates.

Tipam Group

The Tipam Group of rocks unconformably lies over the Surma. This is a molasses facies. The sandstones are massive and highly friable containing subordinate clay and shale. They are Mio-Pliocene in age. The sandstones are generally coarse grained, occasionally gritty, and ferruginous. They are commonly green in colour due to the presence of chlorite but are found to be weathering to different shades of brown. This group is made up of two formations, viz. the older Tipam Sandstones and the younger Girujan Clays. These rocks are exposed along the western fringe of Nagaland in the Belt of Schuppen as long, narrow strips due to strike faulting. The Girujan Clay Formation that overlies the Tipam Sandstones is essentially argillaceous and consisting of mottled clays, sandy clays, and sandstones in subordinate amounts. The Girujan Clays are exposed in the western parts of Nagaland where they are confined to the Belt of Schuppen. The formation also contains bluish-gray mottled clays with minor sandstones.

Namsang Beds

The Namsang Beds belong to the Dupi Tila Group. They lie unconformably over the Girujan clays. These beds have been assigned a Mio-Pliocene age. They consist of sandstones, pebbles of lignite, conglomerate, grit, mottled clay, and lenticular seams of lignite. They are confined to the Belt of Schuppen.

Dihing Group

The Namsang beds are unconformably overlain by the Dihing Group of Plio-Pleistocene age. This group consists of an unconsolidated mass of boulders and pebbles interspersed with clay and soft sand. The boulders and pebbles are undoubtedly products of the Barail. These rocks are found in a few patches in the Belt of Schuppen.

Alluvium and High-level terraces

Alluvium and High-level terraces cover extensive portions of Nagaland. The High-level terraces are dominantly boulder beds with coarse sands, gravels, and un-assorted clays at various levels above the present rivers. The older alluvium occupies the north-eastern tract of the Naga-Patkai ranges while the newer alluvium covers the western border of Nagaland.

1.3 MAJOR STRUCTURAL FEATURES OF NAGALAND

The major structural features of North-East India and Burma are a result of collision of the Indian plate with Eurasia. The evolution of these features is explained in terms of a plate tectonic model (Desikachar, 1974; Nandy, 1976). The Andaman-Arakan-Assam geosyncline came into existence during the Mesozoic between the Burmese landmass and the Indian plate and extended from 5° to 27° N latitudes. This is supported by oceanic magnetic anomalies (McKenzie and Sclater, 1971) and palaeomagnetic studies (McElhinny, 1973). The subduction of the Indian plate under the Burmese block began during the Cretaceous-Eocene. Correlation of high seismicity, depth of foci, and large negative isostatic anomalies to the east of the Arakan-Yoma suggest that subduction is still continuing (Verma, 1985).

Nagaland represents part of the mobile morphotectonic unit of the Indian Plate that collided with the Burmese Plate (Bhattacharjee, 1991). This is a structurally and tectonically complicated region (Fig. 1.2). Nagaland may be divided into four major structural units including the Belt of Schuppen, Patkai Synclinorium, Kohima Synclinorium, and the Ophiolite Complex that all have a NE-SW trend.

Belt of Schuppen

This belt (Fig. 1.3) runs along the north-western margin of Nagaland and comprises about eight NE-SW trending over-thrusts forming a very complex pattern. At the western margin of this belt an en-echelon fault system known as the Naga Thrust is exposed intermittently, juxtaposing parts of the Tipam and Barail against the Sub-Recent to Recent alluvial deposits. The Naga Thrust is made up of a succession of six thrusts. The uppermost member of the Belt of Schuppen is the Disang Thrust which occupies the south-eastern part. This is a very persistent thrust.

Patkai Synclinorium

This elevated synclinorium made up of the Barail make up the intermediate hill ranges of Nagaland (Fig. 1.3). The rocks are broken up by strike faults. The Disang are exposed on either side of this synclinorium. The Disang Thrust separates it from the Belt of Schuppen on its north-western flank.

Kohima Synclinorium

This synclinorium is situated south-south-west of the Patkai Synclinorium and is located at the south-west of Kohima Town (Fig. 1.3). It consists of broad synclines and narrow, sharp crested anticlines with faults trending approximately north-south. The synclinorium is flanked on all sides by the Disang. The younger groups of rocks in this structural unit are encountered toward the Surma valley. It is bound on the north-west by the Disang Thrust and in the south it merges into the eastern Surma Valley.

Three generations of folds are recorded in the litho-units which probably correspond to the first, second, and third phases of the Himalayan orogenies respectively

TECTONIC MAP OF NORTH-EAST INDIA

(After Mathur and Evans, 1964)

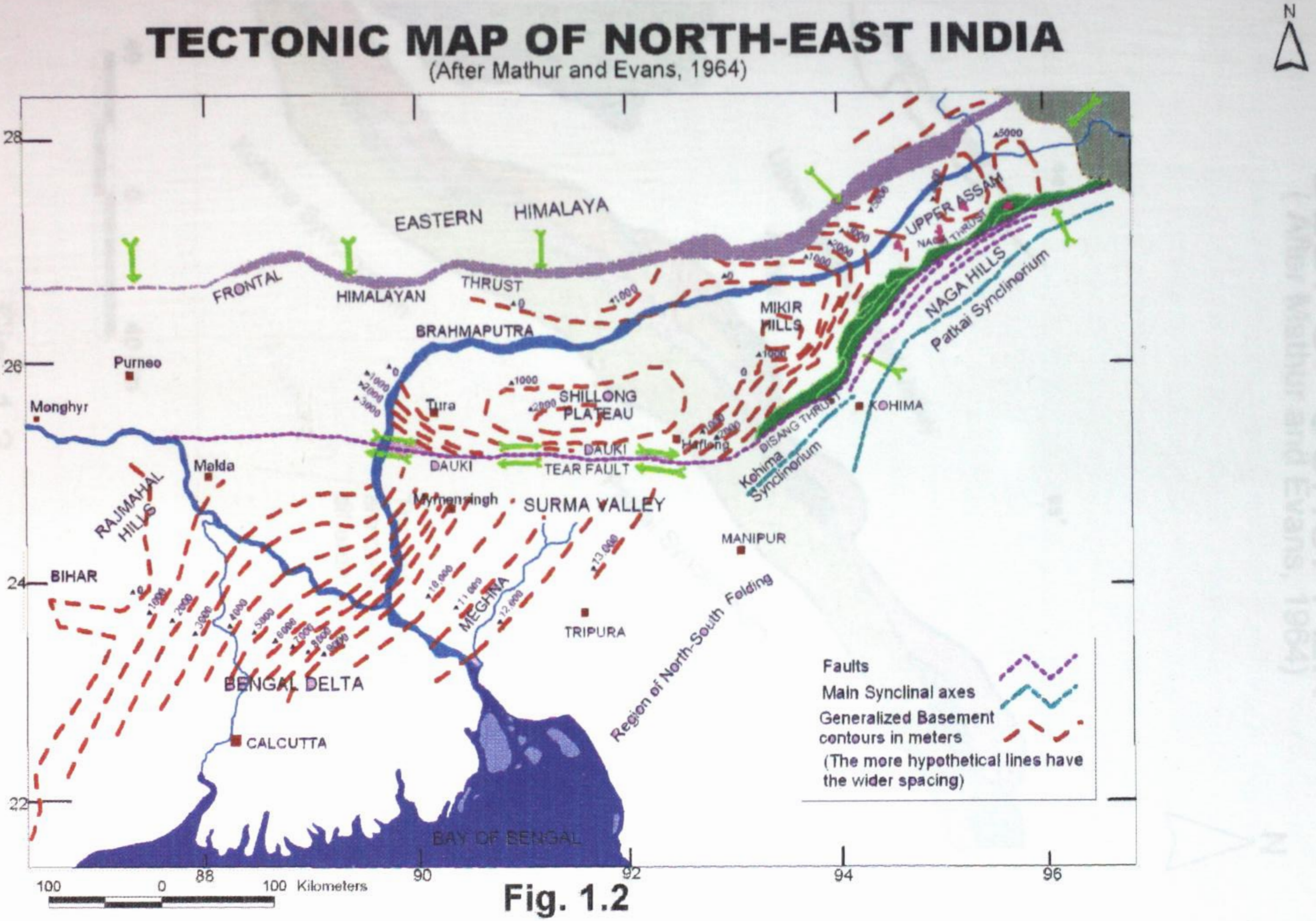


Fig. 1.2

BELT OF SCHUPPEN
(After Mathur and Evans, 1964)

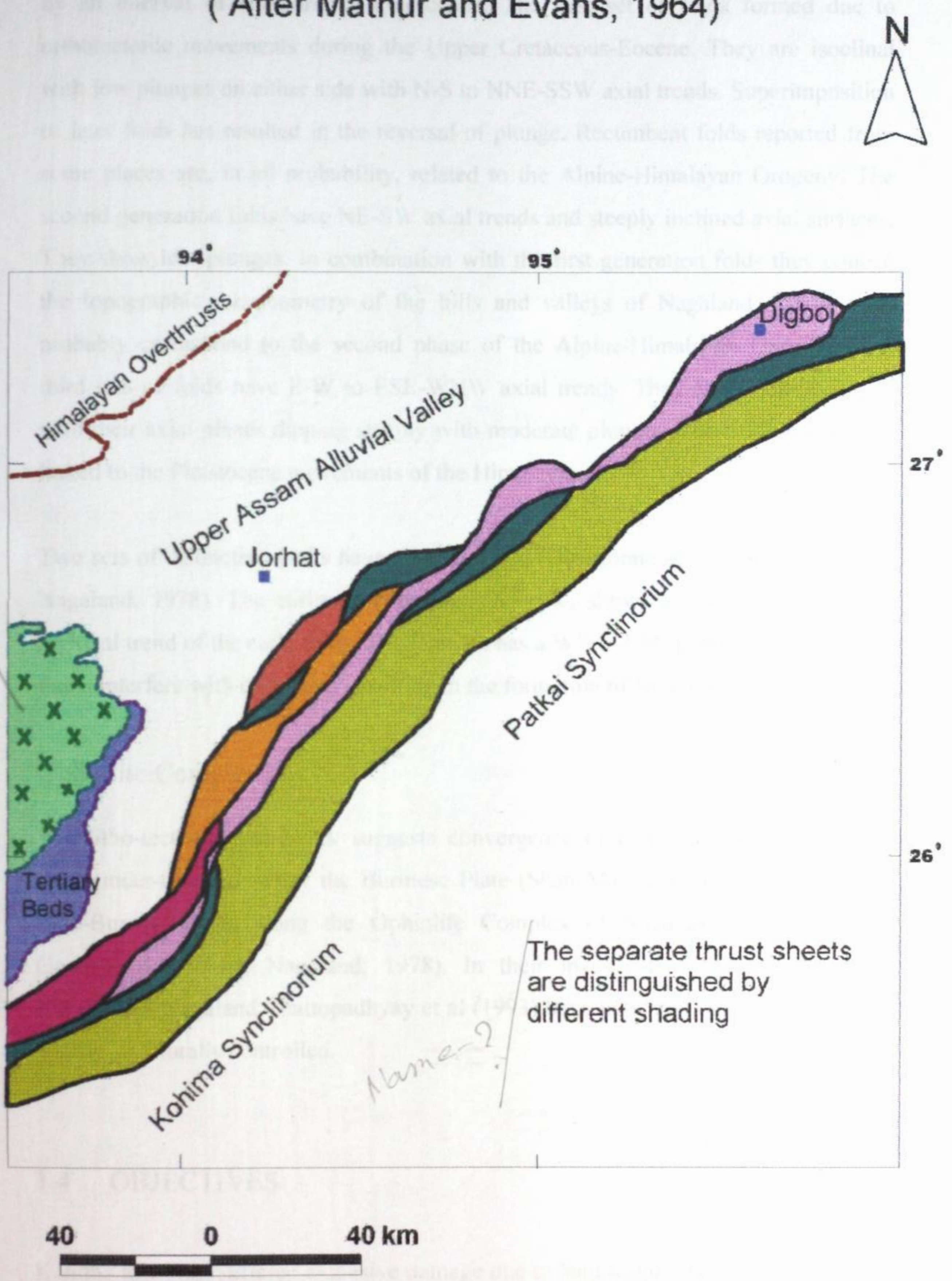


Fig. 1.3

(Directorate of Geology & Mining, Nagaland, 1978). Each generation is punctuated by an interval of comparative quiescence. The first set of folds formed due to orthotectonic movements during the Upper Cretaceous-Eocene. They are isoclinal with low plunges on either side with N-S to NNE-SSW axial trends. Superimposition of later folds has resulted in the reversal of plunge. Recumbent folds reported from some places are, in all probability, related to the Alpine-Himalayan Orogeny. The second generation folds have NE-SW axial trends and steeply inclined axial surfaces. They show low plunges. In combination with the first generation folds they control the topographic morphometry of the hills and valleys of Nagaland. These folds probably correspond to the second phase of the Alpine-Himalayan Orogeny. The third sets of folds have E-W to ESE-WNW axial trends. They are broad and open with their axial planes dipping steeply with moderate plunges. These folds might be linked to the Pleistocene movements of the Himalayas.

Two sets of distinctive faults have been reported (Directorate of Geology & Mining, Nagaland, 1978). The earlier set, trending NE-SW, shows a conformity with the regional trend of the early folds. The later set has a WNW-ESE trend. The two sets of faults interfere with each other resulting in the formation of large tectonic blocks.

Ophiolite Complex

The litho-tectonic framework suggests convergence of plates whereby the Indian Plate under-thrusted below the Burmese Plate (Shan Massif) eastward forming the Indo-Burma ranges along the Ophiolite Complex of Nagaland (Directorate of Geology & Mining, Nagaland, 1978). In their investigations of the Ophiolite Complex of Nagaland Chattopadhyay et al (1993) have indicated that the drainage is mainly structurally controlled.

1.4 OBJECTIVES

Kohima town has suffered extensive damage due to land instability which has been a chronic problem for decades. Damage of property includes buildings, roads, culverts, bridges, and other man made structures besides vegetation. This has caused a serious impact on the socio-economic setup as well as the natural ecosystem. Governmental agencies are constantly engaged, particularly during the monsoon, in clearing of debris to keep the streets motorable. But these are stop-gap arrangements as no major scientific investigations have been carried out in the area to ascertain the causes. Keeping this in mind investigations on land instability in Kohima town have been taken up. The study envisages the:

1. determination of the factors responsible for land instability which include geo-environmental parameters such as slope, relief, lithology, structure, drainage, and land use and land cover;

2. creation of a spatial database using GIS techniques. This consists of construction of maps for facets, slope morphometry, relative relief, drainage density, lithology, structure, and land use and land cover using the Survey of India toposheets on 1:5000 scale, IRS-ID PAN+LISS III merged data on 1:12,500 scale, and information gathered in the field;

3. creation of an attribute database constituting rainfall data;

4. generation of a Landslide Hazard Evaluation Factor (LHEF) rating scheme for each of the geo-environmental parameters and then consolidating them to the determination of the Total Estimated Hazard (TEHD);

5. construction of a Landslide Hazard Zonation (LHZ) map for Kohima town based on the TEHD values.

Three major landslides within the study area are studied in detail while two major slide zones are reviewed. Remedial and/or mitigation measures are provided for these areas in addition to those provided for the two slides investigated.

1.5 GEOLOGY OF THE AREA

The miscellaneous details include accessibility, geomorphology, climate, drainage, flora and fauna, nature of soil and outcrops, lithology, and structure.

1.5.1 Accessibility

The area is well connected to the rest of the country by a good network of roads. The National Highway 39 starting from Numaligarh in Assam runs through Kohima to end at Moreh in Manipur. The National Highway 61 starts at Kohima and ends at Mariani in Assam. The railhead and airport are located at Dimapur which is about 74 kms west of Kohima. The geological map of this area is represented on a scale of 1:30,000 (Fig. 1.4).

1.5.2 Geomorphology

The area is made up of highly dissected denudational hills. This area reflects, more or less, a moderately rugged topography of sub-rounded hills, narrow valleys, deep gorges, etc. The average altitude of the area is about 1444 m above mean sea level. The southern hill ranges, clad with evergreen forests, are very rugged. The lower reaches of the hills are used for cultivation.

1.5.3 Climate

The area of study lies in the North Temperate Zone. Summers are warm while winters are cold. December and January are the coldest part of the year when temperatures fall to 5°C or less. In summer the temperature rises up to 25°C. The area receives abundant rainfall during the monsoon. Cloudbursts are common phenomena in this part of the country. Storms are usual during certain seasons. The maximum and minimum amounts of rainfall recorded in the area of investigation are 689.4 mm and 0.0 mm respectively. The average annual rainfall too varies within wide limits. The maximum and minimum between 1981 and 2002 are 2616.1 mm and 1075.6 mm respectively.

GEOLOGICAL MAP

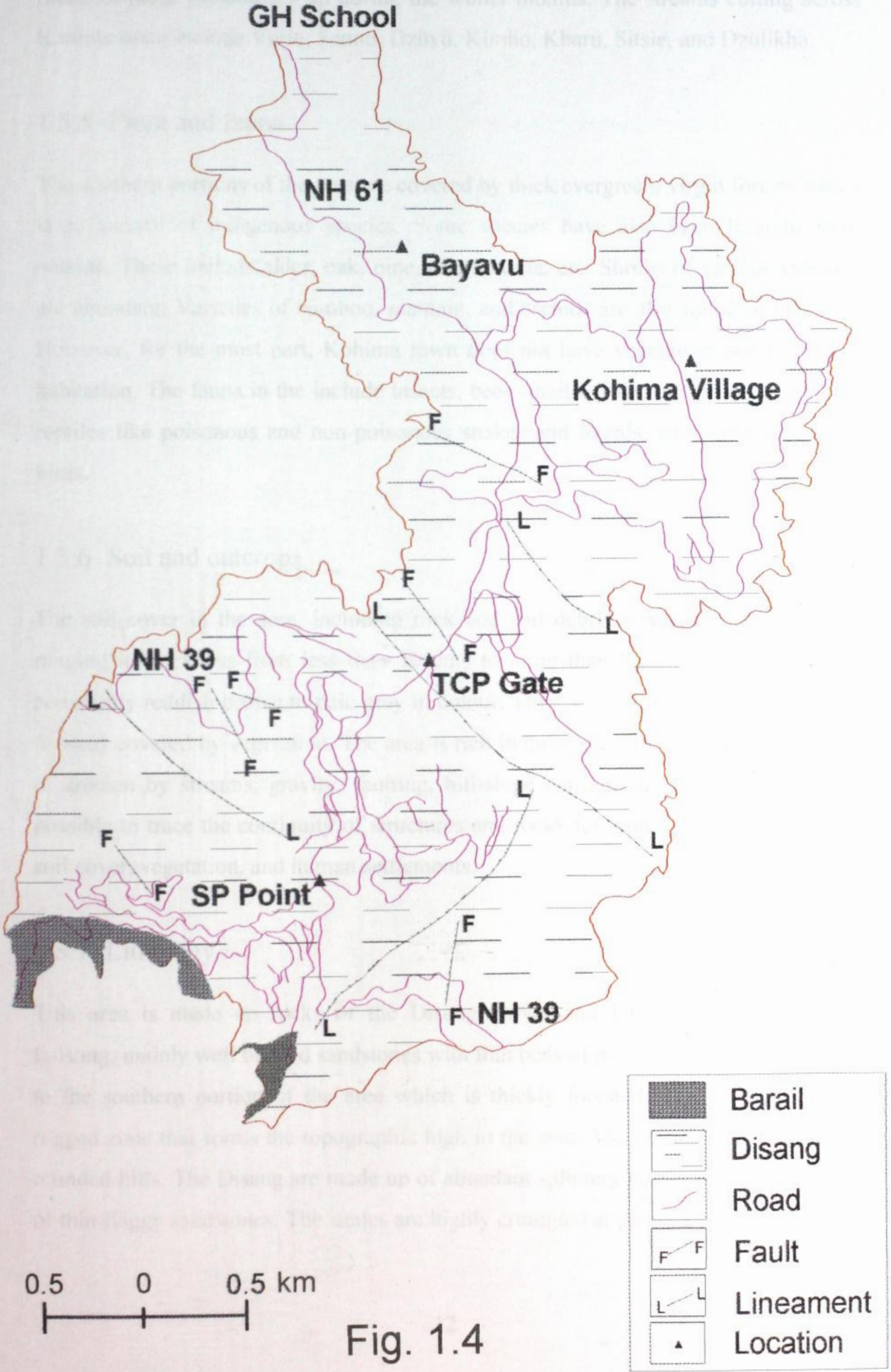


Fig. 1.4

1.5.4 Drainage

This area is cut across by a large number of first, second, and third order streams. Some of these streams dry up during the winter months. The streams cutting across Kohima town include [illegible], [illegible], [illegible], [illegible], [illegible], [illegible], and [illegible].

1.5.5 Flora and fauna

The southern portions of the area are covered by thick evergreen, virgin forests with a large variety of indigenous species. Some species have also been brought from outside. These include alder, oak, pine, cryptomeria, etc. Shrubs of various varieties are abundant. Varieties of bamboo, plantain, and orchids are also found in this area. However, for the most part, Kohima town does not have vegetation due to human habitation. The fauna in the include insects, bees, snails, frogs, etc. of various kinds, reptiles like poisonous and non-poisonous snakes and lizards, and some species of birds.

1.5.6 Soil and outcrops

The soil cover in the area, including rock and soil debris is variable in thickness, ranging in thickness from less than 10 cms to more than 8 m. Soil exposures are commonly reddish-brown to pale grey in colour. They are dark grey, soft and loamy in areas covered by vegetation. The area is rich in outcrops. The outcrops are a result of erosion by streams, gravity, faulting, hill-slope cutting, etc. However, it is not possible to trace the continuity of structures and rocks for large distances due to the soil cover, vegetation, and human settlements.

1.5.7 Lithology

This area is made up rocks of the Disang Group and Laisong Formation. The Laisong, mainly well bedded sandstones with thin beds of papery shales, are confined to the southern portion of the area which is thickly forested. This is a rough and rugged zone that forms the topographic high in the area. The Disang form the rounded hills. The Disang are made up of abundant splintery shales with alternations of thin flaggy sandstones. The shales are highly crumpled in places and at others [illegible] are partially to completely weathered. Landslides frequently occur in the areas made up of the shales. The Barail are also noted in the lower reaches of the area. Their presence at such low altitudes is due to faulting.

Lsu
?

1 5.8 Structure

The south and western parts of the area of investigation is part of the northern edge of the Kohima Synclinorium. This area is highly disturbed due to neotectonism. The disturbances are reflected in the rocks, particularly the Disang sediments which are highly fractured, jointed, and faulted. The rocks show two to four sets of joints trending and dipping in all possible directions. In most parts of the area the rocks are severely fractured with large cracks. This is seen particularly in the sandstones. The same is not noted in the shales because they tend to flow plastically or collapse. The area is dissected by a large network of streams. Satellite imageries indicate the presence of numerous lineaments. It is found that most of the stream channels and lineaments are faults. These faults are of varying dimensions. Some are of very local significance whereas others are comparatively large. One lineament, trending NNE-SSW, cuts through the entire area. The faults, like the joints, trend in various directions without any preferred orientation. A number of shear zones are also noted within the township. These shear zones are responsible for continuous subsidence of roads, particularly during the monsoon. These shear zones are a consequence of faulting in the area. Some of these local shear zones may have originated due to compressive squeezing of the crust which is probably very unstable due to continued movement amongst blocks along faults. These are strong indications of neotectonic activity. Another evidence for neotectonism is the presence of abundant black clays along fault planes. In such areas water normally accumulates so that even in the dry season water is present.

Name

CHAPTER 2

METHODOLOGY

Toposheets on 1:5,000 scales are used for detailed mapping of the area of investigation. Satellite imageries and digital data for the township are available on 1:12,500 and 1:50,000 scales. The area of investigation is divided into two segments, each segment consisting of a number of facets. The reason for dividing the area into two segments is to enable the final plotting of facet, thematic, and Landslide Hazard Zonation maps on 1:25,000 scales. These two segments are further divided into a number of facets. Segment 1 comprises 140 facets (Fig. 2.1.1) while Segment 2 comprises 166 facets (Fig. 2.1.2). Facet boundaries are limited by roads, gullies, streams, ridges, and spurs depending on the topography. Each of these facets is numbered in proper sequence starting from Segment 1. Contours of the toposheets are used for calculation of slope angles and relative relief. Five major recent landslides are studied in detail to ascertain their causes and to provide remedial and mitigation measures. These landslides are mapped on appropriate scales.

2.1 LANDSLIDE HAZARD EVALUATION FACTOR (LHEF) RATING SCHEME

A Landslide Hazard Evaluation Factor (LHEF) rating scheme is followed where values are assigned to each factor depending upon the susceptibility to landsliding due to that factor. The factors governing LHEF rating are slope morphometry, relative relief, lithology, structure, drainage density, and land use and land cover. This rating scheme is a numerical system influenced by the major causative factors of slope instability. These are studied and evaluated for the landslide potential of a slope. The maximum LHEF rating scheme for different causative factors are determined on the basis of their estimated significance in inducing instability. The maximum value for

SEGMENT 1

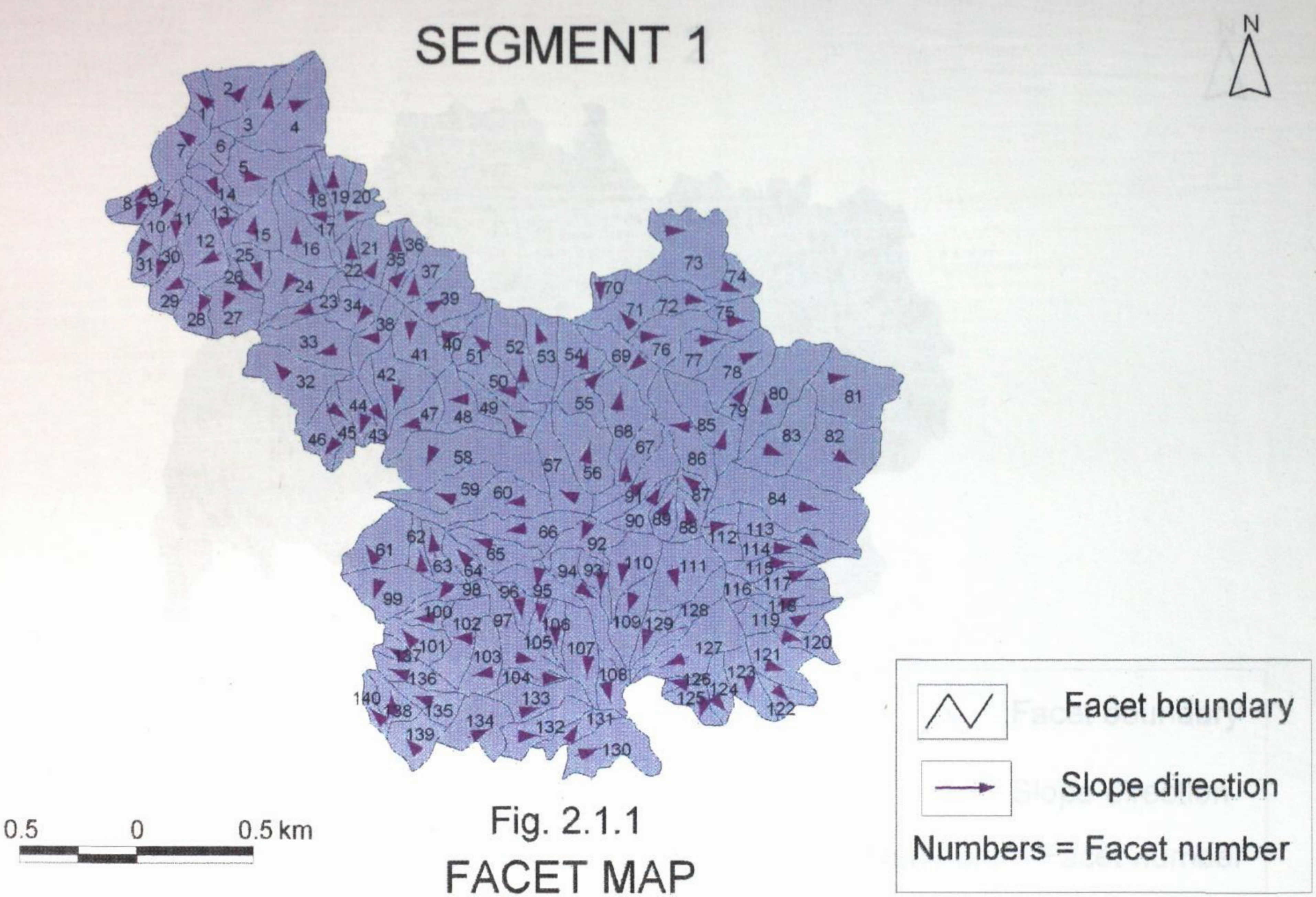


Fig. 2.1.1
FACET MAP

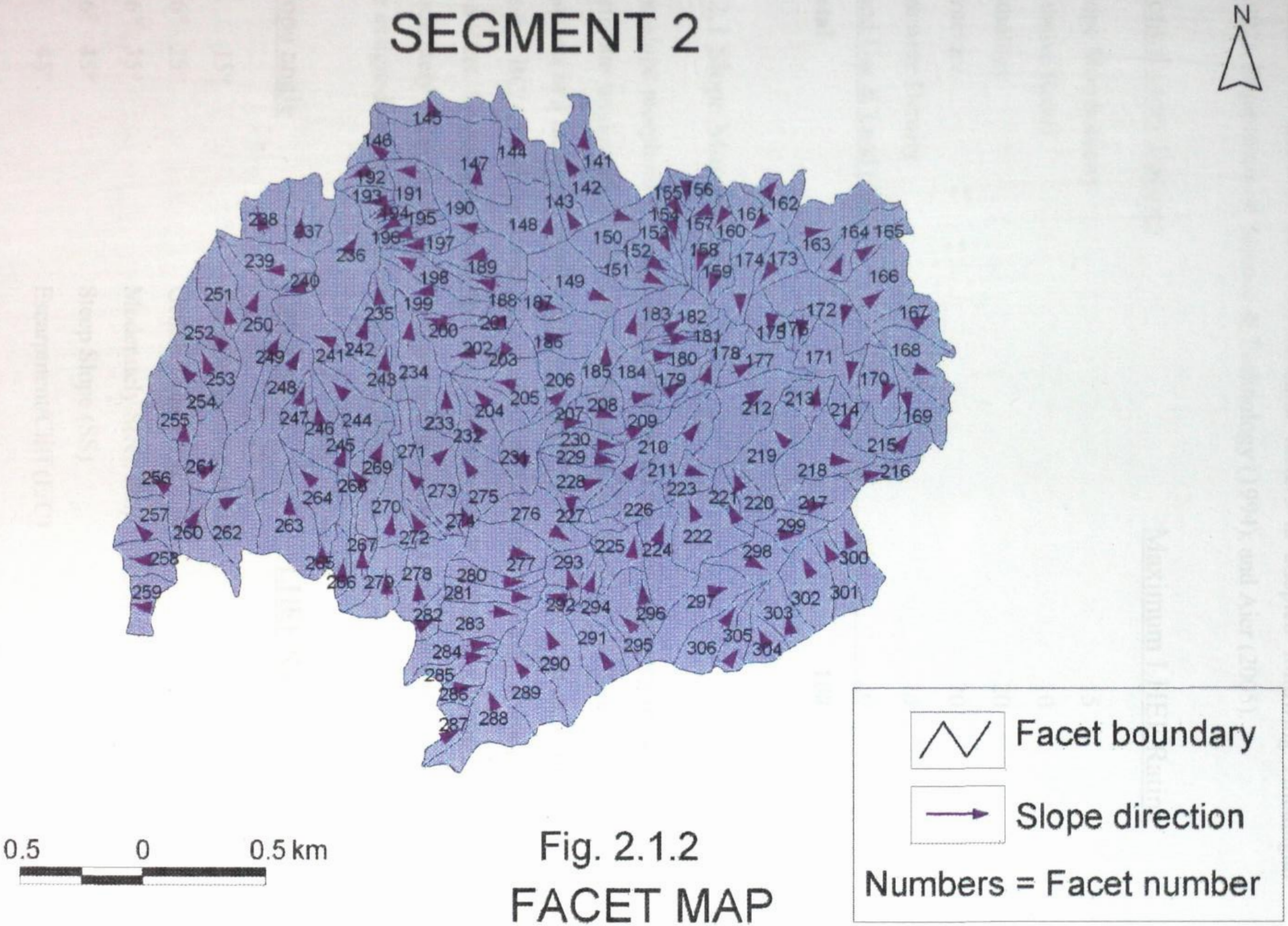


Fig. 2.1.2
FACET MAP

the Total Estimated Hazard (TEHD) is taken as 100. The following LHEF rating scheme for different geo-environmental factors is adopted following Anbalagan (1992), Department of Science & Technology (1994), and Aier (2005).

Contributory Factors	Maximum LHEF Rating
Slope Morphometry	15
Relative Relief	10
Lithology	20
Structure	20
Drainage Density	15
Land Use & Land Cover	20
Total	**100**

2.2.1 Slope Morphometry

The slope morphometric map is prepared on the basis of frequency of occurrence of particular angles of slopes. Slope angles are determined by counting the number of contours in a facet and measuring the length of the facet. This is given by the formula $\tan\theta = BC/AB$, where AB is the length of the facet and BC is the altitude difference in a facet. Slopes may be categorised under five heads including very gentle, gentle, moderately steep, steep, and escarpments/cliffs. Ratings for these categories of slopes are assigned as per the scheme mentioned below.

Slope angle	Category	LHEF Rating (15)
< 15°	Very Gentle Slope (VGS)	03
16° - 25°	Gentle Slope (GS)	06
26° - 35°	Moderately Steep Slope (MSS)	09
36° - 45°	Steep Slope (SS)	12
> 45°	Escarpment/Cliff (E/C)	15

2.2.2 Relative Relief

The maximum and minimum heights within individual facets represent the relative relief. The relative relief is the product of the number of contours and contour interval per centimeter length of the facet. It shows the major breaks in the slopes of the area. It is calculated by the number of contours in a facet divided by the length of the facet multiplied by the contour interval. Relative relief may be categorised under four heads such as low, medium, high, and very high. LHEF ratings for these factors are mentioned below.

Relative Relief	Category	LHEF Rating (10)
< 100 m	Low Relief (LRR)	02
101 - 200 m	Medium Relief (MRR)	05
201 - 300 m	High Relief (HRR)	07
> 300 m	Very High Relief (VHRR)	10

2.2.3 Lithology

The Barail and Disang sediments are classified into several units and each unit is given a rating as per the scheme below.

Lithology	LHEF Rating (20)
Sandstone + Shale Unit	06
Shale + Sandstone Unit	12
Shale Unit	14
Older Compact Soils	15
Crumpled / Partially Weathered Shale	16
Weathered Shale / Loose Debris	20

2.2.4 Structure

The categories of relationships used in this study are modified after the work of Anbalagan (1992).

		LHEF Rating (20)
1.	Dip of discontinuity not in slope direction	5.0
2.	Relation of parallelism between discontinuity and slope	
	0°- 15°	8.0
3.	Relation of dip of discontinuity and inclination of slope	
	a) 0°	10.0
	b) 0°- (-10°)	15.0
	c) > (-10°)	18.0
4	Thickness of soil cover	
	a) up to 6 m	12.0
	b) > 6 m	20.0

2.2.5 Drainage Density

The area in and around the township is divided into nine drainage basins for convenience of study and shown on 1:30,000 scale (Fig. 2.2). All streams in the area are plotted in these basins and from which the drainage density for each basin is determined (Table 2). The drainage density is a measure of the total lengths of streams of different orders in a basin divided by the area of the basin. For purposes of calculation of drainage density it is proposed to have five categories such very low, low, medium, high, and very high. The following rating scheme is assigned for these categories.

Drainage Density	Category	LHEF Rating (15)
< 3	Very Low Drainage Density (VLDD)	02
3.1 - 5	Low Drainage Density (LDD)	05
5.1 - 7	Medium Drainage Density (MDD)	08
7.1 – 10	High Drainage Density (HDD)	10
> 10	Very High Drainage Density (VHDD)	15

TABLE 2

Drainage Basin Parameters

Drainage Basin	Area (sq kms)	Drainage Density
1	2.30	4.92
2	2.86	5.09
3	1.21	5.15
4	0.59	5.16
5	0.59	6.48
6	0.53	7.09
7	0.97	8.15
8	1.23	9.36
9	0.78	9.90
Total	**11.06**	

Drainage Basin

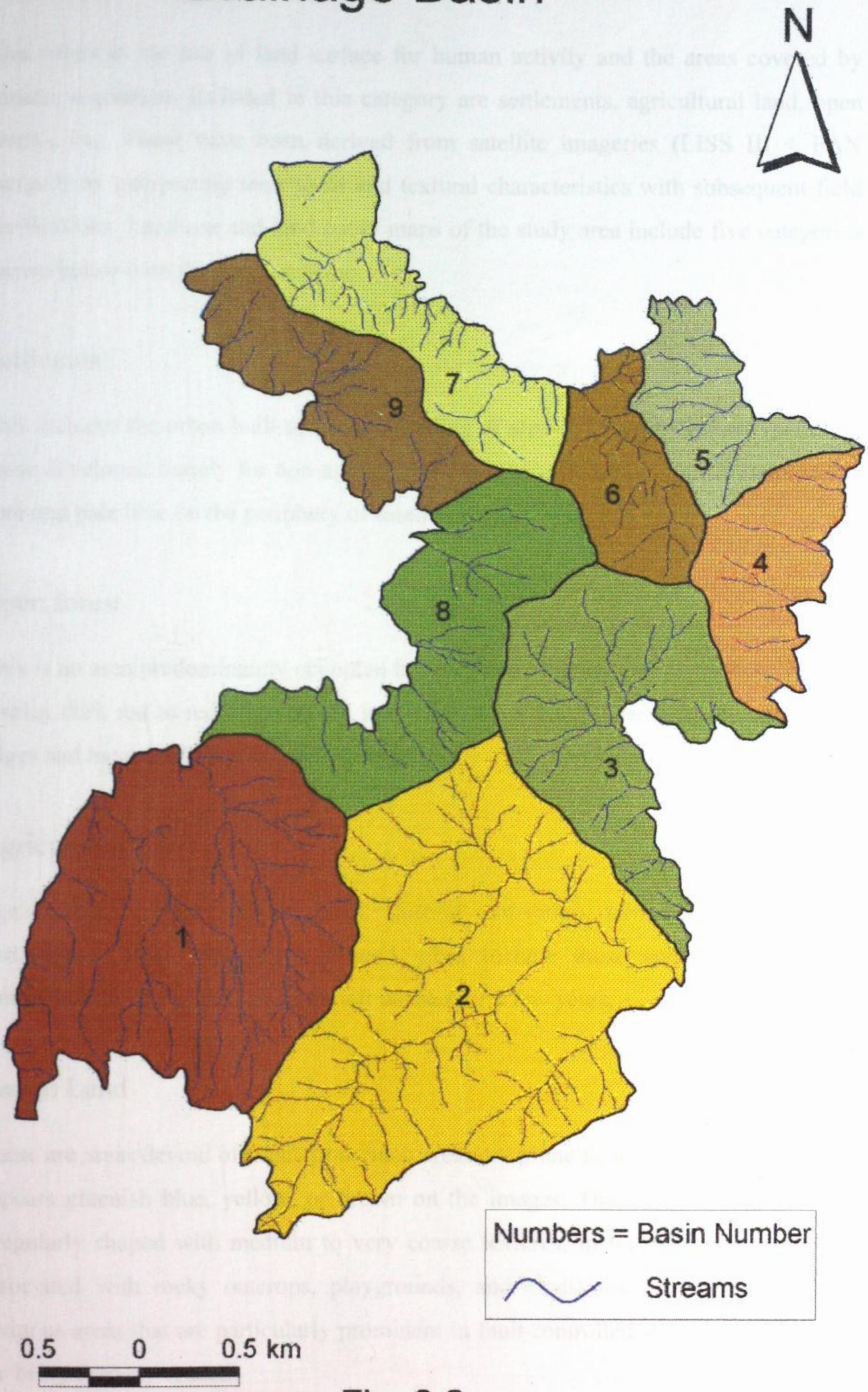


Fig. 2.2

2.2.6 Land use and Land cover

This refers to the use of land surface for human activity and the areas covered by natural vegetation. Included in this category are settlements, agricultural land, open forests, etc. These have been derived from satellite imageries (LISS III + PAN merged) by interpreting their tonal and textural characteristics with subsequent field verifications. Land use and land cover maps of the study area include five categories shown below with the rating scheme.

Settlement

This includes the urban built-up land consisting of areas covered by houses including those developed mainly for non-agricultural use. Built-up land is bluish green at the core and pale blue on the periphery of satellite imageries.

Open forest

This is an area predominantly occupied by trees and other natural vegetation. Forests display dark red to red tones on the imageries. They are regular in shape with sharp edges and have medium to coarse textures.

Agricultural Land

Agricultural land includes cropland, shifting cultivation, terrace cultivation, and horticultural areas. Sparsely vegetated areas include those areas taken up for cultivation for one season and then left unused for a few years.

Barren Land

These are areas devoid of vegetation. Such areas are prone to sheet wash. Barren land appears greenish blue, yellow, or brown on the images. They vary in size and are irregularly shaped with medium to very coarse textures. In the study area they are associated with rocky outcrops, playgrounds, and landslides. Gullies include the ravinous areas that are particularly prominent in fault controlled stream channels that are being actively eroded.

Category	LHEF Rating (20)
Open Forest	05
Low to Moderate Settlement	08
Sparsely Vegetated / Agricultural Land	12
Dense Settlement	15
Barren Land / Gullies	20

2.3 TOTAL ESTIMATED HAZARD (TEHD)

LHEF ratings for individual causative factors including categories are calculated facet-wise. The ratings for all factors are then added up to obtain the TEHD. Thus, TEHD = Ratings of Slope morphometry + Relative relief + Lithology + Structure + Drainage density + Land use / Land cover. It indicates the facet-wise net probability of instability. A rating of 100 will indicate the maximum value of TEHD.

2.4 LANDSLIDE HAZARD ZONATION (LHZ)

Landslide Hazard Zonation of the area is made on the basis of the distribution of TEHD values following the scheme mentioned below. Thus, different categories of hazard with their corresponding values are given below.

Zones	TEHD Values	Description of Zones
I	< 35	Very Low Hazard Zone (VLH)
II	36 - 50	Low Hazard Zone (LH)
III	51 - 60	Moderate Hazard Zone (MH)
IV	61 - 75	High Hazard Zone (HH)
V	> 75	Very High Hazard Zone (VHH)

2.5 GIS & REMOTE SENSING

A number of computer programs and software have been used for generation of the different thematic maps. These are discussed in Chapter 3.

CHAPTER 3

GEOGRAPHIC INFORMATION SYSTEMS AND REMOTE SENSING

INTRODUCTION

Geographic Information System (GIS) effectively synthesizes available information. Developing a GIS application for landslide hazard management requires the identification, collection, and organization of natural and anthropogenic factors. GIS plays an important role in spatial modeling and creation of maps and models for display. It helps assess hazards in terms of risk and planning (Wadge et al, 1993). GIS is suitable for landslide susceptibility mapping (Bonham-Carter, 1994; Chung et al, 1995; Corominas et al, 2003). Various attempts have been made using GIS for spatial prediction of landslides employing statistical models (Yin and Yan, 1988; Westen, 1993; Chung et al, 1995). Terlien et al (1995) and Zêzere et al (2003) demonstrated landslide hazard assessment using deterministic modeling in GIS. Kumar et al (2002) used GIS to analyze slope failure due to earthquakes and rainfall. Nagarajan et al (1998) used GIS to calculate the probability of mass movements while Ajalloeian et al (2000) used GIS to investigate the role of land use change in relation to landslides. Beguería et al (2003) made comparisons between statistical and deterministic models for shallow landslides and debris flows. Sabins (1986), Gupta and Joshi (1990), Gupta (1991), Soeters et al (1991), Carrara et al (1991), McKean et al (1991), Rengers et al (1992), Westen (1994), and Yuan and Mohd (1997) show that remote sensing techniques integrated with GIS can provide a useful tool to study potential landslides. Panigrahi et al (2002) prepared landslide hazard zonation maps using remote sensing in a GIS environment. Remote sensing helps investigate susceptibility of land and vulnerability of society, to construct hazard zonation maps, monitor potential hazards, and to deal with emergencies after a disaster (Verstappen, 1995). Remote sensing offers synoptic viewing, repetitive coverage, and acquisition of reliable, comprehensive, and timely data of the earth's features. It has emerged as a powerful tool for mapping and monitoring the earth's surface (Singh, 2001). The vast capabilities of communication satellites are available for timely dissemination of early warning and real-time coordination of relief operations (Rao, 2000).

The GIS database is developed from drawings and image files. These datasets are converted to GIS compatible mode by scanning, digitization, etc. GIS plays an important role in developing and tailoring integrated spatial datasets, including remote sensing derived thematic layers, for input to models. The rich set of spatial data requirement forges fundamental links between GIS, remote sensing, and environmental models. Remote sensing complements GIS by providing the framework for integrated spatial analyses of diverse data structures in order to help understand and parameterize land surface processes. Database is a collection of information about certain parameters and their relationships to each other. To monitor and understand the dynamic processes as well as to develop environmental simulation models for scientific assessment many diverse types of datasets are necessary. The models require data on the multi-temporal behavior of land surface properties as well as the parameterization of spatially heterogeneous and complex landscape characteristics. These use an integrated system approach for landslide hazard modeling across multiple time and space. Based on sources of acquisition, GIS data may be classified as spatial and attribute. Topographical and thematic data are classified as spatial data whereas field and collateral data are grouped as attribute data. Aldridge (1999) developed a methodology to generate a digital database.

Spatial entity types are the basic topographical properties of location, dimension, and shape. Such data are represented on a map or in a GIS as a point, line, or area features. Spatial data are stored in graphic files and managed by a file management system. The two models that represent the spatial component of geographic information are vector and raster. For the present study, the spatial data is derived from satellite imageries, Survey of India toposheets, and field investigations. The relationship between spatial data and landslide occurrences contained in GIS database can be used to map potential landslide zones (Malkawi et al, 2002; Chung et al, 2002). Various integration techniques and models are also discussed by Bhan and Champati Ray

(1998). Attribute data describe the characteristics of spatial features. The data file can be described in terms of records, fields, and keys. Field data is acquired through field surveys by recording information of landslide events. Collateral data used in this study are rainfall.

3.1 SOURCES OF ACQUISITION

The data obtained for study include geological, geomorphological, and drainage. Toposheets used in the area are from the Survey of India. Merged LISS-III and PAN data of IRS-1D has been obtained from the National Remote Sensing Agency (NRSA), Hyderabad. Field surveys have been carried out with the help of a GPS. Rainfall data is acquired from the Directorate of Soil and Water Conservation, Nagaland.

3.2 SPATIAL DATA CREATION

To enter map features into a digital database, graphic points, lines, and areas are converted into a specific digital data structure. The lines and points representing features on maps are digitized using AutoCAD R14 to produce a vector model of the map. In transforming this raw data to GIS compatible data, care is taken for appropriate level of data precision and accuracy. The digitized coverage is processed for digitization errors such as dangles constituting the overshoots or undershoots and labeling of polygons. The coverage is then processed for topology creation using a GIS ARC/Info package. The attribute codes for the different categories are verified and additional attributes such as feature name, description, etc. are added to the feature database. After these operations the thematic coverage are ready for GIS analysis.

Processed satellite data is procured and worked on by using the image processing softwares EASI/PACE (Geomatica 8.2) and ERDAS Imaging 8.5. Thematic maps of lithology, structure, drainage density, and land use and land cover are generated from satellite data and fieldwork. Slope and relief maps are generated from the toposheets. A Digital Elevation Model (DEM) is generated from contours maps and satellite data. A GPS is used to construct landslide maps from the data generated in the field and from which a Landslide Hazard Zonation map is constructed. Output for all the thematic maps have been generated using ArcView GIS 3.2a.

3.3 GEO-CODING, GEO-REFERENCING, AND MOSAICKING

The 1:5,000 scale toposheets are scanned to produce a raster file of the study area. These are geo-referenced using geographic coordinates. A sufficient number of well-distributed ground control points (GCP) are selected both on the toposheets and corresponding imageries to perform image registration. After geo-referencing the maps are edge-matched and a digital mosaic is obtained to depict the continuity of the study area. A subset of the study area is then carved out on 1:30,000 scale (Fig. 3.1). This distortion-free digital data is used for digital image enhancement, merging of imageries, classification for land use and land cover, and map preparation.

3.4 DIGITAL ELEVATION MODEL

The Digital Elevation Model (DEM) is a three dimensional representation of an area and is the most effective medium for terrain analysis. A DEM is generated to represent the spatial variation in altitude and to show the spatial distribution of landslides. Nakamura et al (2001) and Chi Kwang-Hoon et al (2002) carried out landslide stability analysis and prediction modeling using DEM. DEM are generated from contour maps. In this study, the contours are digitized at 5-meter intervals, rasterised, and then interpolated for generation of DEM by applying surfacing technique (Fig. 3.2).

3.5 THEMATIC MAPS FROM SATELLITE IMAGERIES

Satellite data products are being frequently used in landslide mapping and hazard zonation (Varnes, 1984; Nabil, 1989; Mckean et al, 1991; Westen and Terlien, 1996). Hansen (1984) discussed direct and indirect mapping methods for landslide hazard. The structural, and land use and land cover maps are generated with the help of satellite imageries using visual interpretation techniques with standard basic and key elements to extract information. After interpretation, the paper-based maps are scanned and digitized to create a digital database for GIS analysis and modeling. The procedure consists of identification of image elements like colour, tone, texture,

SUBSET OF STUDY AREA

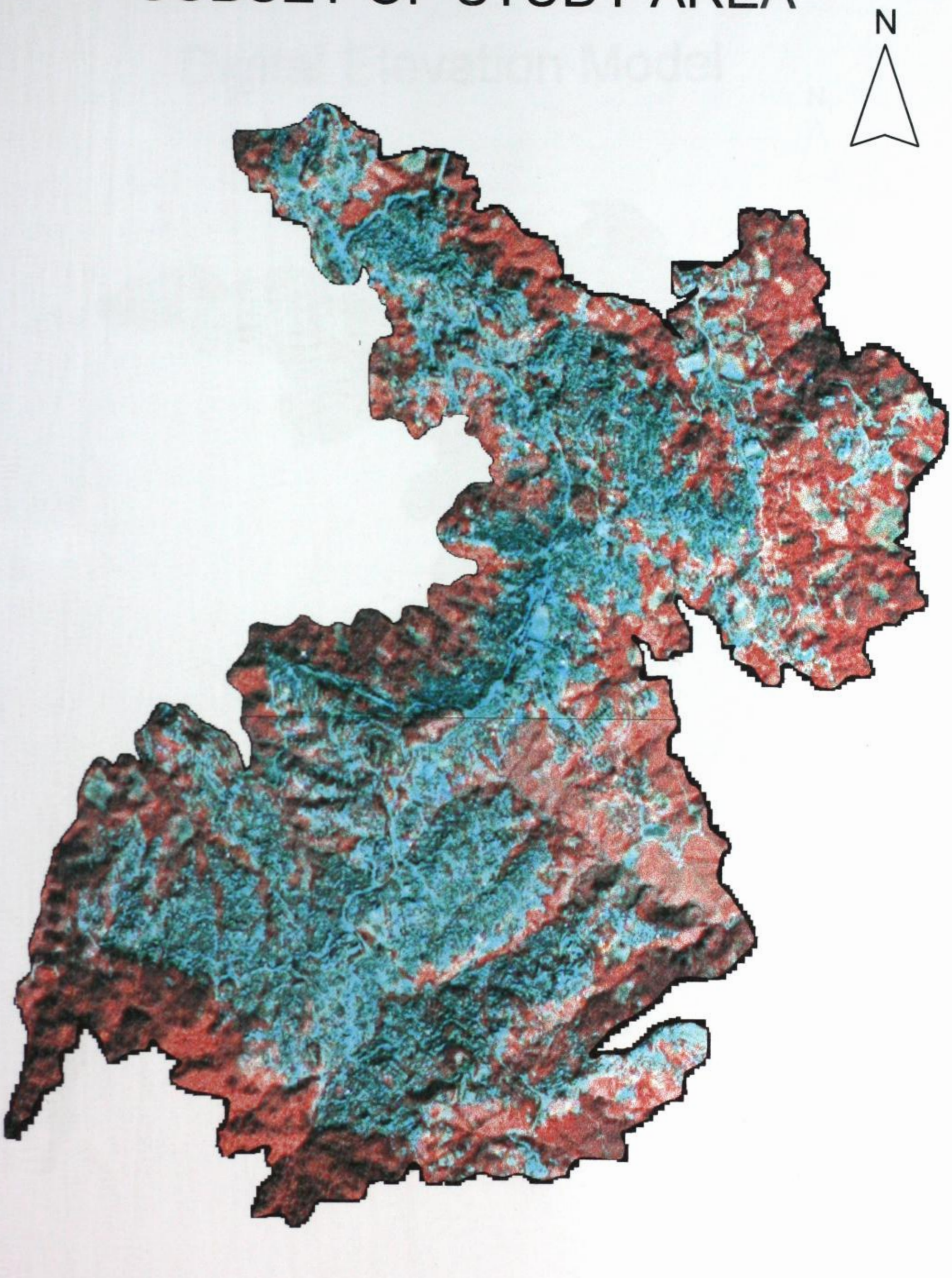


Fig. 3.1

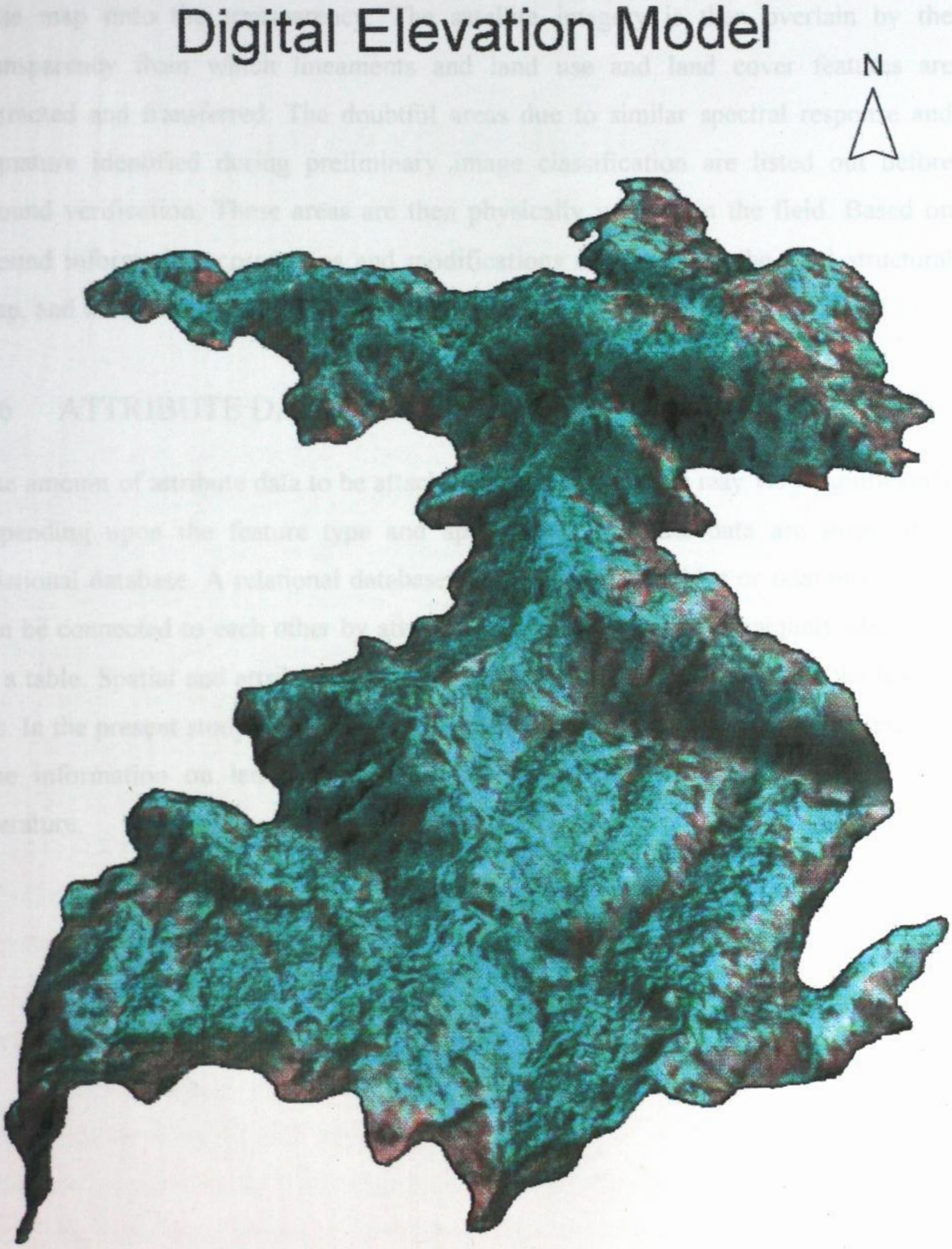


Fig. 3.2

pattern, size, shape, etc. to help in interpretation. A preliminary image interpretation key is prepared for the fused pictorial data that is used to transfer the features from the base map onto the transparency. The satellite imagery is then overlain by the transparency from which lineaments and land use and land cover features are extracted and transferred. The doubtful areas due to similar spectral response and signature identified during preliminary image classification are listed out before ground verification. These areas are then physically verified in the field. Based on ground information, corrections and modifications are made for the final structural map, and land use and land cover classification.

3.6 ATTRIBUTE DATA CREATION

The amount of attribute data to be attached to a spatial feature may vary significantly depending upon the feature type and application. Attribute data are stored in a relational database. A relational database is a collection of tables or relations, which can be connected to each other by attributes whose values can be uniquely identified in a table. Spatial and attribute data in a GIS are typically linked through the feature ids. In the present study, the attribute data comprises of rainfall and landslide records. The information on landslides is recorded during fieldwork and from previous literature.

CHAPTER 4

LITERATURE REVIEW

INTRODUCTION

Contributions to the geology of Nagaland and landslides in particular, are very limited. The first ever attempt of landslide studies was conducted by Sondhi (1941) along the Dimapur-Manipur road. Evans established the tectonic framework of Assam in 1964 where the tectonics of Nagaland is also dealt with. Mathur & Evans (1964) studied the stratigraphy, structure, and conditions of deposition of the Tertiary sediments of Upper Assam and Nagaland. Sharda & Bhambay (1980) prepared geotechnical and slope classification maps of Kohima Town. They also conducted environmental and geotechnical/geoscientific studies of the same area. Anand (1988) conducted preliminary geological investigations of landslides along the Dimapur-Mao section. Sarmah (1989) investigated the clay minerals of the Disang and Barail Groups of sediments. A study of the feasibility of groundwater development in and around Kohima Town was conducted by the Directorate of Geology & Mining, Nagaland (1996). Lotha (1994) investigated some landslides of Kohima. Agarwal and Shukla (1996), in their investigations of Kohima Town, have maintained that drainage is mainly structurally controlled with most rivers flowing along a multitude of lineaments trending NE-SW and NW-SE. Bhattacharjee et al (1998) also added to landslide literature by their investigations of land instability along National Highway 39. The Central Road Research Institute (2000a) has commented on the weak zones along the same highway between Chumukedima and Maram. Thong et al (2004) prepared a preliminary geological report of the Mao Town Slide with mitigation measures for the Border Roads Organisation. Kemas et al (2004) investigated the Chokidzü Debris Slide south of Kohima Town and recommended remedial measures. Aier (2005) investigated instability along the NH 39 between Chumukedima and Kohima and prepared a Landslide Hazard Zonation map of the highway section.

CHAPTER 7 **CASE STUDIES** 77 - 94

Introduction 77

7.1 Chiepfütsiepfe slide 77

7.1.1 Introduction 77

7.1.2 Geology of the area 78

7.1.3 Structure 78

7.1.4 Causes 78

7.1.5 Effects 78

7.1.6 Previous works 79

7.1.7 Recommendations 79

7.2 Keziekie slide 80

7.2.1 Introduction 80

7.2.2 Geology of the area 80

7.2.3 Structure 80

7.2.4 Causes 81

7.2.5 Effects 81

7.2.6 Previous works 82

7.2.7 Recommendations 82

7.3 Lerie slide 83

7.3.1 Introduction 83

7.3.2 Geology of the area 83

7.3.3 Structure 83

7.3.4 Causes 84

7.3.5 Effects 84

7.3.6 Previous works 84

7.3.7 Recommendations 84

7.4 Paramedical slide 86

7.4.1 Introduction 86

7.4.2 Geology of the area 86

Like the other natural hazards landslides too are characterised by suddenness, severity, and shortness of duration and involve death, damage to property, and disruption of communication, sanitation, and transportation systems. It is therefore imperative that the probable locations, causes, and impact of hazards are known so as to provide appropriate remedial or mitigation measures to prevent or minimize the impact of hazards. Pilgrim and Nicholas (1999) worked on landslide risk and decision making in Kinnaur District. Gupta and Joshi (1990) and Saha et al (2002) carried out GIS based landslide hazard zonation mapping in the Himalayas. In recent years risk analysis and assessment has become an important tool in addressing uncertainty inherent in landslide hazards (Dai et al, 2002). During the last century rapid growth in population caused developmental activities to take place to such an extent that the environment was considerably damaged. This has lead to aggravated risk due to the natural hazards. According to Thapliyal (1998) man made disasters can be averted to some extent but with increasing degradation of the environment the frequency and magnitude of natural disasters have increased manifold.

Landslides are geomorphic processes that are influenced by morphometric features such as slope, lithology, structure, drainage, etc. Human activity also has led to landsliding to a very great extent. Only by understanding the causes can appropriate control measures can be brought about. Landslides were not given much importance till recently. Hence attempts to control landslides were made using unscientific means. Growing awareness of their destructive potential has changed the scenario today. This has resulted in landslide investigations receiving increased support from many Governmental and other agencies. Hence, mapping of landslides and landslide-prone topography on both regional and local scales has gained prominence.

Landslides are down-slope movements of masses of rock debris or earth due to failure along weak planes when materials lose their shearing strengths. This may happen with or without the aid of excess water. Every mass beneath a slope has a tendency to slide downward and outward under the influence of gravity. If the shear strength of the soil adequately counters this tendency the slope is stable. Landslides may occur suddenly or through a prolonged period of time, with or without any apparent provocation. It is usually an annual and recurring phenomenon in hilly terrain. Most commonly, however, landslides occur during the monsoon. The process of hill slope movement is generally known as "landslide" but variety and complexity of landslide phenomen great. Varnes (1984) and Crozier (1986) classified landslides into distinct types. According to Caine & Mool (1982) most landslides are complex hybrids between several classes.

There are two basic types of landslides. The first category includes those slides due to mechanical causes including increase of hydrostatic pressure and erosion. In the second category are those slides caused by changes in the physical and/or chemical properties of the soil. Generally a decrease of shear strength in a soil is due to the clay mineral content. Clay minerals are responsible for the effects and the mechanism of water absorption, desorption, ion exchange, swelling, etc. in soils (Veder & Hilbert, 1980). Terzaghi (1950) opines that where silt is interbedded with sand, or clay with silt, water percolating through the coarser permeable units gets trapped above the fine grained units. The resultant increase in pore pressure between the sand and silt grains forces the particles apart, reducing inter-grain friction. As gravitational forces acting on the grains are countered by increased buoyancy, the particles formerly stable on steep slopes, generally greater than 35°, become less stable and cause slope failure. Landslides may also occur as consequences of changes in landforms. They may be categorised as those that are unpredictable, those whose threat is known, and those that occur due to the activities of man. Gray (1973), Swanson & Dyrness (1975), and Swanston & Swanson (1977) blame forest destruction and road construction for initiating landslides. Bhandari (1987) too blames man for his interference in the ecosystem.

Sharma et al (1996) opine that landslides are amongst the most rapid of all mass movements and pose very great hazards in mountainous terrain. Landslides are common in active mountain belts where the terrain is young. Recent research indicates that in mountain chains being uplifted landslides are inevitable (Petley and Reid, 1999). Major slides have occurred due to a combination of factors including thick deposits of unconsolidated material on steep hill slopes, adverse lithological and hydrogeological conditions, and anthropogenic activities such as road cutting, construction of heavy structures, etc. (Kumar et al, 1995). Valdiya (1987) blames poor road construction for causing destructive landslides as most roads are unimaginatively planned and very badly constructed. This has lead to destabilization of hillsides and production of large volumes of debris. According to Ives (1987) most road construction in the Himalaya region is substandard. This has led to greatly increased incidences of landslides. Poor road construction techniques have added to the instability of this area as well.

Nilsen et al (1976) ascribe varying combinations of various factors as responsible for landslides which may occur due to sudden or gradual changes on a slope. These factors may be the types and properties of underlying bedrock, soils and surficial deposits, angle and direction of slope, type of vegetation, amount and distribution of rainfall, types of construction, placement of cuts and fills, and the presence of ancient landslide deposits. They also state that areas of abundant recent landslides are often noted in areas of abundant ancient landslide deposits and suggest that accurate mapping of these ancient deposits in conjunction with other factors such as slope angles and bedrock geology can yield significant data for regional analyses of slope stability. Brabb et al (1972) and Nilsen and Brabb (1972) opine that the evaluation of any region should include an analysis of the slope stability characteristics of the terrain, incorporating factors such as degree of slope, bedrock, soil characteristics, seismic triggering of landslides, and other factors. Sahai (1993) states that lithology, slope, poor vegetative cover, and abnormal rainfall bring about slope instability.

4.1 SLOPE AND RELIEF

Slope is an important parameter that plays an important role in landslide hazard analysis. Slope maps provide data for planning of land use and land developmental activities. The intensity and extent of runoff are influenced by slope. Slope instability hazard assessment is based on the analysis of terrain conditions at palaeoslide sites (Westen, 1993). Slope instability is the product of geodynamic processes, vegetation, and human activity (Soeters and Westen, 1996). Instability of slopes is due to the complex interaction of factors such as geotechnical, geological, hydrological, climatic, and human activities (CRRI, 2000b). Lithology, structure, and drainage are the most important controls of slope characteristics (Aier, 2005). Emelyanova (1977) opines that lithology and structure play a vital role in the development and disposition of slopes and instability pattern in any area. There is a delicate balance of different factors for slope stability. According to Mehrotra et al (1993) human activity disturbs the natural balance of the environment which leads to destabilisation of slopes. Hence, slopes are essential features of geomorphic investigation. Landslides are caused by geological, geomorphological, and human processes (Cruden and Varnes, 1996). Two important characteristics of hill slopes are slope and geology (Galster and Laprade, 1991). A geomorphological approach to the estimation of landslide hazards and risks was carried out by Mantovani et al (1996), Cardinali et al (2000), Westen et al (2003). Tiziano (2003) contributed to monitoring and planning for slope stabilization. Diverse combinations of these factors give rise to a variety of slopes marked by favourable and unfavourable terrain conditions (Shah & Jadhav, 1987). Slope morphometry includes the study of the surficial features such as slope angles with respect to the horizontal and the relative relief of the area. The relative relief is a measure of the ruggedness of the terrain. It is estimated that eighty one percent of landslide events have occurred on slopes that are greater than 30°. Terzaghi (1950) states that debris flows can occur on slopes greater than 30°. This is a lower limit that is somewhat shallower than for slopes on which debris slides are generated.

Slopes are generally transitional in nature so an understanding of their behaviour is very difficult. Slopes are a combination of highly irregular surfaces that cannot be described by a simple mathematical equation (Sharma et al, 1996). Fujita et al (1976) and Fujita (1980) opine that landslide incidences are closely associated with the inclination of slope. Slopes are generally gentle to moderate, becoming steeper near valleys. According to Piteau and Peckover (1989) the safety factor for a slope is the ratio of the sum of resisting forces that act to prevent failure to the sum of the driving forces that tend to cause failure. A landslide will develop at the toe of a slope as soon as the driving forces exceed the resisting forces with average shear strength (Veder & Hilbert, 1980). Thus, slope stability will depend on the forces that tend to resist failure compared with those that tend to cause failure.

Shearing stresses build up with increase in the inclination and height of sloping surfaces. Failure will occur when shearing stresses exceed the shearing strength of the material. The degree of fracturing and shearing, and attitude of beds or joints in relation to slope geometry are important criteria in determining slope stability conditions. Unstable slopes characteristically involve downward and outward movements of material. They are often influenced by driving forces due to huge accumulations of debris in the head regions of slides and diminishing resistance to sliding due to reduction in shear strength. Hence, excessive load on the head of slopes can cause landslides. This is usually attributed to high pore-water pressure and large slope deformations (CRRI, 2000a). Choubey and Lallenmawia (1987) add that failure of natural slopes clears the surface off vegetation and other soil cover thereby exposing the surface to further erosion by surface and subsurface waters.

Matula (1969) opines that the most important factor for slide initiation is the degree of relief. Low values of relief indicate that the area has undergone very little differential erosion whereas high values may indicate the presence of longitudinal or transverse faults passing through the area. Hill-slope systems normally adjust to fluctuations in relief energy due to undercutting by streams, surficial erosion, and biogenic processes by soil creep. Sometimes, however, due to rate of change of energy fluctuations the system is forced to store excess relief energy and becomes over-steepened. An over-steepened slope becomes vulnerable to disturbances such as heavy rainfall, vibration, biogenic, and anthropogenic activity in its environment. Such triggers can push the hill-slope system beyond its intrinsic threshold of stability. The slope then fails, moving abruptly to a new morphological state, often of greater stability (Haigh, 1988).

Kumar et al (1995) are of the opinion that major slides occur in the middle slopes. Piteau & Peckover (1989) opine that concave slopes tend to be more stable than those that are convex and hence, slopes cut in mountainous terrain for highways are often convex and therefore are more unstable. Slope metamorphosis due to anthropogenic activity is a vital factor in slope instability (Thigale et al, 1998). Adverse climatic conditions can destabilise otherwise stable slopes. Prolonged or incessant rainfall is often the triggering factor. However, high rainfall may affect natural slopes differently than slopes that have been extensively cut and filled, deforested, or burnt. Water from precipitation enters cracks causing swelling of the soils. This leads to decrease of shear strength due to which cracks may develop (Nishida et al, 1979; Crozier, 1989). Such slopes may remain stable over very long periods and then suddenly lose their stability due to loss of shearing strength.

4.2 LITHOLOGY

Slopes are made up of various types of rocks and soils. The important properties of rocks include the nature of the mineral assemblage and the strength of the constituent minerals. If their mineral constituents are weak or if the strength of the bonds between the minerals is weak, the rocks tend to be fragile. Weathering greatly reduces the shearing resistance of rocks (Piteau & Peckover, 1989). Planes of weakness within a rock mass determine the stability of rock slopes to a great extent. The physical and mechanical properties of the rock mass are a function of the attitude, geometry, and spatial distribution of these planes. The principles of rock-slope design should therefore be based on the relation of weak planes to possible failure zones. In an analysis of slopes one must recognize the differences in the basic characteristics and behaviour of soil and rock. Unlike a soil mass, which is a relatively homogenous and continuous medium composed of loose particles, a rock mass is a heterogeneous and discontinuous medium composed essentially of partitioned solid blocks that are separated by discontinuities. Failure in soil tends to occur within the soil mass and the direction of the surface of failure does not depend on variations of soil properties. The failure surfaces in rock masses, however, tend to follow pre-existing discontinuities and do not occur throughout the intact rock to any great extent unless the rock is weak or incompetent. Hence, the shear strength of a rock mass is determined largely by the presence of the discontinuities.

Clay minerals are usually dehydrated, compacted, and consolidated due to superimposition of rock layers after sedimentation. On removal of the load water may again be absorbed and adsorbed. Water flows between the platelets causing large increases in volume and consequent reduction of the bonding forces between particles. Thus, in landslide investigations the clays are to be given great importance because their cohesion and shear strength values fall in the presence of water (Veder & Hilbert, 1980). They attribute loss of shear strength in clayey soils to two factors. The first is the water absorption and resultant swelling of the clays. The second is due to ion exchange whereby loosely bonded clay minerals are replaced by others. These two processes frequently interact and may accelerate each other. If a constant water source is present water will flow in and out of clayey and sandy soils. Such flow may cause movements and under certain conditions the fine particles may not be washed out but the whole viscous mass slowly creeps downhill, even up to several millimetres a day, passing over constructions, roads, channels, etc.

Clay deposits are weakened by fine fissures though they are generally less affected by discontinuities as compared to the harder rocks. If the distance between fissures is in the range of a few centimetres then the slope may become unstable and slide down during excavations or shortly after. Such slides of narrowly fissured clays take place as soon as the shear stresses exceed the average shear strength of the material (Ter-Stepanian, 1974; Gudehus et al, 1976; Blight, 1977). In clay deposits landslides are usually deep seated rotational failures. Well consolidated clays generally develop many small cracks and fissures which sometimes form an interconnecting network throughout the material. Occasionally clays also posses well defined joints similar to the hard rocks which influence the style of landslides. Discontinuities in clays facilitate water ingress which in turn softens up the mass thereby. This leads to loss of cohesion and promotes the chances of failure.

4.3 STRUCTURE

Structures favourable for slope deformation are characterised by a certain arrangement of rock complexes and system of faults, joints, etc. They are important only if they occur along the slopes or ridges of local topography (Kandpal and Pant, 1995). The strength of rocks may be reduced due to the presence of bedding planes, joints, or faults. Faults and joints are the most prominent of geological discontinuities that affect slope stability. In areas of unstable slopes it is noted that joint systems are often more troublesome than faults. The seepage of water along joint and bedding planes has been found more responsible for the occurrence of rock slides than the other causes combined. Moisture also causes alteration of rocks. An increase in moisture in the joints filled with clay can cause great swelling pressure which generally leads to rock falls and in some cases rock slides.

Landslides are common phenomena in intensely fractured and sheared areas. Structures that are favourable for slope movement usually are alternations of strata having variable strengths. Orientation of joints or bedding is an important factor. Slope movements take place especially where beds are not parallel to the slope except in cases where toe erosion by streams or cutting for roads, etc. has rendered the area weak. Weak geological structures like faults, folds, joints, bedding, cleavage, and foliation have aggravated slope failure. The origin of discontinuities will affect the engineering significance in the slope. Faults, as compared to joints, have different origins and accordingly different geometry, spatial distribution, weathering, infilling characteristics, and seepage characteristics (Lotha, 1999). Discontinuities such as joints and fractures are occasionally filled with clays which, when mixed with water, act as lubricants, thereby enhancing the failure potential.

Choubey and Lallenmawia (1989) state that, although it has been noted that tectonic structures are commonly responsible for slope failure they have been given very little importance in landslide investigations. Faults, fissures, joints, and shear zones are very pronounced in the Disang. Individually or in varying combinations they play a major role in promoting mass movements in the Kohima Township. Zones of closely spaced lineaments including faults and joints are particularly prone to severe erosion and slope failure (Aier, 2005). The degree of fracturing and shearing and the attitude of bedding or joint planes in relation to slope geometry are important criteria for determination of slope stability. The relation of discontinuities to the direction and inclination of the slope and to other factors that might influence any potential surface failure is important. If the orientation of a joint plane favours potential slope failure, the effects of other properties are generally unimportant. The frequency of landslides is greater near thrust zones and decreases progressively as the distance from the thrust increases. Discontinuities dipping out of slopes are mostly responsible for land instability. Mehrotra et al (1993) opine that instability increases proportionally as the strike of the discontinuities approaches that of the slope. Sharma et al (1996) are of the opinion that secondary discontinuities also play an important role in slope failure. They state that high incidence of discontinuities cause more instability.

4.4 HYDROGEOLOGY

Drainage is a function of slope, lithology, structure, weathering, soil content, vegetation and rainfall. Normally during the dry season most areas are dry because the groundwater table falls. However certain areas are perennially wet indicating high water tables. The high water tables are indicative of high absorption and extremely low drainage in those areas which is the cause of water logging. This is a reflection of the moisture retentivity of the formation. During the monsoons, however, most parts of Kohima are highly saturated with water which brings up the water table to great heights. According to Heller (1981) most first order streams originate in landslide scars while many landslides are concentrated in first and second order drainages. A number of perennial and seasonal streams of the higher orders have cut deep valleys and gorges in this area. A few landslides in this area are triggered by toe erosion by streams. However, the majority are found on free slopes without the influence of streams.

An increase of water pressure in the soil, like the relief of load pressure, may lead to water absorption. The difference between the effective consolidation pressure and the pressure of water in contact with silty clay or clayey soils is the decisive factor for water absorption and proportionate loss of strength. Consequently, a consolidated soil may swell if only hydrostatic pressure increases and earth pressure remains constant (Veder & Hilbert, 1980). A change in flow of underground water may lead to build-up of pore water pressure over a period of time. This may cause a decrease in shear resistance and trigger landslides (Mathewson and Clary, 1997; Bartarya and Valdiya, 1989). Moisture also causes alteration of rocks. An increase of moisture content can cause high swelling pressures in certain clay minerals which may occur in joints either as infilling or as products of alteration. Such high swelling pressures and low shear strength of wet clays may lead to rock falls or rock slides. Fluctuating water tables can also contribute markedly to the alteration and periodic changes in these mechanical properties of rocks (Piteau and Peckover, 1989).

Affected slopes usually have unconsolidated overburden and disturbed bedrock. These offer easy access to percolating waters to saturate the slope-forming material and cause instability. The flow of water through fissures exerts a lateral pressure on the rock mass which is proportional to differential head (Varshney et al, 1987). Surface waters transport clay minerals while travelling through the regolith. These particles accumulate between the regolith and bedrock where they act as lubricants thereby reducing the shear strength by displacing air and building up pore pressure on the regolith. In the regolith and deeply jointed bedrocks water from rainfall or surface runoff will have a very high infiltration rate. Starkel (1972) states that at the margins of landslides infiltration is even higher due to the presence of numerous cracks and joints. As pore-water pressure in joints is responsible for a great many rock slides a thorough knowledge of the hydrogeology of the region is necessary. Knowledge of the controlling influences such as texture, stratigraphy, and structure on factors such as flow, permeability, recharge, and storage capacity is also important while giving consideration to environmental factors such as variations in climatic conditions that result in periods of either high or low recharge or other variation in groundwater conditions (Piteau and Peckover, 1989). Terzaghi (1962), Muller (1964), and Serafim (1968) are of the opinion that water on slopes affect stability by increasing the pore water pressure in joints. This leads to reduction of shearing resistance of rocks along potential failure surfaces. The construction of roads, particularly in areas of unfavourable dips, may disturb the drainage along the slopes. Hence, water should be effectively drained off at various levels and should not be allowed to find its way through the soil and rock mass which will cause a decrease in the shear resistance.

4.5 LAND USE AND LAND COVER

Deforestation, soil erosion, slope modification, heavy constructions, and other detrimental activities have become a menace to the environment. Natural forests have long been exploited causing a gradual decline in the extent of their coverage. Investigations indicate that instability may be brought about by deforestation (Crozier & Vaughan, 1990). Deforestation brings about erosion and soil movement, but its impact on creeping slopes is a matter of debate (Gray, 1973). Crozier (1989) states that slope angles and height appear to be below the critical limits for mass movement on forested, unpopulated slopes. Failure planes of landslides on weathered sedimentary rocks are generally at some depth below the root zone.

The stability of hill slopes is directly or indirectly influenced by land use and land cover because these factors control the rate of weathering and erosion of the underlying rock formations. Deforestation and the creation of arable land may allow considerable water from rainfall to seep into the soil while evaporation decreases. Deforestation has an especially harmful effect if the remaining top soil is strongly eroded by the flow of surface waters. However, Brown and Sheu (1975), on experimental observation, conclude that removal of large heavy trees which also eliminates wind action on the vegetative cover, improves stability. Bishop and Stevens (1964) and Swanston (1974) state that in shallow-depth landslides that are confined to the root zone, the apparent cohesion of slope material are reduced with the gradual decay of tree roots following deforestation. This increases the likelihood of slope failure.

Zaruba & Mencl (1969) state that vegetative-type conversion commonly involves the changing of an area from trees and brush to a grass cover. Woodland plants enhance stability in regolith by physical consolidation through the network of roots and by drying out of the surface layers. Several studies (Swanston and Dyrness, 1973; O'Loughlin, 1974; Burroughs and Thomas, 1977) illustrate the stabilizing effect of tree-root networks. The peak and residual shearing resistances were found to increase two and four times respectively due to the roots. Lopez-Tello (1977) reports an increase of 33 percent of the "Safety Factor" for a 10 m high cut-slope in clay when covered with vegetation having a root density of 5000 Kg/ha.

Shifting cultivation, locally known as jhum cultivation, is an aimless, unplanned, nomadic movement or an abrupt change in location either of which may be referred to the cropping areas, the agriculturist, or both (Conklin, 1957). However, where the accumulation of detrital matter is increased with increasing jhum cycling period, the water holding capacity and soil moisture content shows a significant increase (Arunachalam, 1998). Road construction activity including repeated back cutting required for restoring the road width year after year, poor drainage, recurring debris slides in the colluvium of the slopes which destroy the vegetative cover, and toe erosion by streams have all been responsible in the development and increase of landslides.

4.6 RAINFALL

High intensity of rainfall generally leads to increased landslide activity. The amount, type, and yearly distribution of precipitation also affect other factors that control landslides such as vegetation, soils, and steepness of slopes. In addition to the annual rainfall, the recurrence interval of major storms, the yearly pattern of rainfall and longer-term changes in rainfall must be considered. Areas with high mean annual rainfall are generally associated with abundant recent landslides. Extreme rainfall often triggers landslides, sometimes with a considerable delay, pointing to a decrease in the shearing strength of the soil due to swelling (Veder and Hilbert, 1980). According to Jworchan and Nutalaya (1994) the addition of water on slopes due to rainfall triggers landslides. Higher rainfall intensity is probably required to generate landslides during the early months of the rainy seasons than the later months. Landsliding apparently occurs more easily when the ground is saturated or has been previously wetted and the groundwater table is high. The sequence of wet and dry spells during the rainy season is another important factor affecting landslide activity. The dry period probably reduces the effects of the previous precipitation on the landslide-generating capabilities of succeeding storms (Nilsen and Turner, 1975). Pichler (1957), Barata (1969), Endo (1970), Vargas (1971), and Guidicini & Iwasa (1977) have attempted correlation between landslides and precipitation levels. During periods of very intense rainfall abundant landslides generally occur although the time sequence and amount of the annual rainfall vary greatly at any particular place. The effect of these factors complicates the relation between rainfall and landsliding (Nilsen et al, 1976). The largest number of landslides will occur during and after long periods of relatively continuous rainfall (Nilsen and Turner, 1975). Debris accumulation on slopes is usually excessive. Brand (1981) explains the mechanism of rain induced failure in unsaturated residual soil. Chenniah et al (1994) and Abdullah and Ali (1994) determined the safety factor for unsaturated residual soil slopes considering pore water pressure. Abundance of water during the monsoon combines with it to cause debris flows.

There is only one recording station in Kohima Town. This is maintained by the Directorate of Soil & Water Conservation, Government of Nagaland. However, it is noted in this area that the rainfall patterns change even within a few square kilometres. The minimum and maximum monthly rainfall recorded at Kohima is 0.0 mm and 689.4 mm respectively with a total annual ranging between 1075.6 and 2616.1 mm (Table 4). The rainfall pattern is very erratic and varies from month to month and year to year. Sometimes the monsoon is early while at times it is late. The rainy season terminates by October at times while it continues right into November at others. The CRRI (2000a) is of the opinion that the majority of landslide incidences in India fall in the category of rainfall-induced landslides, especially in areas subject to limited periods of intense monsoon but that which remain dry during the rest of the year. The mechanism by which rainstorms can lead to slope instability in the unsaturated zone in weathered rock profiles include percolation into the unsaturated part of a slope resulting in rise of the groundwater tables (Zhang et al, 2000). Cloud bursts are common phenomena in this region. It has been noted that cloud bursts, particularly those occurring well into the rainy season or those following prolonged wet spells, have been the cause for some of the most damaging landslides in this terrain (Thong et al, 2004; Kemas et al, 2004; Aier, 2005).

4.7 SEISMICITY

Nagaland falls in Zone-V of the Seismic Zonation Map of India with an expected maximum magnitude greater than 8. More than 40 earthquakes of magnitudes greater than 6 on the Richter scale have been recorded in the last century in the NE region. Two earthquakes with magnitudes greater than 8 occurred in 1897 and 1950 in the north-eastern region. The role of seismicity as a triggering mechanism should be studied for historic landslide events (Thigale, 1999). Many large landslides have been triggered by earthquakes (Schuster and Highland, 2001).

TABLE 4

Station: Meteorological Observatory, Kohima
(Directorate of Soil & Water Conservation, Nagaland)

Altitude: 1420 meters

Year	Minimum (month) mm	Maximum (month) mm	Total Annual Rainfall mm
1981	7.0 (December)	402.8 (July)	1575.7
1982	6.3 (December)	394.5 (July)	1648.8
1983	11.3 (January)	353.5 (July)	1720.3
1984	14.6 (January)	517.7 (June)	1627.5
1985	6.5 (November)	393.1 (August)	1075.6
1986	8.6 (January)	260.8 (August)	1514.3
1987	3.3 (December)	394.0 (July)	1507.2
1988	3.4 (January)	365.3 (July)	1632.7
1989	5.8 (November)	358.0 (August)	1729.7
1990	32.9 (November)	558.9 (July)	2114.6
1991	5.6 (November)	417.2 (June)	2291.9
1992	7.2 (March)	669.6 (July)	2466.9
1993	18.0 (January)	689.4 (August)	2616.1
1994	3.4 (January)	480.4 (June)	1950.0
1995	6.8 (January)	501.8 (September)	1768.8
1996	0.0 (January)	454.1 (August)	1571.9
1997	1.5 (November)	262.4 (August)	1242.2
1998	0.8 (December)	289.1 (August)	1384.2
1999	0.5 (February)	403.8 (August)	1778.0
2000	0.0 (December)	547.2 (August)	1958.2
2001	0.0 (December)	360.0 (June)	1731.2
2002	10.0 (December)	335.4 (July)	1577.3
2003	5.2 (November)	358.4 (August)	1736.1
2004	0.3 (December)	505.8 (July)	1871.8

Repeated earthquakes in the NE region caused by intermittent tectonic stress release indicate that the orogenic movements are still in progress (Verma, 1985). Froehlich et al (1992) maintain that high density of joints in rocks is probably connected with high seismicity of any region. This would also support large scale mass wasting. However, no data of landsliding due to earthquakes is available so a study cannot be made.

CHAPTER 5

THEMATIC MAPPING

INTRODUCTION

The total area of investigation is about 11.06 sq kms. To facilitate study on a larger scale, the area of investigation is divided into two segments such that each segment is mapped on 1:25,000 scales. These are referred to as Segment 1 and Segment 2. Each segment is divided into a number of facets. Segment 1 comprises of 140 facets and includes facets 1 to 140. This segment, with an area of 5.16 sq kms, represents 46.65 percent of the total area of investigation. Segment 2 comprises 166 facets and includes facets 141 to 306. This segment occupies an area of 5.9 sq kms which represents 53.35 percent of the total area of investigation.

Segment 1 is exclusively made up of the Disang sediments whereas Segment 2 is made up of the Disang sediments for the most part and partially by the Laisong sediments of the Barail Group.

5.1 SLOPE MORPHOMETRY

Segment 1

This segment consists of three categories of slopes. These include very gentle slopes that cover an area of 2.28 sq kms, gentle slopes in 2.83 sq kms, and moderately steep slopes in 0.05 sq kms (Table 5.1.1a). The area of very gentle slopes is 44.21 percent, gentle slopes occupy 54.80 percent, and moderately steep slopes are found in 0.99 percent of the total area of this segment. The slope morphometric map of this segment is shown in Fig. 5.1.1. while ratings are given in table 5.2a.

TABLE 5.1.1a

Slope Morphometry and Drainage parameters

SEGMENT 1

Facet No	Slope Angle	Category	Relative Relief	Category	Drainage Density	Category
1	22	GS	100	LRR	6.48	MDD
2	16	GS	71	LRR	6.48	MDD
3	13	VGS	55	LRR	6.48	MDD
4	13	VGS	58	LRR	6.48	MDD
5	13	VGS	59	LRR	6.48	MDD
6	7	VGS	29	LRR	6.48	MDD
7	9	VGS	41	LRR	6.48	MDD
8	11	VGS	46	LRR	5.15	MDD
9	12	VGS	52	LRR	5.15	MDD
10	14	VGS	64	LRR	5.15	MDD
11	13	VGS	58	LRR	5.15	MDD
12	17	GS	73	LRR	5.15	MDD
13	9	VGS	41	LRR	6.48	MDD
14	9	VGS	40	LRR	6.48	MDD
15	14	VGS	63	LRR	6.48	MDD
16	15	VGS	64	LRR	6.48	MDD
17	15	VGS	67	LRR	6.48	MDD
18	20	GS	88	LRR	6.48	MDD
19	21	GS	95	LRR	6.48	MDD
20	15	VGS	64	LRR	6.48	MDD
21	22	GS	102	MRR	6.48	MDD
22	17	GS	76	LRR	6.48	MDD
23	19	GS	83	LRR	5.15	MDD
24	19	GS	85	LRR	5.15	MDD
25	13	VGS	56	LRR	5.15	MDD
26	13	VGS	56	LRR	5.15	MDD
27	22	GS	100	LRR	5.15	MDD
28	16	GS	71	LRR	5.15	MDD
29	15	VGS	66	LRR	5.15	MDD
30	15	VGS	64	LRR	5.15	MDD
31	21	GS	93	LRR	5.15	MDD
32	13	VGS	57	LRR	5.15	MDD
33	15	VGS	66	LRR	5.15	MDD
34	14	VGS	60	LRR	5.15	MDD
35	21	GS	93	LRR	6.48	MDD
36	21	GS	93	LRR	6.48	MDD
37	22	GS	98	LRR	6.48	MDD
38	11	VGS	46	LRR	5.15	MDD

39	18	GS	81	LRR	6.48	MDD
40	19	GS	87	LRR	6.48	MDD
41	13	VGS	56	LRR	6.48	MDD
42	14	VGS	61	LRR	5.15	MDD
43	15	VGS	68	LRR	5.15	MDD
44	15	VGS	67	LRR	5.15	MDD
45	13	VGS	55	LRR	5.15	MDD
46	13	VGS	59	LRR	5.15	MDD
47	14	VGS	60	LRR	5.15	MDD
48	11	VGS	49	LRR	6.48	MDD
49	14	VGS	62	LRR	6.48	MDD
50	14	VGS	61	LRR	6.48	MDD
51	22	GS	100	LRR	6.48	MDD
52	15	VGS	68	LRR	6.48	MDD
53	18	GS	79	LRR	6.48	MDD
54	17	GS	74	LRR	7.09	HDD
55	19	GS	87	LRR	7.09	HDD
56	8	VGS	33	LRR	7.09	HDD
57	11	VGS	47	LRR	7.09	HDD
58	16	GS	73	LRR	5.09	MDD
59	15	VGS	67	LRR	5.09	MDD
60	17	GS	73	LRR	5.09	MDD
61	18	GS	78	LRR	5.09	MDD
62	13	VGS	55	LRR	5.09	MDD
63	13	VGS	57	LRR	5.09	MDD
64	17	GS	76	LRR	5.09	MDD
65	17	GS	76	LRR	5.09	MDD
66	17	GS	76	LRR	5.09	MDD
67	12	VGS	50	LRR	7.09	HDD
68	20	GS	89	LRR	7.09	HDD
69	18	GS	79	LRR	7.09	HDD
70	13	VGS	58	LRR	7.09	HDD
71	15	VGS	65	LRR	7.09	HDD
72	15	VGS	65	LRR	8.15	HDD
73	10	VGS	43	LRR	8.15	HDD
74	27	MSS	125	MRR	8.15	HDD
75	22	GS	101	MRR	8.15	HDD
76	10	VGS	45	LRR	8.15	HDD
77	14	VGS	62	LRR	8.15	HDD
78	19	GS	88	LRR	8.15	HDD
79	20	GS	89	LRR	8.15	HDD
80	18	GS	83	LRR	8.15	HDD
81	11	VGS	50	LRR	5.16	MDD
82	14	VGS	63	LRR	5.16	MDD
83	18	GS	82	LRR	5.16	MDD
84	18	GS	79	LRR	5.16	MDD
85	16	GS	73	LRR	8.15	HDD
86	9	VGS	42	LRR	7.09	HDD

87	16	GS	72	LRR	7.09	HDD
88	16	GS	71	LRR	7.09	HDD
89	15	VGS	66	LRR	7.09	HDD
90	15	VGS	65	LRR	7.09	HDD
91	10	VGS	45	LRR	7.09	HDD
92	22	GS	100	LRR	4.92	LDD
93	15	VGS	65	LRR	4.92	LDD
94	22	GS	101	MRR	4.92	LDD
95	17	GS	78	LRR	4.92	LDD
96	17	GS	79	LRR	4.92	LDD
97	11	VGS	50	LRR	4.92	LDD
98	15	VGS	65	LRR	5.09	MDD
99	17	GS	75	LRR	5.09	MDD
100	17	GS	75	LRR	5.09	MDD
101	15	VGS	68	LRR	5.09	MDD
102	19	GS	88	LRR	5.09	MDD
103	0	VGS	0	LRR	4.92	LDD
104	16	GS	71	LRR	4.92	LDD
105	18	GS	81	LRR	4.92	LDD
106	18	GS	83	LRR	4.92	LDD
107	17	GS	77	LRR	4.92	LDD
108	17	GS	77	LRR	4.92	LDD
109	23	GS	106	MRR	4.92	LDD
110	22	GS	99	LRR	4.92	LDD
111	17	GS	75	LRR	4.92	LDD
112	20	GS	92	LRR	5.16	MDD
113	18	GS	81	LRR	5.16	MDD
114	20	GS	93	LRR	5.16	MDD
115	21	GS	97	LRR	5.16	MDD
116	18	GS	80	LRR	5.16	MDD
117	20	GS	91	LRR	5.16	MDD
118	18	GS	80	LRR	5.16	MDD
119	17	GS	74	LRR	5.16	MDD
120	19	GS	86	LRR	5.16	MDD
121	20	GS	93	LRR	5.16	MDD
122	13	VGS	58	LRR	4.92	LDD
123	18	GS	80	LRR	4.92	LDD
124	16	GS	74	LRR	4.92	LDD
125	21	GS	94	LRR	4.92	LDD
126	18	GS	81	LRR	4.92	LDD
127	18	GS	83	LRR	4.92	LDD
128	17	GS	75	LRR	4.92	LDD
129	23	GS	106	MRR	4.92	LDD
130	18	GS	80	LRR	4.92	LDD
131	14	VGS	61	LRR	4.92	LDD
132	18	GS	81	LRR	4.92	LDD
133	18	GS	82	LRR	4.92	LDD
134	3	VGS	13	LRR	4.92	LDD

135	16	GS	73	LRR	5.09	MDD
136	16	GS	74	LRR	5.09	MDD
137	19	GS	86	LRR	5.09	MDD
138	13	VGS	58	LRR	5.09	MDD
139	12	VGS	51	LRR	5.09	MDD
140	13	VGS	59	LRR	5.09	MDD

TABLE 5.2a

Landslide Hazard Evaluation Factor & Total Estimated Hazard

SEGMENT 1

Facet No	SM (15)	RR (10)	Lithology (20)	Structure (20)	DD (15)	LU/LC (20)	TEHD (100)	LHZ
1	6	2	15	12	8	15	58	MH
2	6	2	15	12	8	15	58	MH
3	3	2	15	12	8	15	55	MH
4	3	2	15	12	8	5	45	LH
5	3	2	15	12	8	15	55	MH
6	3	2	15	12	8	15	55	MH
7	3	2	15	12	8	15	55	MH
8	3	2	20	20	8	15	68	HH
9	3	2	20	20	8	15	68	HH
10	3	2	20	20	8	15	68	HH
11	3	2	20	20	8	15	68	HH
12	6	2	20	20	8	15	71	HH
13	3	2	15	12	8	15	55	MH
14	3	2	15	12	8	15	55	MH
15	3	2	14	18	8	15	60	MH
16	3	2	14	18	8	15	60	MH
17	3	2	14	10	8	15	52	MH
18	6	2	15	12	8	15	58	MH
19	6	2	15	12	8	12	55	MH
20	3	2	15	12	8	12	52	MH
21	6	5	15	12	8	15	61	HH
22	6	2	14	18	8	15	63	HH
23	6	2	20	20	8	20	76	VHH
24	6	2	20	20	8	20	76	VHH
25	3	2	20	20	8	15	68	HH
26	3	2	20	20	8	15	68	HH
27	6	2	20	20	8	15	71	HH
28	6	2	20	20	8	15	71	HH
29	3	2	20	20	8	15	68	HH
30	3	2	20	20	8	15	68	HH
31	6	2	20	20	8	12	68	HH
32	3	2	20	20	8	12	65	HH
33	3	2	20	20	8	15	68	HH
34	3	2	20	20	8	15	68	HH
35	6	2	15	12	8	12	55	MH
36	6	2	15	12	8	12	55	MH
37	6	2	14	10	8	15	55	MH
38	3	2	20	20	8	15	68	HH

39	6	2	14	18	8	15	63	HH
40	6	2	15	12	8	15	58	MH
41	3	2	14	15	8	15	57	MH
42	3	2	20	20	8	15	68	HH
43	3	2	20	20	8	15	68	HH
44	3	2	20	20	8	15	68	HH
45	3	2	20	20	8	15	68	HH
46	3	2	20	20	8	12	65	HH
47	3	2	15	12	8	15	55	MH
48	3	2	15	12	8	15	55	MH
49	3	2	14	18	8	15	60	MH
50	3	2	14	15	8	15	57	MH
51	6	2	15	12	8	15	58	MH
52	3	2	14	10	8	15	52	MH
53	6	2	14	15	8	12	57	MH
54	6	2	16	18	10	15	67	HH
55	6	2	16	15	10	15	64	HH
56	3	2	15	12	10	15	57	MH
57	3	2	15	12	10	15	57	MH
58	6	2	14	18	8	15	63	HH
59	3	2	20	20	8	20	73	HH
60	6	2	20	20	8	20	76	VHH
61	6	2	20	20	8	20	76	VHH
62	3	2	20	20	8	20	73	HH
63	3	2	20	20	8	20	73	HH
64	6	2	20	20	8	20	76	VHH
65	6	2	20	20	8	20	76	VHH
66	6	2	20	20	8	20	76	VHH
67	3	2	20	20	10	12	67	HH
68	6	2	20	20	10	12	70	HH
69	6	2	20	20	10	5	63	HH
70	3	2	15	12	10	15	57	MH
71	3	2	15	12	10	15	57	MH
72	3	2	20	20	10	12	67	HH
73	3	2	15	12	10	15	57	MH
74	9	5	20	20	10	20	84	VHH
75	6	5	20	20	10	20	81	VHH
76	3	2	15	12	10	15	57	MH
77	3	2	20	20	10	15	70	HH
78	6	2	20	20	10	5	63	HH
79	6	2	15	12	10	12	57	MH
80	6	2	14	18	10	12	62	HH
81	3	2	15	12	8	12	52	MH
82	3	2	15	20	8	8	56	MH
83	6	2	15	20	8	5	56	MH
84	6	2	20	20	8	20	76	VHH
85	6	2	14	15	10	12	59	MH
86	3	2	20	20	10	15	70	HH

87	6	2	14	10	10	15	57	MH
88	6	2	15	12	10	15	60	MH
89	3	2	15	12	10	15	57	MH
90	3	2	15	12	10	15	57	MH
91	3	2	20	20	10	12	67	HH
92	6	2	15	20	5	15	63	HH
93	3	2	20	20	5	15	65	HH
94	6	5	15	12	5	15	58	MH
95	6	2	14	18	5	15	60	MH
96	6	2	15	12	5	15	55	MH
97	3	2	15	12	5	15	52	MH
98	3	2	15	12	8	15	55	MH
99	6	2	15	12	8	8	51	LH
100	6	2	20	20	8	15	71	HH
101	3	2	20	20	8	15	68	HH
102	6	2	20	20	8	15	71	HH
103	3	2	15	12	5	12	49	LH
104	6	2	15	12	5	15	55	MH
105	6	2	15	12	5	15	55	MH
106	6	2	20	20	5	15	68	HH
107	6	2	20	20	5	15	68	HH
108	6	2	20	20	5	12	65	HH
109	6	5	20	20	5	15	71	HH
110	6	2	14	8	5	15	50	MH
111	6	2	14	15	5	15	57	MH
112	6	2	15	20	8	15	66	HH
113	6	2	20	20	8	20	76	VHH
114	6	2	20	20	8	20	76	VHH
115	6	2	20	20	8	12	68	HH
116	6	2	14	18	8	15	63	HH
117	6	2	20	20	8	12	68	HH
118	6	2	20	20	8	12	68	HH
119	6	2	15	12	8	12	55	MH
120	6	2	15	12	8	15	58	MH
121	6	2	14	10	8	15	55	MH
122	3	2	15	12	5	15	52	MH
123	6	2	14	10	5	15	52	MH
124	6	2	16	12	5	15	56	MH
125	6	2	15	12	5	15	55	MH
126	6	2	15	12	5	12	52	MH
127	6	2	16	12	5	15	56	MH
128	6	2	15	12	5	15	55	MH
129	6	5	15	20	5	15	66	HH
130	6	2	20	20	5	15	68	HH
131	3	2	20	20	5	15	65	HH
132	6	2	20	20	5	15	68	HH
133	6	2	20	20	5	15	68	HH
134	3	2	15	12	5	15	52	MH

135	6	2	20	20	8	15	71	HH
136	6	2	20	20	8	12	68	HH
137	6	2	20	20	8	12	68	HH
138	3	2	20	20	8	20	73	HH
139	3	2	20	20	8	15	68	HH
140	3	2	20	20	8	20	73	HH

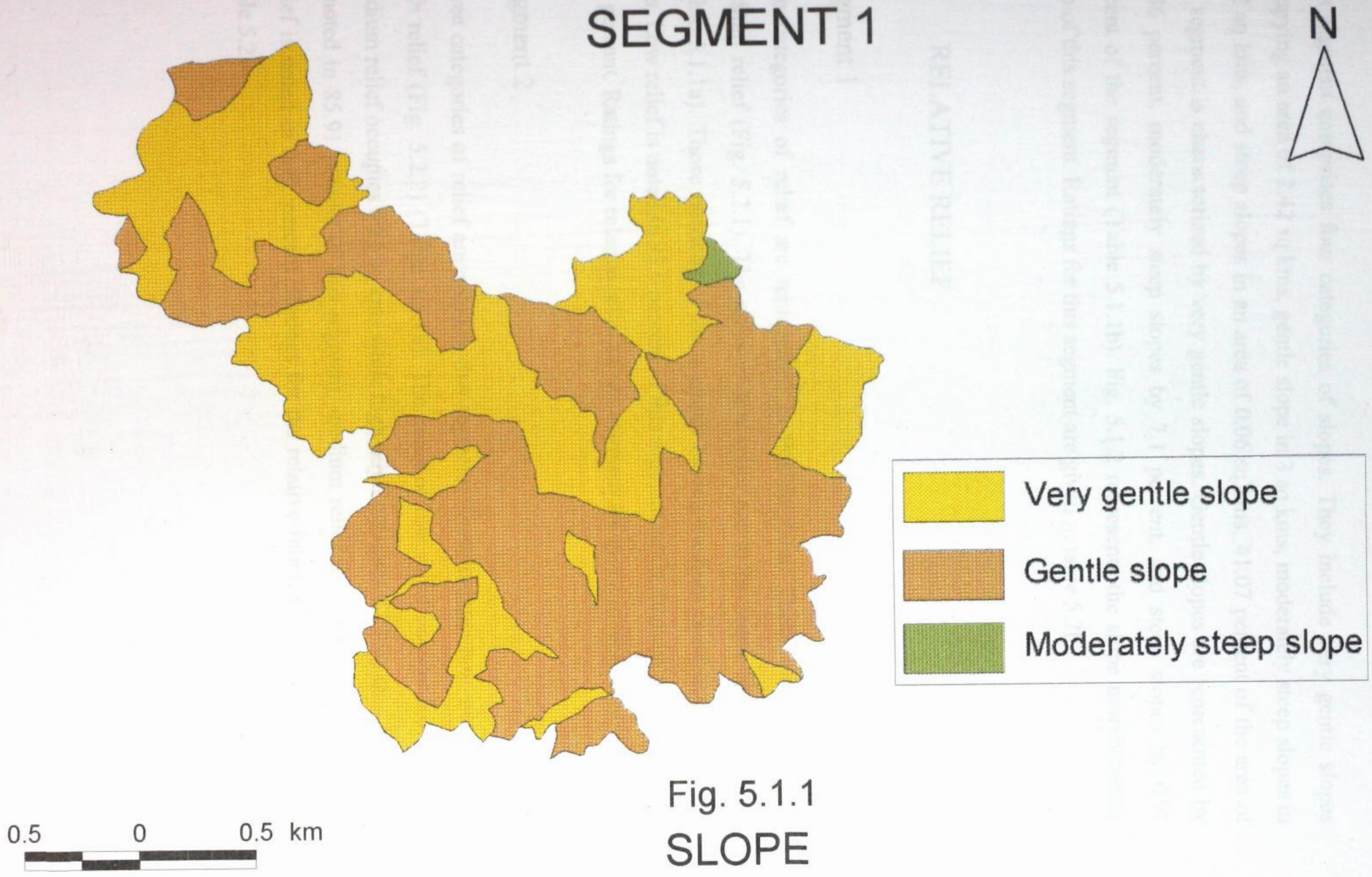


Fig. 5.1.1
SLOPE

Segment 2

This segment comprises four categories of slopes. They include very gentle slopes occupying an area of 2.42 sq kms, gentle slope in 3 sq kms, moderately steep slopes in 0.42 sq kms, and steep slopes in an area of 0.06 sq kms. 41.07 percent of the area of this segment is characterized by very gentle slopes. Gentle slopes are represented by 50.86 percent, moderately steep slopes by 7.1 percent, and steep slopes by 0.97 percent of the segment (Table 5.1.1b). Fig. 5.1.2 represents the slope morphometric map of this segment. Ratings for this segment are given in table 5.2b.

5.2 RELATIVE RELIEF

Segment 1

Two categories of relief are represented in this segment. These include low and medium relief (Fig. 5.2.1). The areas of low relief are to be found in 4.85 sq kms (Table 5.1.1a). Those portions of the segment having medium relief occupy 0.31 sq kms. Low relief is noted in 93.9 percent of this segment while medium relief in seen in 6.1 percent. Ratings for relative relief of this segment are given in table 5.2a.

Segment 2

Three categories of relief are noted in this segment. These include low, medium, and high relief (Fig. 5.2.2) (Table 5.1.1b). The areas of low relief occupy 5.07 sq kms; medium relief occupies 0.81 sq kms while high relief occupies 0.02 sq kms. Low relief is noted in 85.91 percent of this segment, medium relief in 13.68 percent, and high relief is noted in 0.41 percent. Ratings for the relative relief of the area are given in table 5.2b.

TABLE 5.1.1b

Slope Morphometry and Drainage parameters

SEGMENT 2

Facet No	Slope Angle	Category	Relative Relief	Category	Drainage Density	Category
141	15	GS	68	LRR	5.09	MDD
142	19	GS	87	LRR	5.09	MDD
143	18	GS	83	LRR	5.09	MDD
144	14	VGS	63	LRR	5.09	MDD
145	14	VGS	63	LRR	5.09	MDD
146	27	MSS	125	MRR	5.09	MDD
147	21	GS	96	LRR	5.09	MDD
148	20	GS	92	LRR	5.09	MDD
149	17	GS	76	LRR	9.9	HDD
150	14	VGS	63	LRR	9.9	HDD
151	15	GS	69	LRR	9.9	HDD
152	16	GS	71	LRR	9.9	HDD
153	15	VGS	66	LRR	9.9	HDD
154	12	VGS	55	LRR	9.9	HDD
155	11	VGS	50	LRR	9.9	HDD
156	18	GS	80	LRR	9.9	HDD
157	12	VGS	55	LRR	9.9	HDD
158	14	VGS	60	LRR	9.9	HDD
159	14	VGS	63	LRR	9.9	HDD
160	15	VGS	68	LRR	9.9	HDD
161	2	VGS	10	LRR	9.9	HDD
162	13	VGS	58	LRR	4.92	LDD
163	16	GS	74	LRR	4.92	LDD
164	17	GS	77	LRR	4.92	LDD
165	22	GS	103	MRR	4.92	LDD
166	19	GS	86	LRR	4.92	LDD
167	16	GS	73	LRR	4.92	LDD
168	16	GS	71	LRR	4.92	LDD
169	16	GS	72	LRR	9.9	HDD
170	19	GS	88	LRR	9.9	HDD
171	27	MSS	125	MRR	9.9	HDD
172	15	VGS	68	LRR	9.9	HDD
173	17	GS	75	LRR	9.9	HDD
174	16	GS	71	LRR	9.9	HDD
175	27	MSS	125	MRR	9.9	HDD
176	20	GS	93	LRR	9.9	HDD
177	14	VGS	61	LRR	9.9	HDD
178	14	VGS	63	LRR	9.9	HDD

179	14	VGS	65	LRR	9.9	HDD
180	16	GS	70	LRR	9.9	HDD
181	14	VGS	64	LRR	9.9	HDD
182	14	VGS	64	LRR	9.9	HDD
183	14	VGS	63	LRR	9.9	HDD
184	9	VGS	42	LRR	9.9	HDD
185	12	VGS	55	LRR	9.9	HDD
186	18	GS	80	LRR	9.9	HDD
187	25	MSS	119	MRR	9.9	HDD
188	18	GS	80	LRR	9.36	HDD
189	19	GS	85	LRR	9.36	HDD
190	12	VGS	53	LRR	5.09	MDD
191	11	VGS	49	LRR	5.09	MDD
192	25	GS	117	MRR	5.09	MDD
193	28	MSS	131	MRR	9.36	HDD
194	21	GS	94	LRR	9.36	HDD
195	21	GS	95	LRR	9.36	HDD
196	20	GS	92	LRR	9.36	HDD
197	22	GS	99	LRR	9.36	HDD
198	19	GS	86	LRR	9.36	HDD
199	19	GS	84	LRR	9.36	HDD
200	26	MSS	122	MRR	9.36	HDD
201	18	GS	80	LRR	9.36	HDD
202	23	GS	104	MRR	9.36	HDD
203	17	GS	75	LRR	9.36	HDD
204	14	VGS	61	LRR	9.36	HDD
205	14	VGS	64	LRR	9.36	HDD
206	17	GS	75	LRR	9.9	HDD
207	14	VGS	64	LRR	9.9	HDD
208	8	VGS	33	LRR	9.9	HDD
209	14	VGS	63	LRR	9.9	HDD
210	6	VGS	28	LRR	9.9	HDD
211	6	VGS	27	LRR	9.9	HDD
212	14	VGS	63	LRR	9.9	HDD
213	17	GS	78	LRR	9.9	HDD
214	33	MSS	163	MRR	9.9	HDD
215	24	GS	110	MRR	9.9	HDD
216	16	GS	69	LRR	9.9	HDD
217	14	VGS	64	LRR	9.9	HDD
218	9	VGS	40	LRR	9.9	HDD
219	13	VGS	56	LRR	9.9	HDD
220	19	GS	87	LRR	9.9	HDD
221	16	GS	71	LRR	9.9	HDD
222	20	GS	89	LRR	9.9	HDD
223	27	MSS	125	MRR	9.9	HDD
224	19	GS	86	LRR	9.9	HDD
225	22	GS	99	LRR	9.9	HDD
226	33	MSS	163	MRR	9.9	HDD

227	14	VGS	62	LRR	9.9	HDD
228	14	VGS	60	LRR	9.9	HDD
229	13	VGS	56	LRR	9.9	HDD
230	14	VGS	60	LRR	9.9	HDD
231	9	VGS	40	LRR	9.9	HDD
232	14	VGS	61	LRR	9.36	HDD
233	11	VGS	50	LRR	9.36	HDD
234	14	VGS	61	LRR	9.36	HDD
235	13	VGS	59	LRR	9.36	HDD
236	14	VGS	61	LRR	9.36	HDD
237	16	GS	72	LRR	9.36	HDD
238	20	GS	90	LRR	9.36	HDD
239	15	VGS	65	LRR	9.36	HDD
240	18	GS	83	LRR	9.36	HDD
241	8	VGS	35	LRR	9.36	HDD
242	16	GS	73	LRR	9.36	HDD
243	14	VGS	63	LRR	9.36	HDD
244	13	VGS	57	LRR	9.36	HDD
245	14	VGS	61	LRR	9.36	HDD
246	16	GS	71	LRR	9.36	HDD
247	16	GS	74	LRR	9.36	HDD
248	43	SS	235	HRR	9.36	HDD
249	14	VGS	63	LRR	9.36	HDD
250	15	VGS	66	LRR	9.36	HDD
251	16	GS	73	LRR	9.36	HDD
252	15	VGS	67	LRR	9.36	HDD
253	17	GS	77	LRR	9.36	HDD
254	16	GS	72	LRR	9.36	HDD
255	20	GS	90	LRR	9.36	HDD
256	20	GS	89	LRR	9.36	HDD
257	30	MSS	145	MRR	9.36	HDD
258	24	GS	113	MRR	9.36	HDD
259	37	SS	185	MRR	9.36	HDD
260	24	GS	112	MRR	9.36	HDD
261	11	VGS	48	LRR	9.36	HDD
262	15	VGS	67	LRR	9.36	HDD
263	22	GS	100	LRR	9.36	HDD
264	13	VGS	56	LRR	9.36	HDD
265	21	GS	94	LRR	9.36	HDD
266	27	MSS	125	MRR	9.36	HDD
267	14	VGS	63	LRR	9.36	HDD
268	13	VGS	57	LRR	9.36	HDD
269	12	VGS	55	LRR	9.36	HDD
270	12	VGS	53	LRR	9.36	HDD
271	10	VGS	43	LRR	9.36	HDD
272	14	VGS	63	LRR	9.36	HDD
273	10	VGS	43	LRR	9.36	HDD
274	17	GS	77	LRR	9.36	HDD

275	13	VGS	57	LRR	9.36	HDD
276	13	VGS	56	LRR	9.9	HDD
277	16	GS	71	LRR	9.9	HDD
278	11	VGS	48	LRR	9.36	HDD
279	13	VGS	60	LRR	9.36	HDD
280	16	GS	73	LRR	9.9	HDD
281	17	GS	74	LRR	9.9	HDD
282	10	VGS	44	LRR	9.9	HDD
283	17	GS	77	LRR	9.9	HDD
284	20	GS	92	LRR	9.9	HDD
285	15	GS	69	LRR	9.9	HDD
286	24	GS	111	MRR	9.9	HDD
287	27	MSS	130	MRR	9.9	HDD
288	16	GS	71	LRR	9.9	HDD
289	15	GS	68	LRR	9.9	HDD
290	19	GS	85	LRR	9.9	HDD
291	16	GS	73	LRR	9.9	HDD
292	17	GS	75	LRR	9.9	HDD
293	19	GS	85	LRR	9.9	HDD
294	19	GS	84	LRR	9.9	HDD
295	19	GS	88	LRR	9.9	HDD
296	21	GS	96	LRR	9.9	HDD
297	18	GS	80	LRR	9.9	HDD
298	17	GS	76	LRR	9.9	HDD
299	14	VGS	65	LRR	9.9	HDD
300	17	GS	74	LRR	9.9	HDD
301	18	GS	81	LRR	9.9	HDD
302	17	GS	76	LRR	9.9	HDD
303	17	GS	76	LRR	9.9	HDD
304	16	GS	74	LRR	9.9	HDD
305	20	GS	90	LRR	9.9	HDD
306	19	GS	85	LRR	9.9	HDD

TABLE 5.2b

Landslide Hazard Evaluation Factor & Total Estimated Hazard

SEGMENT 2

Facet No	SM (15)	RR (10)	Lithology (20)	Structure (20)	DD (15)	LU/LC (20)	TEHD (100)	LHZ
141	6	2	20	20	8	20	76	VHH
142	6	2	20	20	8	20	76	VHH
143	6	2	20	20	8	20	76	VHH
144	3	2	20	20	8	20	73	HH
145	3	2	15	12	8	5	45	LH
146	9	5	15	12	8	15	64	HH
147	6	2	20	20	8	12	68	HH
148	6	2	20	20	8	5	61	HH
149	6	2	20	20	10	15	73	HH
150	3	2	15	12	10	15	57	MH
151	6	2	20	20	10	15	73	HH
152	6	2	15	12	10	15	60	MH
153	3	2	15	12	10	15	57	MH
154	3	2	15	12	10	15	57	MH
155	3	2	15	12	10	15	57	MH
156	6	2	15	12	10	15	60	MH
157	3	2	15	12	10	15	57	MH
158	3	2	15	12	10	15	57	MH
159	3	2	15	12	10	15	57	MH
160	3	2	20	20	10	15	70	HH
161	3	2	15	12	10	12	54	MH
162	3	2	15	12	5	15	52	MH
163	6	2	20	20	5	12	65	HH
164	6	2	20	20	5	12	65	HH
165	6	5	20	20	5	12	68	HH
166	6	2	20	20	5	12	65	HH
167	6	2	15	12	5	12	52	MH
168	6	2	15	12	5	12	52	MH
169	6	2	15	12	10	15	60	MH
170	6	2	15	12	10	15	60	MH
171	9	5	20	20	10	15	79	HH
172	3	2	20	20	10	12	67	HH
173	6	2	20	20	10	12	70	HH
174	6	2	15	12	10	15	60	MH
175	9	5	20	20	10	15	79	HH
176	6	2	20	20	10	5	63	HH
177	3	2	20	20	10	12	67	HH
178	3	2	20	20	10	15	70	HH

179	3	2	20	20	10	15	70	HH
180	6	2	20	20	10	15	73	HH
181	3	2	15	12	10	12	54	MH
182	3	2	15	12	10	15	57	MH
183	3	2	20	20	10	15	70	HH
184	3	2	14	10	10	15	54	MH
185	3	2	20	20	10	20	75	VHH
186	6	2	20	20	10	20	78	VHH
187	9	5	20	20	10	15	79	HH
188	6	2	20	20	10	15	73	HH
189	6	2	20	20	10	15	73	HH
190	3	2	15	12	8	15	55	MH
191	3	2	15	12	8	15	55	MH
192	6	5	15	12	8	15	61	HH
193	9	5	15	12	10	20	71	HH
194	6	2	20	20	10	20	78	VHH
195	6	2	20	20	10	20	78	VHH
196	6	2	20	20	10	20	78	VHH
197	6	2	20	20	10	15	73	HH
198	6	2	20	20	10	20	78	VHH
199	6	2	20	20	10	20	78	VHH
200	9	5	15	12	10	5	56	MH
201	6	2	12	15	10	15	60	MH
202	6	5	20	20	10	12	73	HH
203	6	2	20	20	10	20	78	VHH
204	3	2	20	20	10	20	75	VHH
205	3	2	20	20	10	15	70	HH
206	6	2	20	20	10	15	73	HH
207	3	2	15	12	10	15	57	MH
208	3	2	15	12	10	15	57	MH
209	3	2	15	12	10	15	57	MH
210	3	2	15	12	10	15	57	MH
211	3	2	20	20	10	15	70	HH
212	3	2	15	12	10	15	57	MH
213	6	2	15	12	10	12	57	MH
214	9	5	15	12	10	12	63	HH
215	6	5	20	20	10	12	73	HH
216	6	2	15	12	10	15	60	MH
217	3	2	15	12	10	12	54	MH
218	3	2	15	12	10	15	57	MH
219	3	2	15	12	10	12	54	MH
220	6	2	15	20	10	15	68	HH
221	6	2	20	20	10	20	78	VHH
222	6	2	20	20	10	15	73	HH
223	9	5	15	12	10	15	66	HH
224	6	2	20	20	10	15	73	HH
225	6	2	15	12	10	15	60	MH
226	9	5	20	20	10	15	79	VHH

227	3	2	15	12	10	15	57	MH
228	3	2	15	12	10	15	57	MH
229	3	2	15	12	10	15	57	MH
230	3	2	15	12	10	15	57	MH
231	3	2	15	12	10	15	57	MH
232	3	2	20	20	10	15	70	HH
233	3	2	20	20	10	20	75	VHH
234	3	2	20	20	10	15	70	HH
235	3	2	15	12	10	12	54	MH
236	3	2	14	10	10	15	54	MH
237	6	2	15	12	10	12	57	MH
238	6	2	15	12	10	12	57	MH
239	3	2	20	12	10	15	62	MH
240	6	2	15	12	10	15	60	MH
241	3	2	20	20	10	15	70	HH
242	6	2	20	20	10	15	73	HH
243	3	2	20	20	10	15	70	HH
244	3	2	20	20	10	15	70	HH
245	3	2	15	12	10	12	54	MH
246	6	2	15	12	10	15	60	MH
247	6	2	20	20	10	20	78	VHH
248	12	7	20	20	10	12	81	VHH
249	3	2	20	20	10	12	67	HH
250	3	2	20	20	10	8	63	HH
251	6	2	20	12	10	15	65	HH
252	3	2	20	12	10	15	62	HH
253	6	2	15	12	10	8	53	MH
254	6	2	15	12	10	12	57	MH
255	6	2	15	12	10	8	53	MH
256	6	2	15	20	10	15	68	HH
257	9	5	20	12	10	15	71	HH
258	6	5	20	20	10	5	66	HH
259	12	5	20	20	10	5	72	HH
260	6	5	6	10	10	15	52	MH
261	3	2	15	12	10	12	54	MH
262	3	2	6	15	10	15	51	MH
263	6	2	20	20	10	12	70	HH
264	3	2	20	20	10	12	67	HH
265	6	2	14	10	10	12	54	MH
266	9	5	6	15	10	12	57	MH
267	3	2	15	12	10	12	54	MH
268	3	2	15	12	10	15	57	MH
269	3	2	15	12	10	15	57	MH
270	3	2	15	12	10	12	54	MH
271	3	2	14	18	10	15	62	HH
272	3	2	15	12	10	15	57	MH
273	3	2	15	12	10	15	57	MH
274	6	2	15	12	10	15	60	MH

275	3	2	15	12	10	15	57	MH
276	3	2	15	12	10	15	57	MH
277	6	2	15	12	10	15	60	MH
278	3	2	15	12	10	15	57	MH
279	3	2	15	12	10	15	57	MH
280	6	2	15	12	10	15	60	MH
281	6	2	14	10	10	15	57	MH
282	3	2	15	12	10	15	57	MH
283	6	2	15	12	10	15	60	MH
284	6	2	20	20	10	15	73	HH
285	6	2	20	20	10	15	73	HH
286	6	5	14	10	10	12	57	MH
287	9	5	15	12	10	15	66	HH
288	6	2	15	12	10	12	57	MH
289	6	2	16	10	10	12	56	MH
290	6	2	14	10	10	15	57	MH
291	6	2	14	15	10	15	62	HH
292	6	2	14	10	10	15	57	MH
293	6	2	14	15	10	15	62	HH
294	6	2	15	20	10	15	68	HH
295	6	2	14	18	10	15	65	HH
296	6	2	20	20	10	15	73	HH
297	6	2	6	15	10	15	54	MH
298	6	2	20	20	10	15	73	HH
299	3	2	14	12	10	15	56	MH
300	6	2	16	12	10	12	58	MH
301	6	2	15	10	10	12	55	MH
302	6	2	20	20	10	12	70	HH
303	6	2	20	20	10	12	70	HH
304	6	2	20	20	10	12	70	HH
305	6	2	20	20	10	20	78	VHH
306	6	2	20	20	10	20	78	VHH

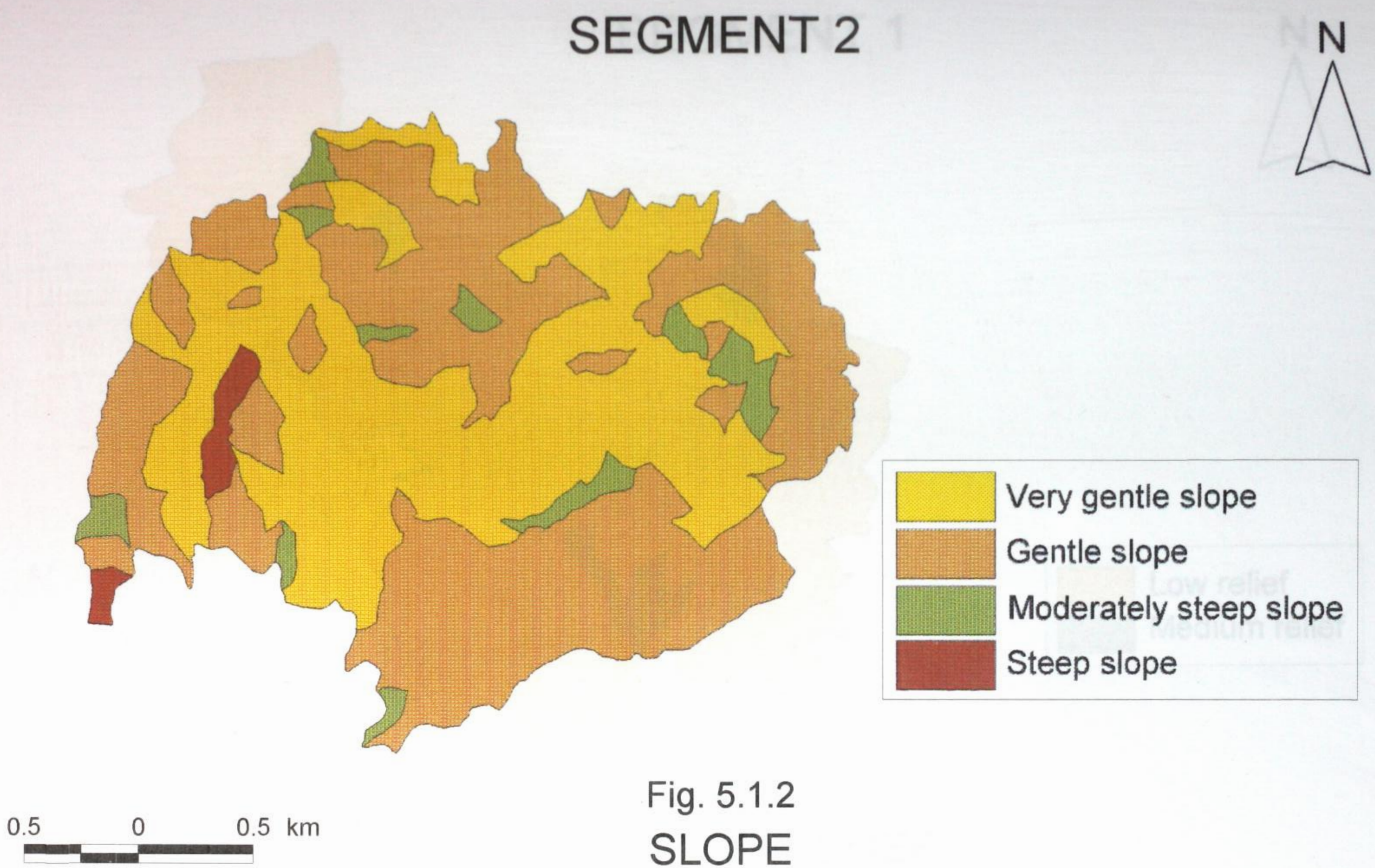


Fig. 5.1.2
SLOPE

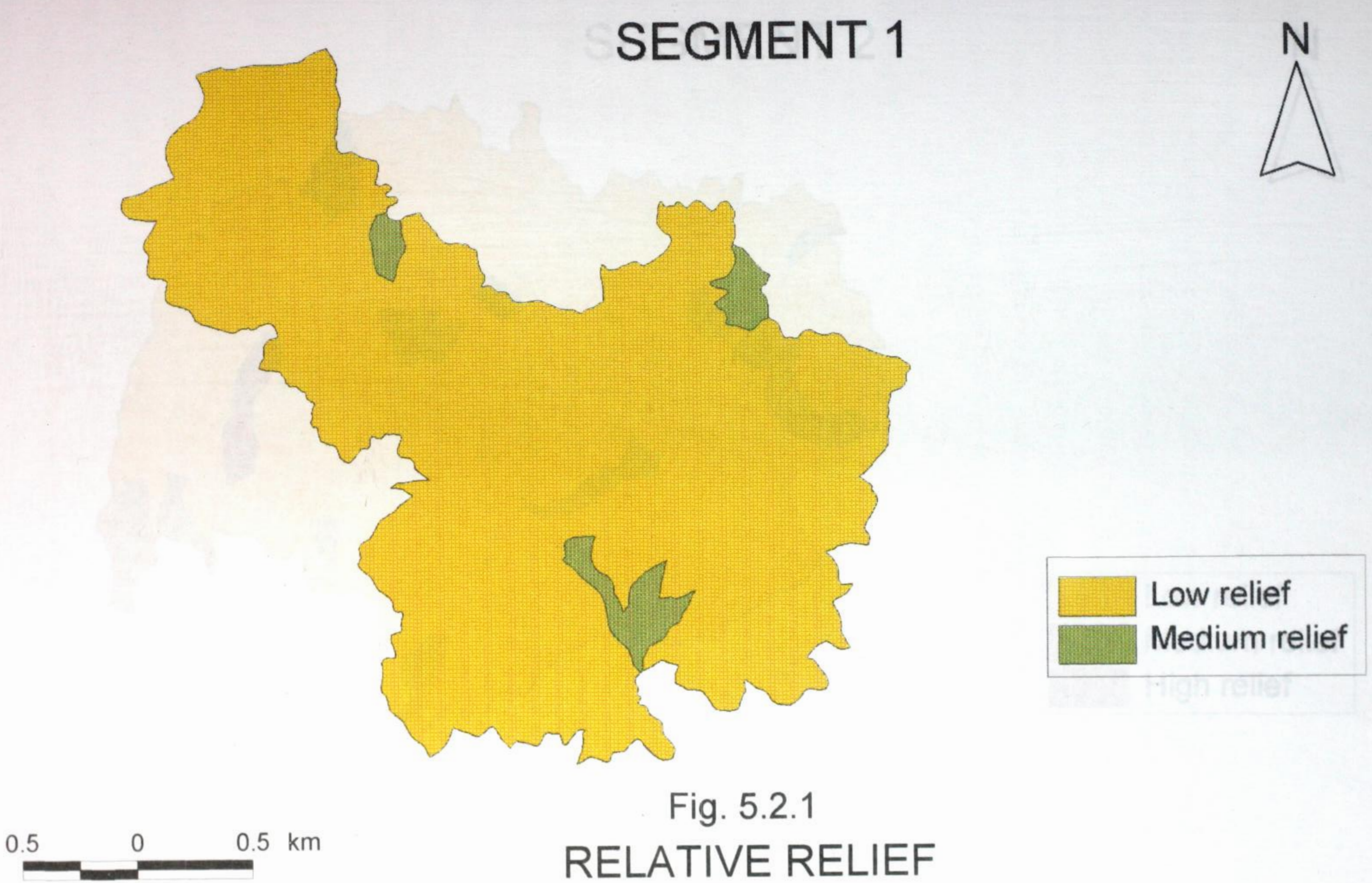


Fig. 5.2.1
RELATIVE RELIEF

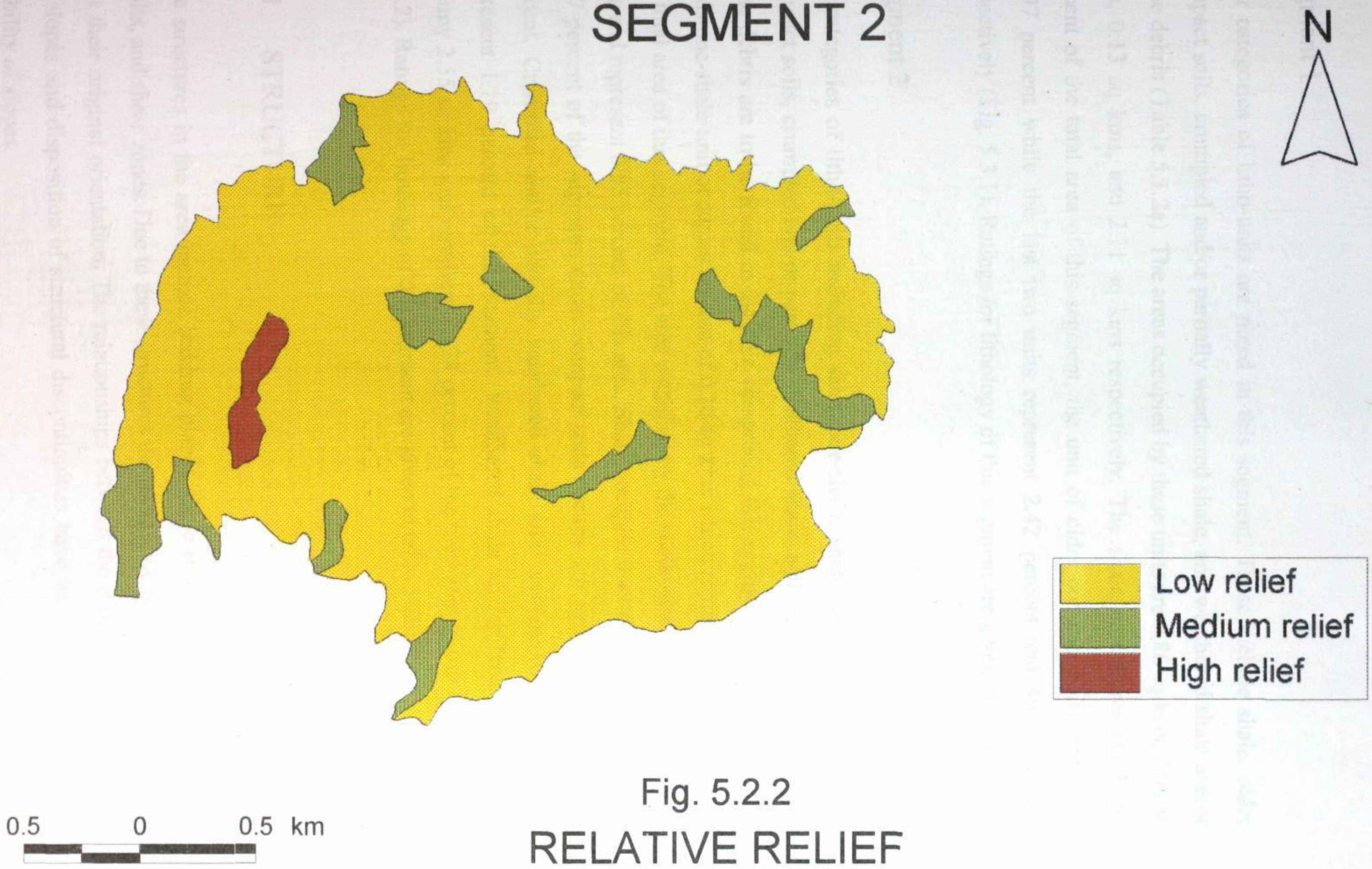


Fig. 5.2.2
RELATIVE RELIEF

5.3 LITHOLOGY

Segment 1

Four categories of litho-units are noted in this segment. These include shale, older compact soils, crumpled and/or partially weathered shale, and weathered shale and/or loose debris (Table 5.1.2a). The areas occupied by these units are 0.86 sq kms, 2.06 sq kms, 0.13 sq kms, and 2.11 sq kms respectively. The shale unit represents 16.67 percent of the total area of this segment; the unit of older compact soils represents 39.97 percent while the last two units represent 2.42 percent and 40.94 percent respectively (Fig. 5.3.1). Ratings for lithology of this segment are given in table 5.2a.

Segment 2

Six categories of litho-units including sandstone-shale, shale-sandstone, shale, older compact soils, crumpled and/or partially weathered shale, and weathered shale and/or loose debris are to be found in the area comprising this segment (Table 5.1.2b). The sandstone-shale unit occupies an area of 0.16 sq kms which represents 2.66 percent of the total area of this segment. The area occupied by the shale-sandstone unit is 0.05 sq kms and represent 0.85 percent of this area. Shale occupies 0.47 sq kms and represents 7.97 percent of the segment. Older compact soils occupy 2.6 sq kms which is 44.09 percent. Crumpled and/or partially weathered shale units occupy 0.07 sq kms and represent 1.19 percent of this segment. Weathered shale and/or loose debris units occupy 2.55 sq kms and represent 43.24 percent of the total area of this segment (Fig. 5.3.2). Ratings for lithology of this segment are given in table 5.2b.

5.4 STRUCTURE

The structures in the area include bedding planes, three to four sets of joints, folds, faults, and shear zones. Due to these structures the rocks have become fragile and have lost their original orientation. The relationships between the direction and inclination of slopes and disposition of structural discontinuities have important bearing on the stability of slopes.

TABLE 5.1.2a

Lithology & Land use/Land cover

SEGMENT 1

Facet No	Lithologic units	Land use & Land cover categories
1	Soil and rock debris	Settlement
2	Soil and rock debris	Settlement
3	Soil and rock debris	Settlement
4	Soil and rock debris	Vegetation
5	Soil and rock debris	Settlement
6	Soil and rock debris	Settlement
7	Soil and rock debris	Settlement
8	Soil and rock debris	Settlement
9	Soil and rock debris	Settlement
10	Soil and rock debris	Settlement
11	Soil and rock debris	Settlement
12	Soil and rock debris	Settlement
13	Soil and rock debris	Settlement
14	Soil and rock debris	Settlement
15	Shale	Settlement
16	Shale	Settlement
17	Shale	Settlement
18	Soil and rock debris	Settlement
19	Soil and rock debris	Vegetation and settlement
20	Soil and rock debris	Vegetation and settlement
21	Soil and rock debris	Settlement
22	Shale	Settlement
23	Clay	Settlement
24	Shale	Settlement
25	Shale	Settlement
26	Soil and rock debris	Settlement
27	Soil and rock debris	Settlement
28	Soil and rock debris	Settlement
29	Soil and rock debris	Settlement
30	Soil and rock debris	Settlement
31	Soil and rock debris	Vegetation and settlement
32	Soil and rock debris	Vegetation and settlement
33	Soil and rock debris	Settlement
34	Shale	Settlement
35	Soil and rock debris	Vegetation and settlement
36	Soil and rock debris	Vegetation and settlement
37	Shale	Settlement
38	Shale	Settlement

39	Shale	Settlement
40	Soil and rock debris	Settlement
41	Shale	Settlement
42	Shale	Settlement
43	Soil and rock debris	Settlement
44	Soil and rock debris	Settlement
45	Soil and rock debris	Settlement
46	Soil and rock debris	Settlement and vegetation
47	Soil and rock debris	Settlement
48	Soil and rock debris	Settlement
49	Shale	Settlement
50	Shale	Settlement
51	Soil and rock debris	Settlement
52	Shale	Settlement
53	Shale	Settlement and vegetation
54	Crumpled and partially weathered shale	Settlement
55	Crumpled and partially weathered shale	Settlement
56	Soil and rock debris	Settlement
57	Soil and rock debris	Settlement
58	Shale	Settlement
59	Soil and rock debris	Settlement and vegetation
60	Shale	Settlement and vegetation
61	Soil and rock debris	Vegetation
62	Soil and rock debris	Vegetation
63	Soil and rock debris	Settlement
64	Soil and rock debris	Settlement
65	Soil and rock debris	Settlement
66	Shale	Settlement
67	Shale	Settlement and vegetation
68	Shale	Settlement and vegetation
69	Soil and rock debris	Vegetation
70	Soil and rock debris	Settlement
71	Soil and rock debris	Settlement
72	Soil and rock debris	Settlement and vegetation
73	Soil and rock debris	Vegetation
74	Soil and rock debris	Vegetation
75	Soil and rock debris	Settlement
76	Soil and rock debris	Settlement
77	Soil and rock debris	Vegetation
78	Shale	Settlement and vegetation
79	Soil and rock debris	Settlement and vegetation
80	Shale	Vegetation and settlement
81	Soil and rock debris	Vegetation and settlement
82	Crumpled and partially weathered shale	Vegetation
83	Shale	Vegetation and settlement
84	Crumpled and partially weathered shale	Vegetation
85	Shale	Settlement
86	Soil and rock debris	Settlement

87	Soil and rock debris	Settlement
88	Soil and rock debris	Settlement and vegetation
89	Soil and rock debris	Settlement
90	Shale	Settlement
91	Soil and rock debris	Settlement
92	Shale	Settlement
93	Shale	Settlement
94	Soil and rock debris	Settlement
95	Soil and rock debris	Settlement
96	Soil and rock debris	Settlement
97	Soil and rock debris	Settlement
98	Soil and rock debris	Vegetation
99	Soil and rock debris	Settlement
100	Soil and rock debris	Settlement
101	Soil and rock debris	Settlement
102	Soil and rock debris	Barren land and settlement
103	Soil and rock debris	Settlement
104	Soil and rock debris	Settlement
105	Soil and rock debris	Settlement
106	Soil and rock debris	Settlement and vegetation
107	Soil and rock debris	Settlement
108	Soil and rock debris	Settlement
109	Soil and rock debris	Settlement
110	Shale	Settlement
111	Soil and rock debris	Settlement
112	Soil and rock debris	Vegetation
113	Soil and rock debris	Vegetation and settlement
114	Crumpled and partially weathered shale	Vegetation and settlement
115	Shale	Settlement
116	Soil and rock debris	Vegetation and settlement
117	Clay	Vegetation and settlement
118	Soil and rock debris	Vegetation and settlement
119	Soil and rock debris	Settlement
120	Shale	Settlement
121	Soil and rock debris	Settlement
122	Shale	Settlement
123	Crumpled and partially weathered shale	Settlement
124	Soil and rock debris	Settlement
125	Soil and rock debris	Settlement and vegetation
126	Crumpled and partially weathered shale	Settlement
127	Soil and rock debris	Settlement
128	Soil and rock debris	Settlement
129	Soil and rock debris	Settlement
130	Soil and rock debris	Settlement
131	Soil and rock debris	Settlement
132	Soil and rock debris	Settlement
133	Soil and rock debris	Vegetation and settlement
134	Soil and rock debris	Vegetation and settlement

135	Soil and rock debris	Vegetation and settlement
136	Soil and rock debris	Settlement
137	Soil and rock debris	Vegetation and settlement
138	Soil and rock debris	Settlement and vegetation
139	Shale	Settlement and vegetation
140	Soil and rock debris	Shrub and settlement

TABLE 5.1.2b

Lithology & Land use/Land cover

SEGMENT 2

Facet No	Lithologic units	Land use & Land cover categories
141	Soil and rock debris	Vegetation and settlement
142	Soil and rock debris	Vegetation
143	Soil and rock debris	Settlement
144	Shale	Settlement and vegetation
145	Shale and sandstone	Vegetation
146	Soil and rock debris	Settlement
147	Soil and rock debris	Settlement
148	Soil and rock debris	Settlement
149	Soil and rock debris	Settlement
150	Soil and rock debris	Settlement
151	Soil and rock debris	Settlement
152	Soil and rock debris	Settlement
153	Soil and rock debris	Settlement
154	Soil and rock debris	Settlement
155	Soil and rock debris	Shrub
156	Soil and rock debris	Shrub
157	Soil and rock debris	Settlement
158	Soil and rock debris	Barren land and settlement
159	Soil and rock debris	Settlement and shrub
160	Soil and rock debris	Settlement and shrub
161	Soil and rock debris	Settlement and shrub
162	Soil and rock debris	Settlement and shrub
163	Soil and rock debris	Settlement and shrub
164	Soil and rock debris	Settlement and shrub
165	Soil and rock debris	Settlement and shrub
166	Soil and rock debris	Shrub
167	Soil and rock debris	Shrub
168	Soil and rock debris	Settlement and shrub
169	Soil and rock debris	Shrub
170	Soil and rock debris	Vegetation
171	Soil and rock debris	Shrub
172	Soil and rock debris	Shrub
173	Soil and rock debris	Settlement and shrub
174	Soil and rock debris	Settlement
175	Soil and rock debris	Settlement
176	Shale	Settlement
177	Soil and rock debris	Settlement and shrub
178	Soil and rock debris	Cultivated land and settlement

179	Shale	Cultivated land and settlement
180	Soil and rock debris	Settlement and cultivated land
181	Clay	Settlement and vegetation
182	Soil and rock debris	Settlement
183	Shale	Settlement
184	Soil and rock debris	Settlement
185	Soil and rock debris	Settlement
186	Soil and rock debris	Settlement
187	Soil and rock debris	Settlement
188	Soil and rock debris	Vegetation
189	Soil and rock debris	Vegetation and settlement
190	Soil and rock debris	Vegetation and settlement
191	Shale	Shrub
192	Shale	Settlement and shrub
193	Shale and sandstone	Settlement
194	Shale and sandstone	Settlement
195	Shale	Vegetation and settlement
196	Soil and rock debris	Vegetation
197	Shale	Vegetation and settlement
198	Clay	Cultivated land and settlement
199	Clay	Settlement
200	Soil and rock debris	Settlement
201	Soil and rock debris	Settlement
202	Soil and rock debris	Settlement
203	Shale	Settlement
204	Soil and rock debris	Settlement
205	Soil and rock debris	Settlement
206	Soil and rock debris	Settlement
207	Soil and rock debris	Settlement
208	Soil and rock debris	Settlement
209	Soil and rock debris	Cultivated land
210	Soil and rock debris	Vegetation and settlement
211	Soil and rock debris	Settlement and cultivated land
212	Soil and rock debris	Cultivated land
213	Soil and rock debris	Settlement and vegetation
214	Soil and rock debris	Settlement
215	Soil and rock debris	Settlement and vegetation
216	Crumpled and partially weathered shale	Vegetation and settlement
217	Shale	Settlement
218	Soil and rock debris	Settlement
219	Soil and rock debris	Settlement
220	Shale	Settlement
221	Shale	Settlement
222	Shale	Settlement
223	Soil and rock debris	Settlement
224	Soil and rock debris	Settlement
225	Soil and rock debris	Settlement
226	Soil and rock debris	Settlement

227	Soil and rock debris	Settlement
228	Soil and rock debris	Settlement
229	Soil and rock debris	Settlement
230	Soil and rock debris	Cultivated land
231	Soil and rock debris	Settlement
232	Soil and rock debris	Settlement and shrub
233	Shale	Settlement
234	Clay	Settlement
235	Shale	Cultivated land and settlement
236	Soil and rock debris	Vegetation and settlement
237	Soil and rock debris	Vegetation and settlement
238	Soil and rock debris	Settlement and vegetation
239	Soil and rock debris	Settlement
240	Shale	Settlement and cultivated land
241	Soil and rock debris	Settlement
242	Soil and rock debris	Settlement
243	Soil and rock debris	Settlement
244	Soil and rock debris	Settlement and vegetation
245	Soil and rock debris	Settlement
246	Shale	Settlement
247	Soil and rock debris	Settlement
248	Soil and rock debris	Settlement
249	Soil and rock debris	Settlement
250	Soil and rock debris	Settlement
251	Soil and rock debris	Settlement
252	Shale	Settlement
253	Soil and rock debris	Settlement
254	Shale	Settlement
255	Shale and sandstone	Settlement
256	Sandstone and shale	Cultivated land and settlement
257	Sandstone and shale	Cultivated land and settlement
258	Soil and rock debris	Settlement and shrub
259	Soil and rock debris	Settlement and shrub
260	Soil and rock debris	Settlement and shrub
261	Shale	Settlement and shrub
262	Soil and rock debris	Vegetation and settlement
263	Soil and rock debris	Settlement
264	Shale	Settlement
265	Shale	Settlement
266	Shale	Settlement
267	Soil and rock debris	Settlement
268	Shale	Settlement
269	Soil and rock debris	Settlement
270	Crumpled and partially weathered shale	Settlement and vegetation
271	Soil and rock debris	Settlement and vegetation
272	Soil and rock debris	Shrub
273	Shale	Settlement and shrub
274	Soil and rock debris	Settlement

275	Soil and rock debris	Shrub
276	Soil and rock debris	Shrub
277	Soil and rock debris	Settlement
278	Soil and rock debris	Settlement
279	Soil and rock debris	Settlement and vegetation
280	Sandstone and shale	Settlement and vegetation
281	Shale	Vegetation and settlement
282	Soil and rock debris	Settlement and vegetation
283	Soil and rock debris	Settlement and vegetation
284	Soil and rock debris	Settlement
285	Soil and rock debris	Settlement
286	Shale	Settlement and vegetation
287	Shale	Settlement
288	Soil and rock debris	Vegetation
289	Soil and rock debris	Vegetation
290	Soil and rock debris	Cultivated land and vegetation
291	Soil and rock debris	Vegetation
292	Soil and rock debris	Vegetation and settlement
293	Soil and rock debris	Vegetation
294	Soil and rock debris	Shrub and vegetation
295	Soil and rock debris	Vegetation and settlement
296	Clay	Settlement and vegetation
297	Shale	Settlement and vegetation
298	Sandstone and shale	Settlement and vegetation
299	Sandstone and shale	Settlement and vegetation
300	Clay	Shrub
301	Sandstone and shale	Vegetation
302	Sandstone and shale	Vegetation
303	Soil and rock debris	Shrub and settlement
304	Soil and rock debris	Vegetation
305	Soil and rock debris	Settlement
306	Shale	Settlement and cultivated land

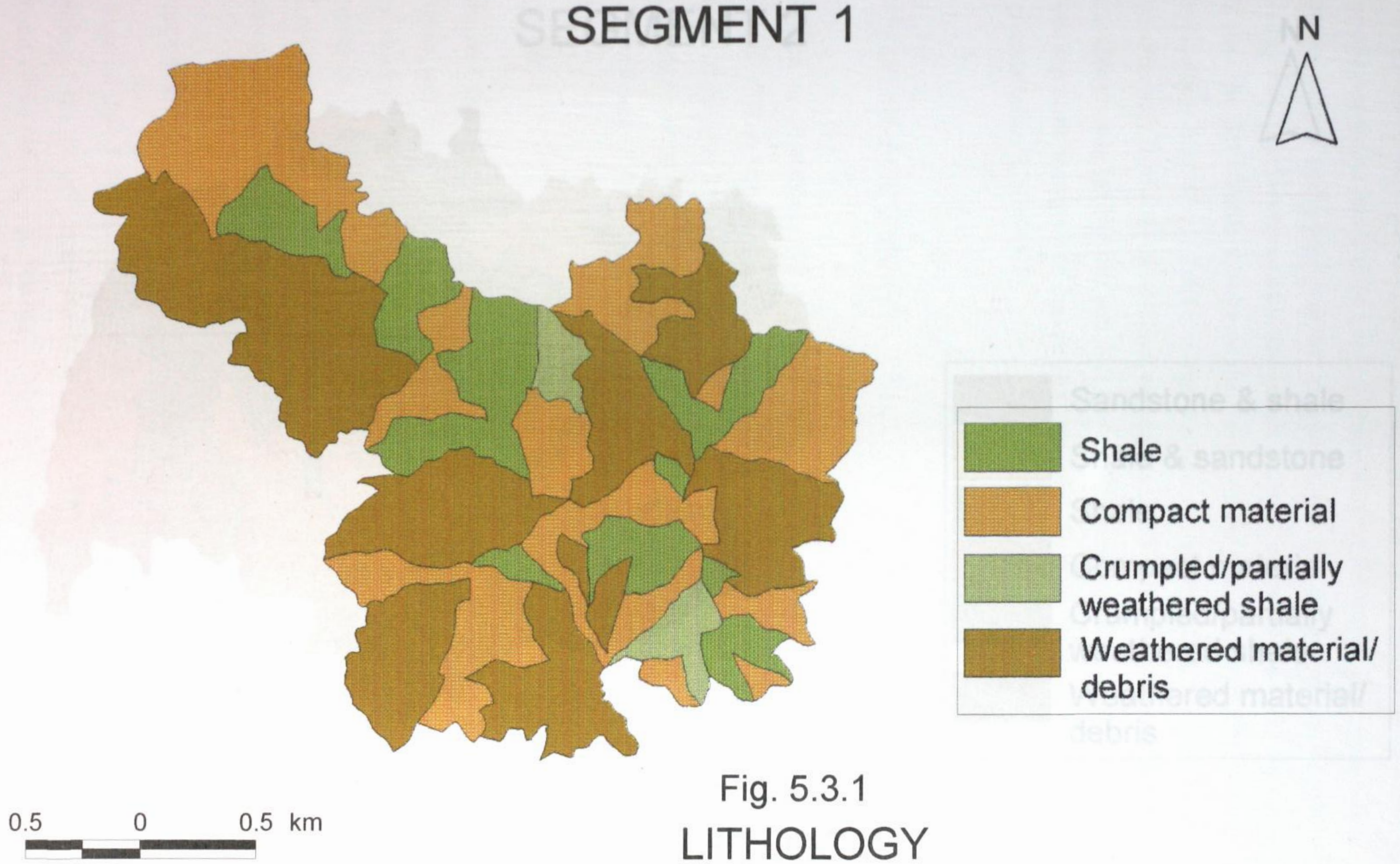


Fig. 5.3.1
LITHOLOGY

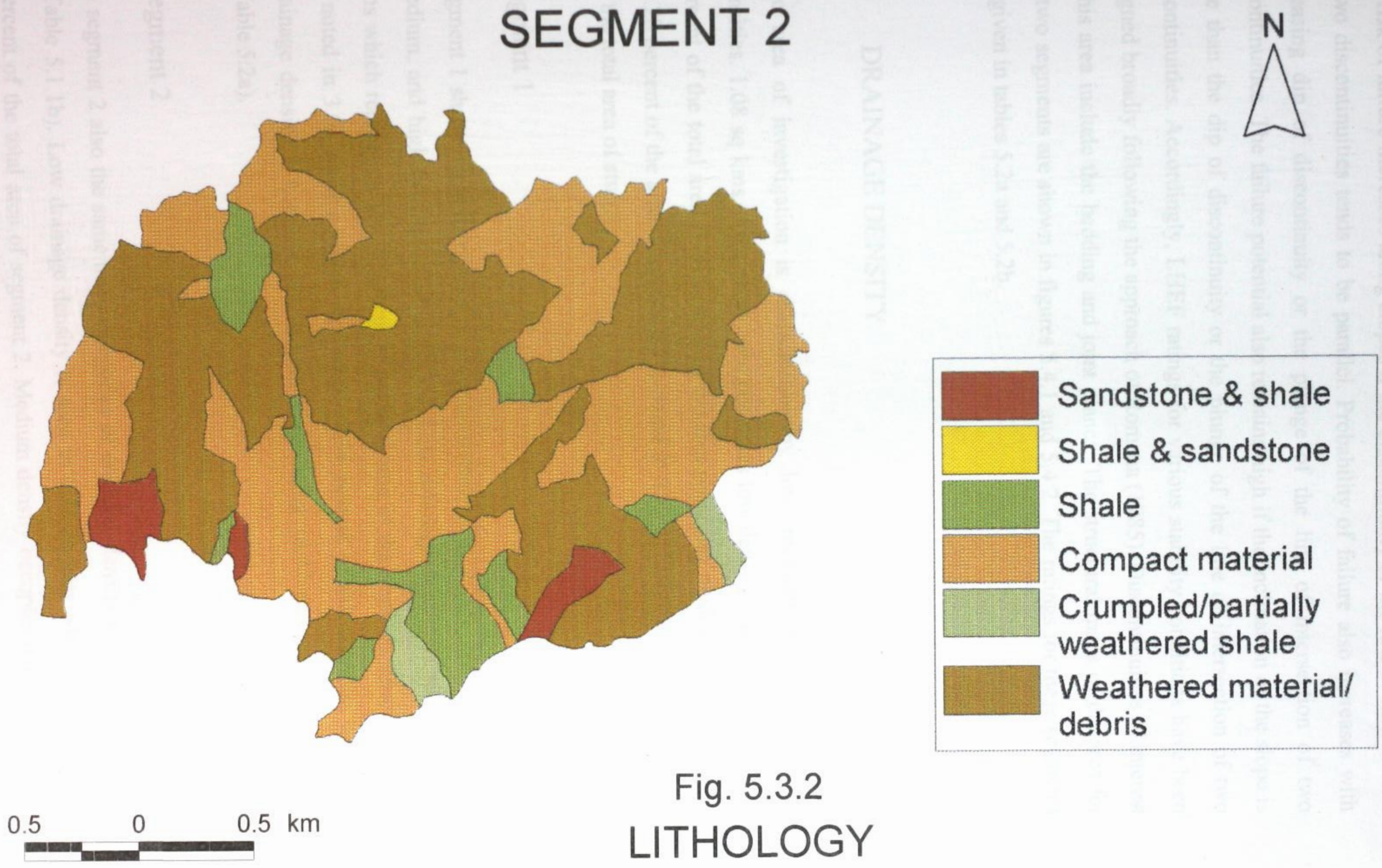


Fig. 5.3.2
LITHOLOGY

The risk of failure increases along slopes if the discontinuity or the line of intersection of two discontinuities tends to be parallel. Probability of failure also increases with increasing dip of discontinuity or the plunge of the line of intersection of two discontinuities. The failure potential also remains high if the inclination of the slope is more than the dip of discontinuity or the plunge of the line of intersection of two discontinuities. Accordingly, LHEF ratings for various stability conditions have been assigned broadly following the approach of Romana (1985). Discontinuities of interest in this area include the bedding and joint planes. The structural maps of the area for the two segments are shown in figures 5.4.1 and 5.4.2. The ratings for these segments are given in tables 5.2a and 5.2b.

5.5 DRAINAGE DENSITY

The area of investigation is characterised by low, medium, and high drainage densities. 1.08 sq kms of the study area possesses low density which represents 9.77 percent of the total area. 3.46 sq kms of the area possesses medium density which is 31.28 percent of the area. High density is noted in 6.52 sq kms which is 58.95 percent of the total area of study.

Segment 1

Segment 1 shows three categories of drainage density (Fig. 5.5.1). These include low, medium, and high densities (Table 5.1.1a). Low drainage density is seen in 0.85 sq kms which represents 16.47 percent of the total area of the segment. Medium density is noted in 3.01 sq kms which represents 58.34 percent of this segment while high drainage density is noted in 1.3 sq kms representing 16.47 percent of this segment (Table 5.2a).

Segment 2

In segment 2 also the same three categories of drainage density are noted (Fig. 5.5.2) (Table 5.1.1b). Low drainage density is seen in 0.23 sq kms which represents 3.90 percent of the total area of segment 2. Medium density occupies 0.45 sq kms which

SEGMENT 1

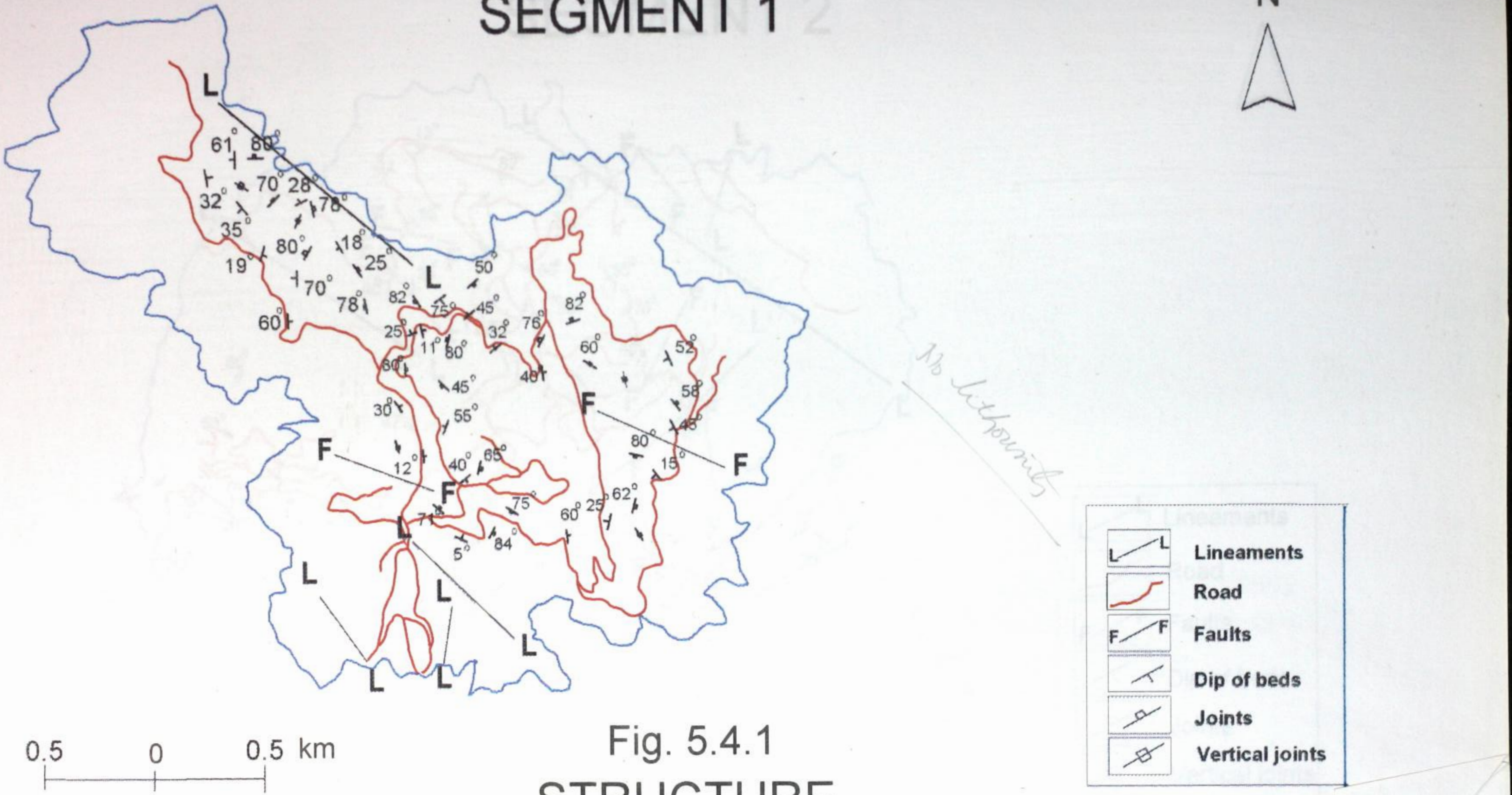
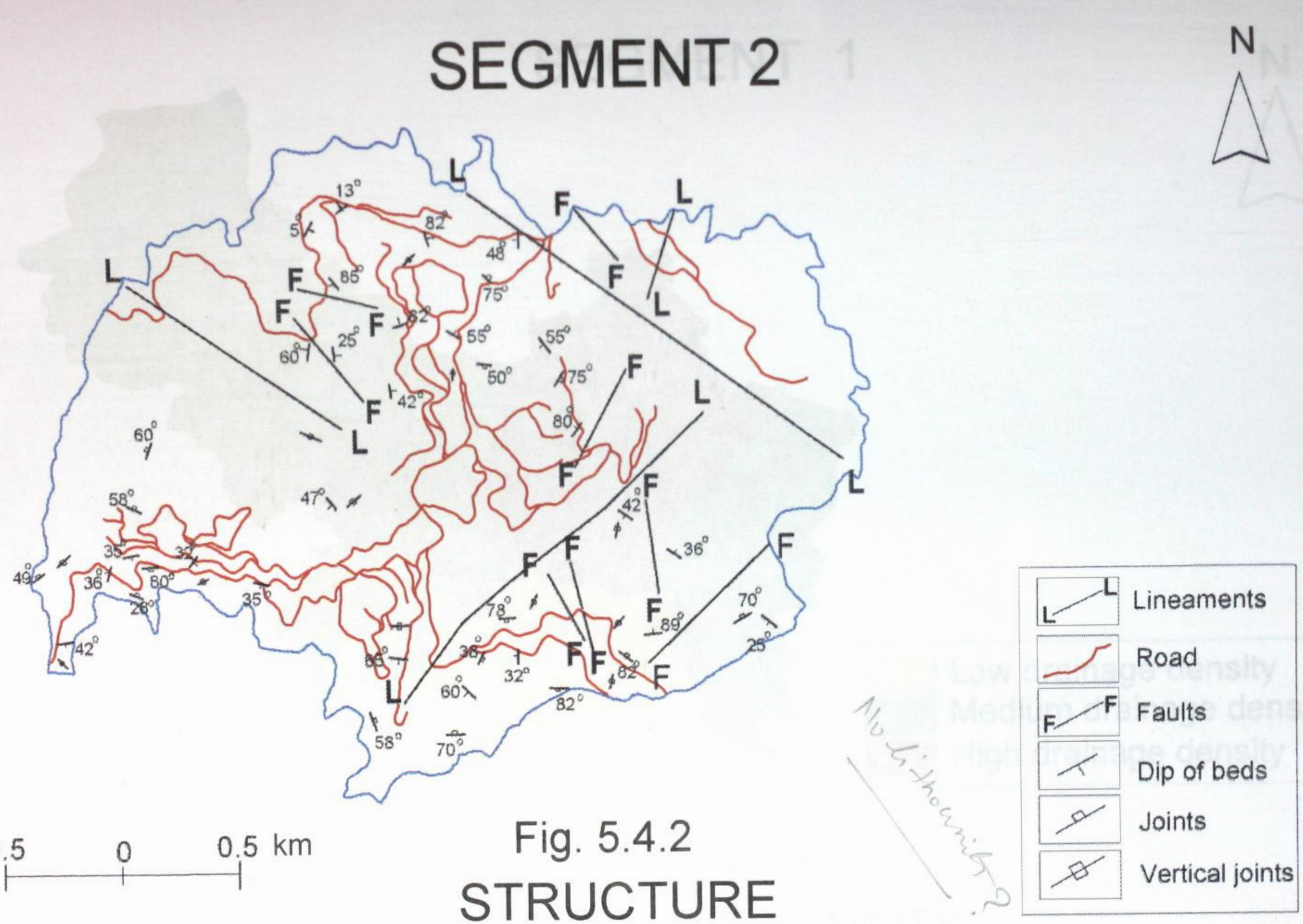


Fig. 5.4.1
STRUCTURE

SEGMENT 2



No lithounity?

Fig. 5.4.2
STRUCTURE

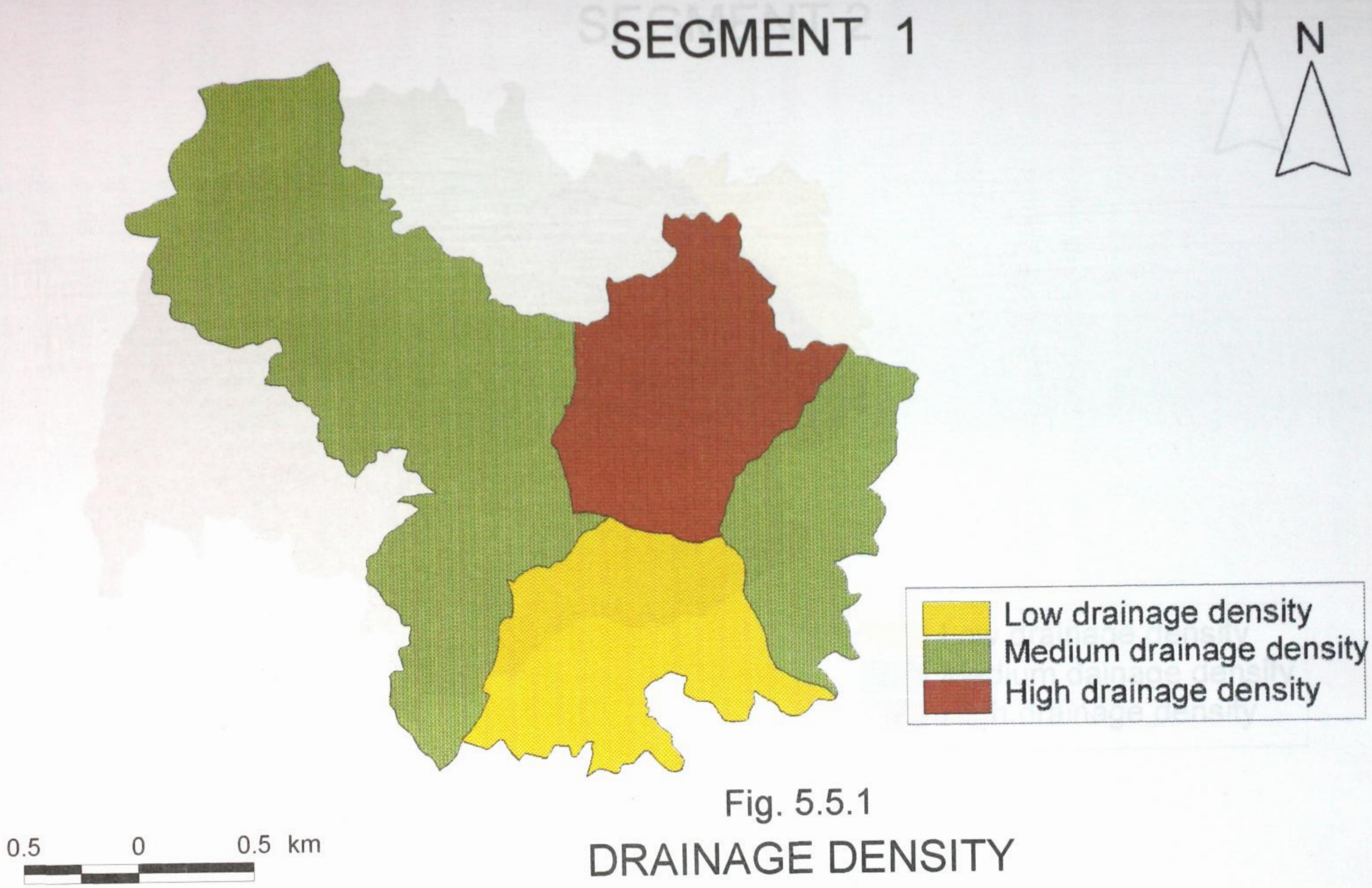


Fig. 5.5.1

DRAINAGE DENSITY

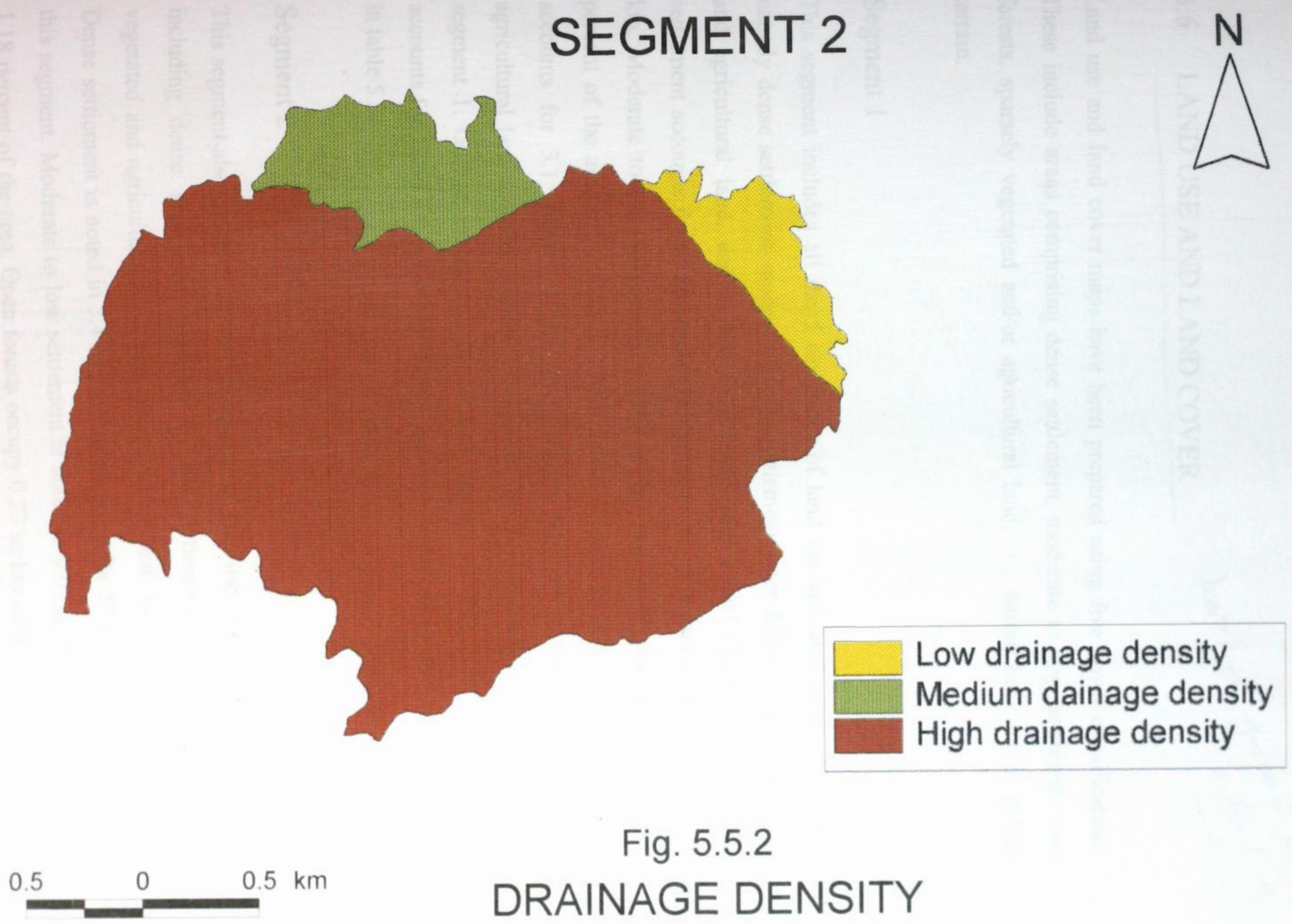


Fig. 5.5.2
DRAINAGE DENSITY

represents 7.63 percent of this segment. High drainage density is noted in 5.22 sq kms which represents 88.47 percent of segment 2 (Table 5.2b).

based on ground check what -?

5.6 LAND USE AND LAND COVER

Land use and land cover maps have been prepared using five broad classifications. These include areas comprising dense settlement, moderate to low settlement, open forests, sparsely vegetated and/or agricultural land, and barren land and/or gullied terrain.

Segment 1

This segment includes all the 5 categories of land use and land cover (Fig. 5.6.1) namely dense settlement, moderate to low settlement, open forest, sparsely vegetated and agricultural land, and gullied terrain and barren land (Table 5.1.2a). Dense settlement accounts for 62.98 percent of the total area of segment 1 which is 3.25 sq km. Moderate to low settlement is noted in 0.07 sq km which accounts for 1.36 percent of the area of segment 1. Open forests occupy an area of 0.16 sq km that accounts for 3.1 percent of the area of this segment. Sparsely vegetated and agricultural land together occupy 1.04 sq km which is 20.16 percent of the area of segment 1. Gullied terrain and barren land occupy an area of 0.64 sq km which accounts for 12.40 percent of the area of segment 1. Ratings for this segment is given in table 5.2a.

Segment 2

This segment also includes all the 5 categories of land use and land cover (Fig. 5.6.2) including dense settlement, moderate to low settlement, open forests, sparsely vegetated and agricultural land, and gullied terrain and barren land (Table 5.1.2b). Dense settlement is noted in 3.4 sq km that accounts for 57.63 percent of the area of this segment. Moderate to low settlement is noted in 0.07 sq km which accounts for 1.18 percent of the area. Open forests occupy 0.22 sq km of the area of this segment and accounts for 3.73 percent of the area. Sparsely vegetated and agricultural land

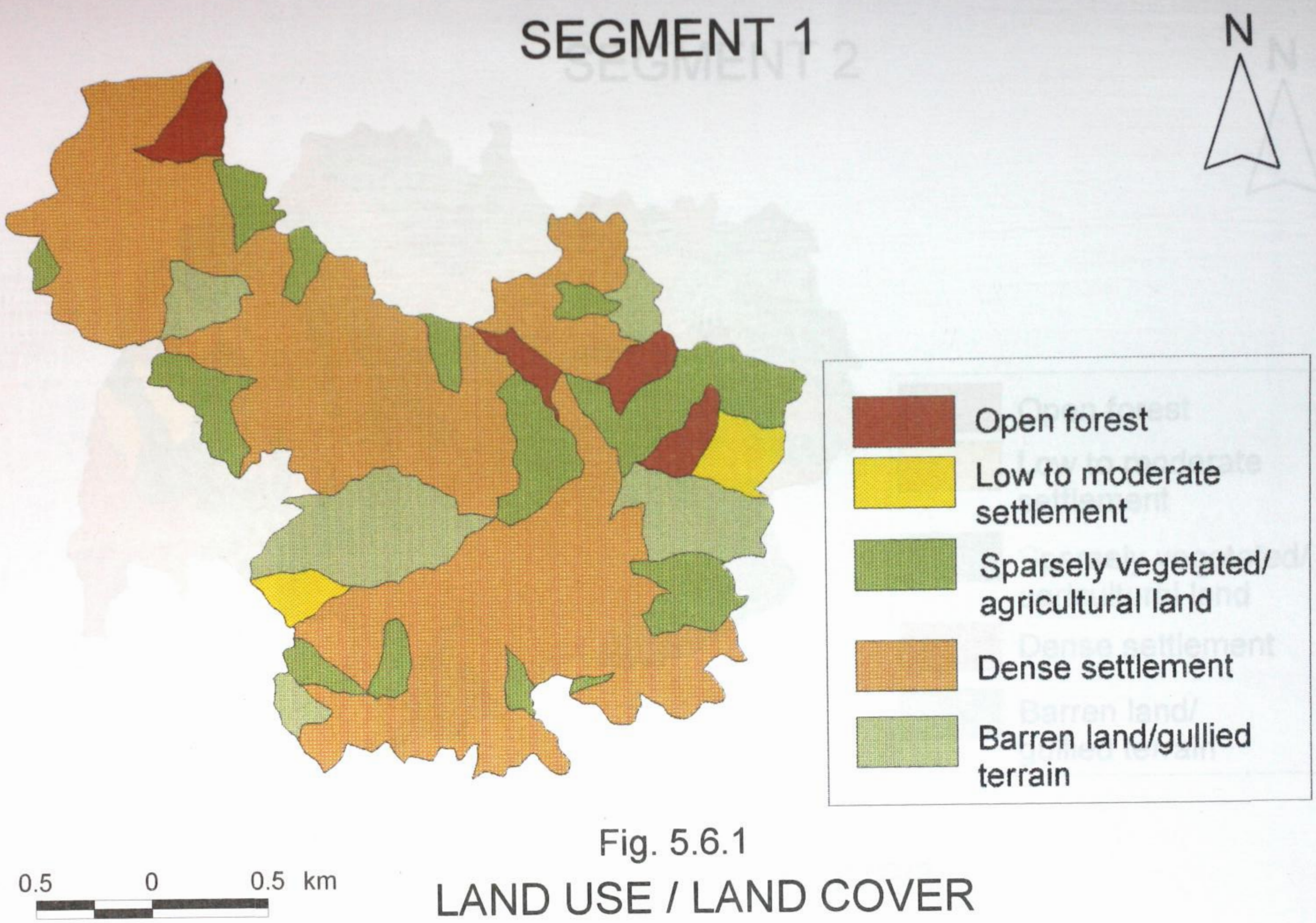


Fig. 5.6.1

LAND USE / LAND COVER

SEGMENT 2

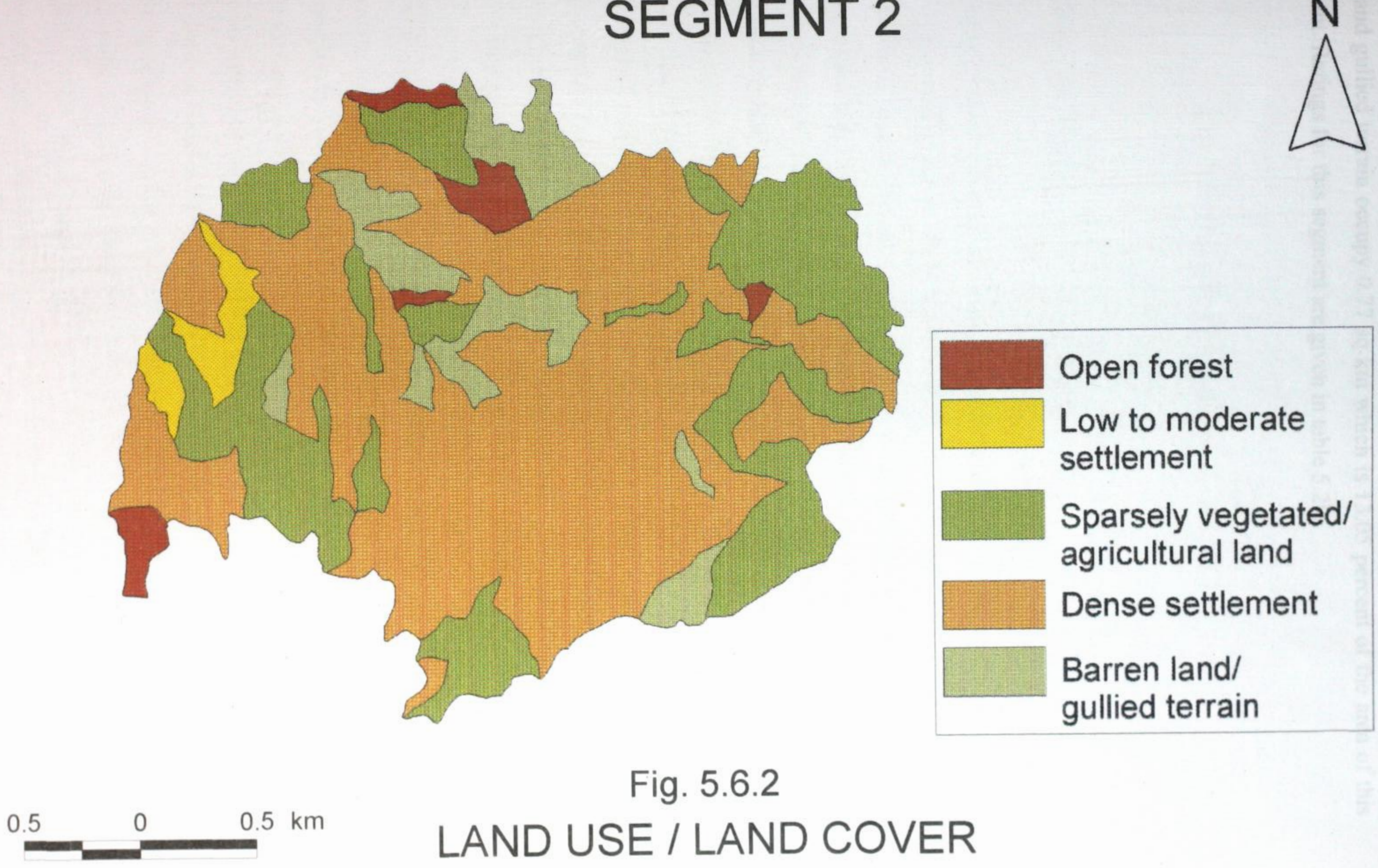


Fig. 5.6.2

LAND USE / LAND COVER

occupy 1.44 sq km. This accounts for 24.41 percent of the area of segment 2. Barren land and gullied terrain occupy 0.77 sq km which is 13.05 percent of the area of this segment. Ratings for this segment are given in table 5.2b.

CHAPTER 6

LANDSLIDE HAZARD ZONATION

INTRODUCTION

Landslide Hazard Zonation mapping has been attempted in different parts of the world for nearly three decades. It implies the identification of zones in a mountainous terrain having varying degree of proneness to landslides. Sharan (1995) states that LHZ maps are prepared to evaluate landslide susceptible zones. However, the prediction of mass wasting events in an area remains enigmatic, both in time and space. The present attempt at zonation mapping of Kohima Town takes into account the topography, lithology, structural details, geohydrology, and land use and land cover. The maps thus prepared are superimposed to provide essential data for the Landslide Hazard Zonation (LHZ) maps. Such maps are useful in that they provide data regarding stability of areas. Hence, high instability risks can be minimized or avoided. The Landslide Hazard Zonation map can play a significant role in minimizing loss to life and property and to give a boost to development.

Several workers, spanning nearly four decades, attempted Landslide Hazard Zonation by Cartographic methods. Today Remote Sensing and GIS with the help of computers have changed the scenario. Slope surfaces may be divided into different categories related to stability if the required information on terrain characteristics is available. Geological formations of different lithologic groups that are combined with slope categories, below and above the critical, have been used to prepare Landslide Hazard Zonation maps by Blanc and Cleveland (1968) for Southern California. The San Francisco Bay region was studied by Nilsen and Brabb (1972) using maps showing geological formations, slope ranges, and landslide debris to prepare a Landslide Zonation map. On the basis of percentage of outcrop area of a formation occupied by landslide debris in combination with slope categories Brabb et al (1972) have rated the slope stability of geological units in San Mateo County. Radbruch and Crowther (1973), in California, classified the area on the basis of lithology and the number of landslides present. In the United States, Radbruch et al (1976) considered the frequency of slope failure in different groups of geologic units. A similar grouping of lithology and mass movements was used by Rodriguez et al (1978) in southern Spain.

The ZERMOS method of hazard mapping adopted in France includes factors like lithology, structure, slope morphology, and hydrology where the mapped area is divided into four zones of different levels of hazards with types of movement and direction, activity, and sites of erosion that are noted using different symbols. Varnes (1980) prepared a Landslide Zonation map using slope, soil thickness, land use practice, and drainage as the basic factors. The type of rock fracturing, weathering characteristics, springs, vegetation, valley slopes, etc. were taken into account to describe methods for making Debris Flow Hazard maps (Takie, 1982). Hansen (1984) discussed two principal categories of Landslide Hazard mapping, namely direct and indirect mapping. Kawakami and Saito (1984) used valley density, elevation, slope angle, and formations for preparing a quantified landslide risk map. Brabb (1984) provided a useful review of development of Landslide Hazard mapping. Risk maps for road alignment using geologic, structural, slope, and geomorphologic factors was also prepared for rock and debris slide (Wagner et al, 1987). Koirala and Watkins (1988) described a slope ranking system mainly for adopting preventive measures during excavations. Fugita (1994) worked out the relationship of landslides with the geomorphologic and geological features of SW Japan.

In India too several workers have attempted LHZ mapping considering various factors of the terrain. Using numerical ratings of slope, land use, soil cover, and drainage, and depending on the frequency of landslides, Seshagiri and Badrinarayan (1982) carried out the zonation of the Nilgiri hills. Hazard Zonation studies were taken up during 1984 at four locations in North and East Sikkim (CRRI, 1989). On the basis of the nature and characteristics of the rock and soil materials the overall stability of the slope constituting the slope formation, the slope angle, condition of the slope surface, hydrological features, and toe erosion was assessed quantitatively. In this study the overall rating of slope stability was divided into three categories, viz., very good, good, and fair. Similarly Gupta and Joshi (1990), using a GIS approach, worked in the Himalayas where an index value was given to factors like land use, lithology, major tectonic features, and azimuth of landslides. Considering slope, lithology, structure, and earthquake epicentres a LHZ mapping was constructed in the Garhwal Himalayas (Choubey and Litoria, 1990). Mehrotra et al (1992) attempted an empirical approach for LHZ mapping based on a Landslide Susceptibility Index (LSI) using factors like lithology, slope angle, distance from major thrusts and faults, land use pattern, and drainage density in relation to frequency of existing landslides. Anbalagan (1992) carried out Landslide Hazard Zonation mapping of the Kathgodam-Nainital area in the Kumaon Himalayas. This was prepared based on slope, lithology, structure, relative relief, land use and land cover, and groundwater conditions. For preparation of the LHZ maps he proposed the Landslide Hazard Evaluation Factor (LHEF) rating scheme. This method is suitable for zonation mapping of mountainous terrain. The method involves demarcation of facets, preparation of thematic maps, estimation of LHEF ratings, calculation of Total Estimated Hazard (TEHD) values, and construction of Hazard Zonation maps of the area. Kohima Town is studied following Anbalagan (1992) and the recommendations of the DST (1994). However, difficulties exist in preparing Hazard Zonation maps. This is mainly due to the paucity of data on topography, climate, geology, hydrogeology, seismicity, and anthropogenic activity, and their components or variables (Thigale et al, 1998).

LANDSLIDE HAZARD ZONATION MAPPING

The Landslide Hazard Zonation maps of this area indicates that the area of investigation is made up of categories of land comprising low, moderate, high hazard, and very high hazard zones. The low hazard zones together cover an area of about 0.18 sq kms. This represents 1.63 percent of the total area of investigation. Medium hazard zones occupy an area of 5.28 sq km which represents 47.74 percent of the area while high hazard zones are noted in an area of 4.39 sq km, i.e., 39.69 percent of the total area. Very high hazard is noted in 1.21 sq kms that represents 10.94 percent of the area of investigation. Detailed Landslide Hazard Zonation mapping on closer domain may be carried out for the High Hazard and Very High Hazard zones to accurately assess the causative factors and evolve precautionary and mitigation measures.

Segment 1

Segment 1 is made up of categories including low hazard, moderate hazard, high hazard, and very high hazard zones (Fig. 6.1). Low hazard is noted in 0.1 sq kms which represents 1.94 percent of segment 1. Medium hazard zones are noted in 2.43 sq km that represents 47.1 percent of the segment while high hazard zones cover are noted in 2.17 sq km, i.e., 42.05 percent of the area. Very high hazard is noted in 0.46 sq kms, i.e., 8.91 percent of the area of segment 1. The different categories of hazard in relation to TEHD values for this segment are given in table 5.2a.

Segment 2

In segment 2 also the same four categories of hazard zones are identified (Fig. 6.2). Low hazard is noted in 0.08 sq kms, i.e., 1.36 percent of segment 2. Medium

zard zones to accurately assess the causative factors and evolve
nd mitigation measures.
nade up of categories including low hazard, moderate hazard, high
ry high hazard zones (Fig. 6.1). Low hazard is noted in 0.1 sq kms
nts 1.94 percent of segment 1. Medium hazard zones are noted in
at represents 47.1 percent of the segment while high hazard zones
d in 2.17 sq km, i.e., 42.05 percent of the area. Very high hazard is
sq kms, i.e., 8.91 percent of the area of segment 1. The different
azard in relation to TEHD values for this segment are given in table
lso the same four categories of hazard zones are identified (Fig. 6.2).
Zonation mapp
Very High Ha
precautionary a
Segment 1
Segment 1 is
hazard, and ve
which represe
2.43 sq km th
cover are note
noted in 0.46
categories of l
5.2a.
Segment 2
In segment 2

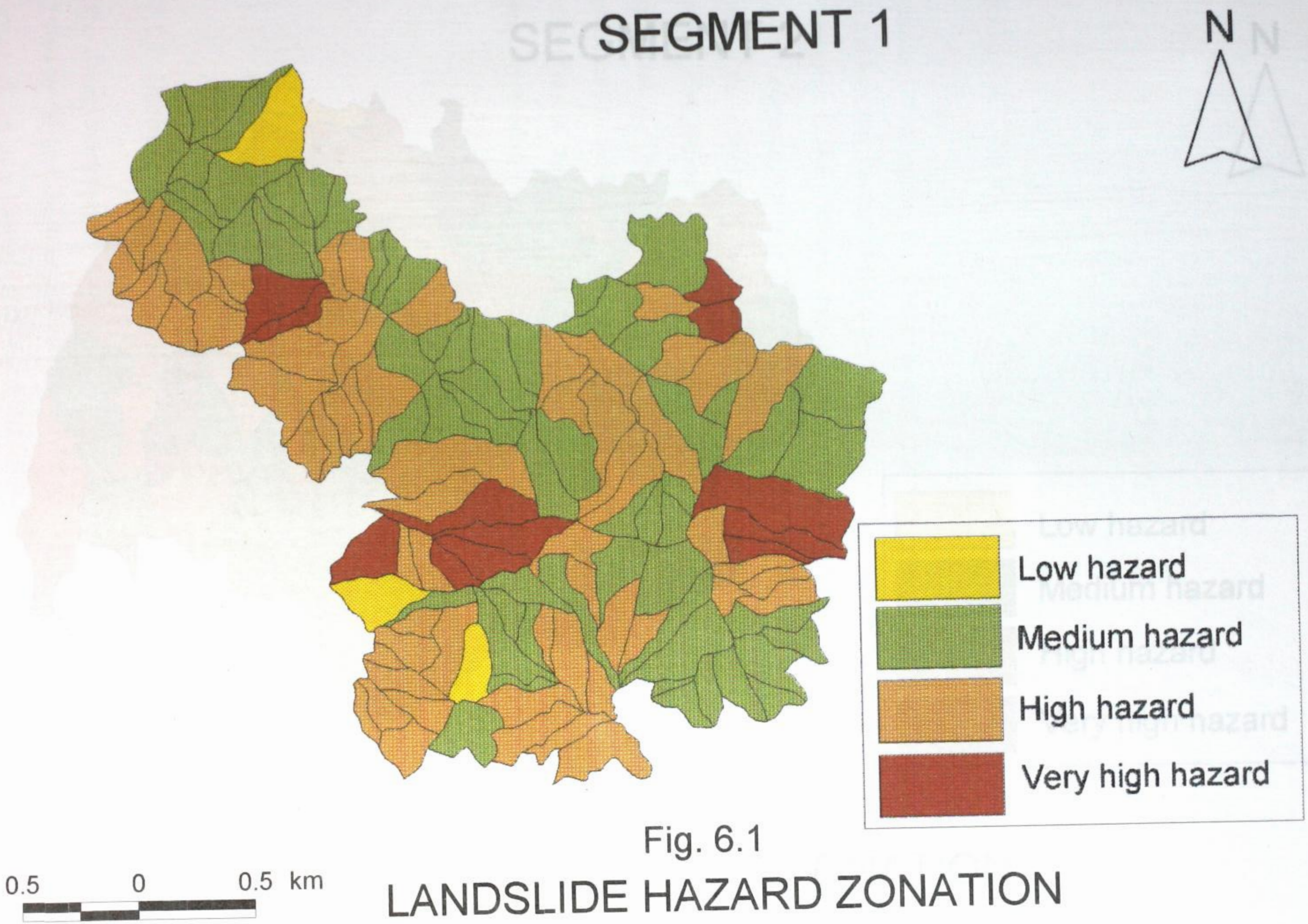


Fig. 6.1
LANDSLIDE HAZARD ZONATION

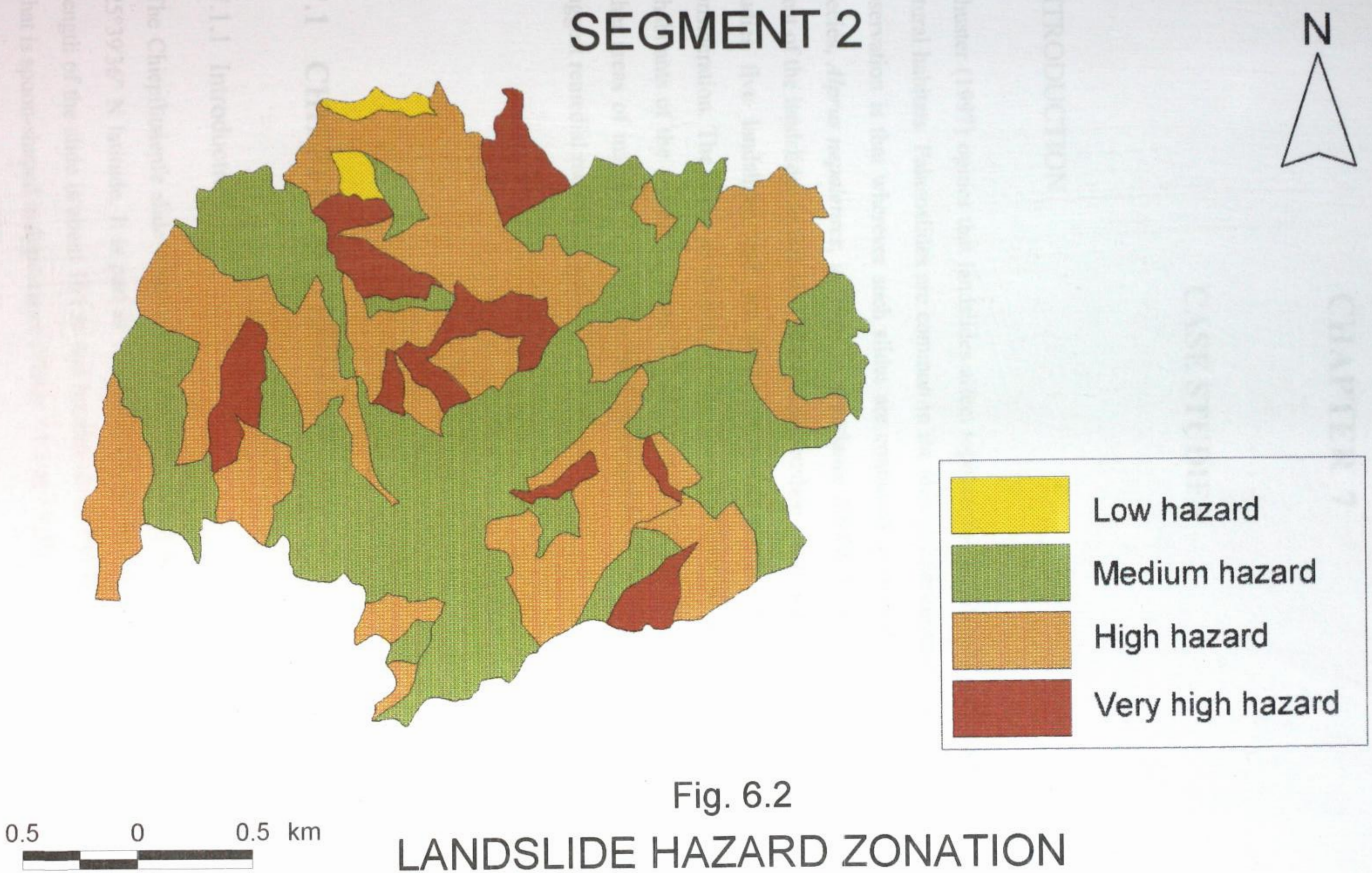


Fig. 6.2
LANDSLIDE HAZARD ZONATION

CHAPTER 7

CASE STUDIES

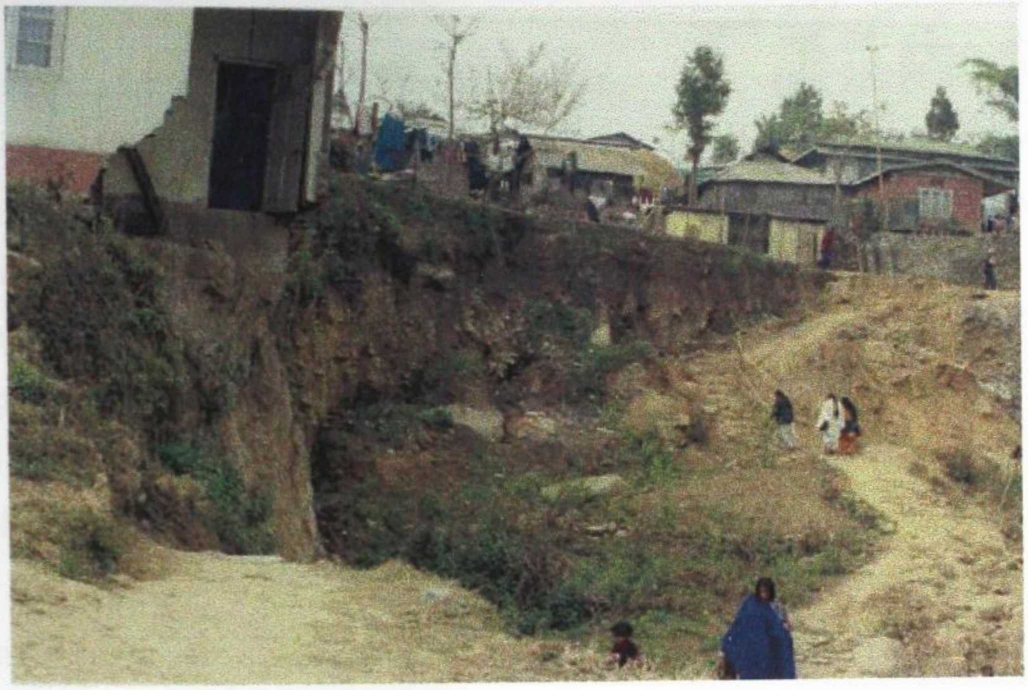
INTRODUCTION

Schuster (1997) opines that landslides affect topography, forests and grasslands, and natural habitats. Palaeoslides are common in the area of investigation. An interesting observation is that wherever such slides are contained or controlled, a certain plant species, *Alprus nepalenses*, is found in abundance (DGM, 1996). It is observed that most of the landslides in this area occur in palaeoslide zones. For purposes of detailed studies five landslides that are active or are potential threats are taken into consideration. The slides so chosen are also those that have left a deep impact on the inhabitants of the respective areas. In addition to the above five slides some of the other areas of instability have also been investigated to determine their causes and suggest remedial measures (Table 7).

7.1 CHIEPFÜTSIEPFE SLIDE

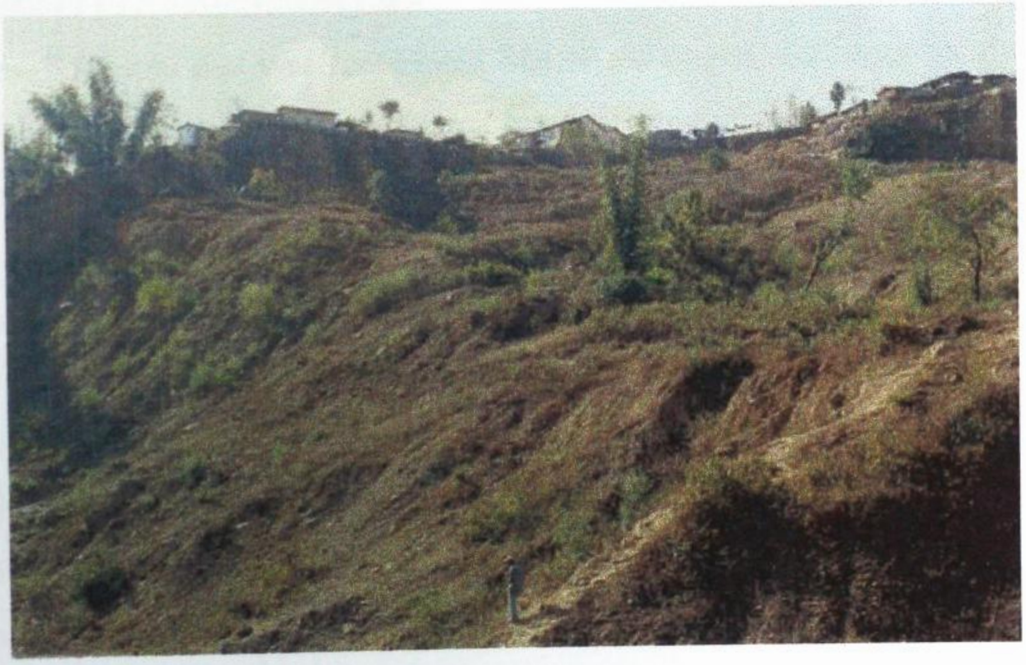
7.1.1 Introduction

The Chiepfütsiepfe slide occurred in July 1993. It lies at 94°07'00" E longitude and 25°39'36" N latitude. It is part of Toposheet no. 83 K/2 of the Survey of India. The length of the slide is about 165 m and breadth about 130 m. This is a rotational slide that is spoon-shaped in appearance (Plates 7.1.1 & 7.1.2).



Chiepfütsiepfe slide

Plate 7.1.1



Chiepfütsiepfe slide zone

Plate 7.1.2

7.1.2 Geology of the area

The rocks making up the area are the Disang Group of sediments that are regionally folded. They consist of dark gray splintery shale with thin bedded, fine grained sandstone and siltstone. The shale is highly susceptible to spheroidal weathering and disintegrates on exposure to air. The trend of the rocks is N-S to NE-SW with varying degrees of dips. The clays that are the products of weathering of the shale are highly plastic and expansive. The rocks are overlain by a thick layer of palaeoslide debris which may be more than thirty feet. This debris is a mixture of unsorted boulders, pebbles, gravel, and clay material.

7.1.3 Structure

A fault traversing the slide zone runs N40°W - S40°E and dips inclined towards the NE along and parallel to the stream Dzüna. This fault has displaced the rocks and sheared them to a great extent. Three sets of joints are noted.

7.1.4 Causes

This is a palaeoslide zone that was reactivated due to prolonged and heavy rainfall. Evidence for this palaeoslide is the presence of huge accumulations of rock and soil debris. The major cause of the slide is toe erosion by the Dzüna River. In the vicinity of this slide a fault is noted. The rocks are highly sheared due to this fault. Construction of heavy structures and other developmental activities have also added to the head load in the area. As this area is poor in vegetation, seepage of water is very high into this zone. This has allowed water to concentrate in the zone. Another problem in this area is the lack of proper drainage. Moreover, the overburden is very thick. This has led to the development of a very heavy load on the weak zone. All these factors have combined to aggravate the situation in this zone.

7.1.5 Effects

Due to this landslide the main street was totally damaged up to a length of 73 m. This put a permanent stop to vehicular movement which remains cut off till date. Pedestrians commute from one end of the former street to the other by a narrow footpath. Some concrete structures were also severely damaged leading to great loss to the inhabitants and government. Tensional cracks and fissures that have developed have also extended to more than fifty meters away from the affected zone (Fig. 7.1). Due to the development of these cracks and fissures many inhabitants were forced to vacate their houses. Tensional cracks in the vicinity of the slide zone and around the crown of the slide indicate future failure planes.

7.1.6 Previous works

As the immediate cause of this slide is toe erosion by the perennial Dzüna, the Directorate of Geology and Mining, Nagaland suggested straightening of the stream from its previous meandering course. The stream waters have been diverted through a box-cut which was the only viable solution for immediate relief. This action involved cutting through the thick and well bedded sandstones protruding towards the zone. Construction of a groyne at the slide toe with appropriate materials was another action that was executed. Some check dams have been constructed along the river bed to check excessive erosion.

7.1.7 Recommendations

Embankments should be erected further upslope to arrest movement. The most viable material for these embankments would be boulders locally available enmeshed in sausage wire that is firmly anchored into the bedrock. To prevent excessive erosion of the river bed in the nearby areas which may lead to reactivation of the slide, more check dams should be constructed around the existing check dams. As the area is poor in vegetation the surface is very susceptible to erosion. Hence surface run-off should not be allowed to percolate into the subsurface. Rather it should be trained out of the slide zone. To further fortify the area some varieties of grasses that are good soil binders should be planted in the area. To regulate surface run-off and prevent seepage, proper lined surface drains should be constructed. This category of runoff includes domestic and natural water from rainfall. Catch water drains should be constructed to intercept subsurface waters including seepages into the slide zone. Cracks and fractures developed in the slide zone and its periphery should be grouted or sealed off using mortar or asphalt. These measures will further reduce infiltration.

CHIEPFUTSIEPFE SLIDE

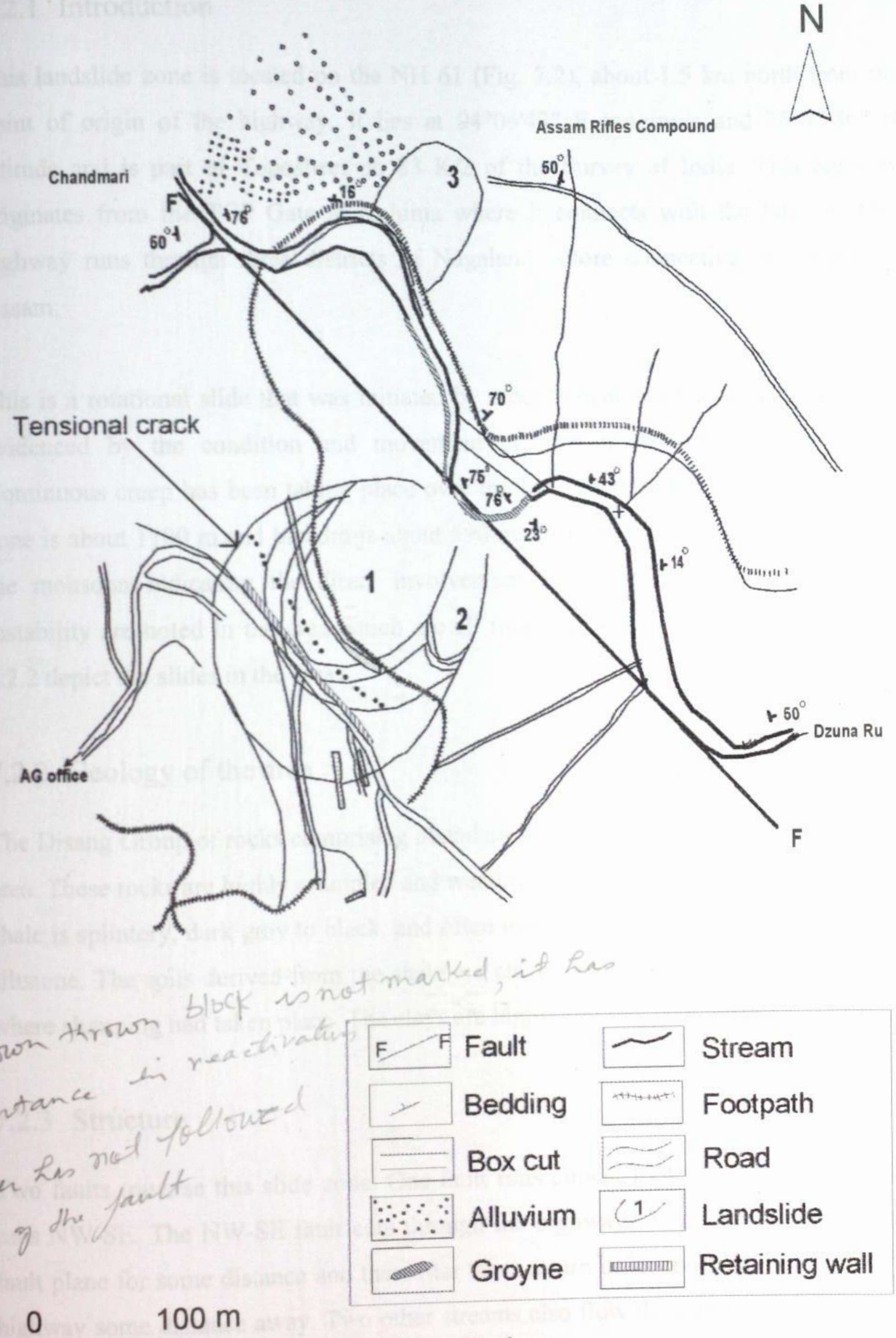


Fig. 7.1

1) up/down thrown block is not marked, it has importance in reactivating

2) the river has not followed the trace of the fault

7.2 KEZIEKIE SLIDE

7.2.1 Introduction

This landslide zone is located on the NH 61 (Fig. 7.2), about 1.5 km north from the point of origin of the highway. It lies at 94°06'43" E longitude and 25°40'36" N latitude and is part of Toposheet no 83 K/2 of the Survey of India. This highway originates from the TCP Gate at Kohima where it connects with the NH 39. This highway runs through three districts of Nagaland before connecting to Amguri of Assam.

This is a rotational slide that was initiated by creep. Local creep still continues as is evidenced by the condition and movement of man made structures and trees. Continuous creep has been taking place over the last few decades. The length of this zone is about 1100 m and breadth is about 590 m. Parts of this slide are active during the monsoon indicating the direct involvement of water. Three active areas of instability are noted in the area which are all rotational debris slides. Plates 7.2.1 & 7.2.2 depict the slides in the area.

7.2.2 Geology of the area

The Disang Group of rocks comprising abundant shale makes up the sediments of this area. These rocks are highly crumpled and weathered in addition to being sheared. The shale is splintery, dark gray to black, and often interbedded with minor sandstone and siltstone. The soils derived from the shale are clayey and mixed with rock fragments where slumping had taken place. The clays are highly plastic and expansive.

7.2.3 Structure

Two faults traverse this slide zone. One fault runs almost E-W while the other fault runs NW-SE. The NW-SE fault cuts through the highway. A stream runs along this fault plane for some distance and thereafter takes a turn in its course to cut across the highway some distance away. Two other streams also flow through this slide zone. A palaeoslide zone is noted in the northwestern portion of the present slide where it is cut by the NW-SE trending fault. As a result of faulting the rocks are highly crumpled

KEZIEKIE SLIDE

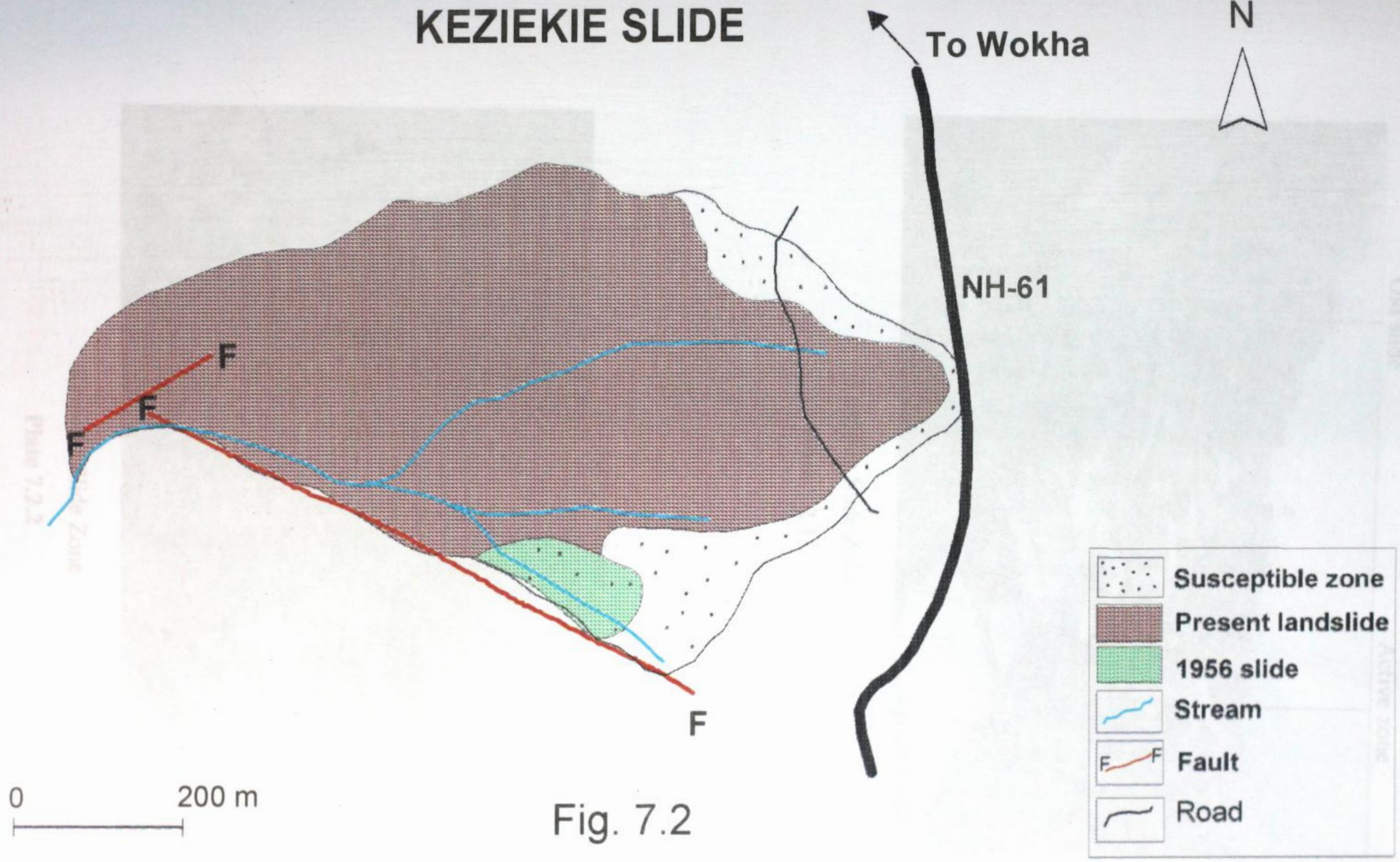
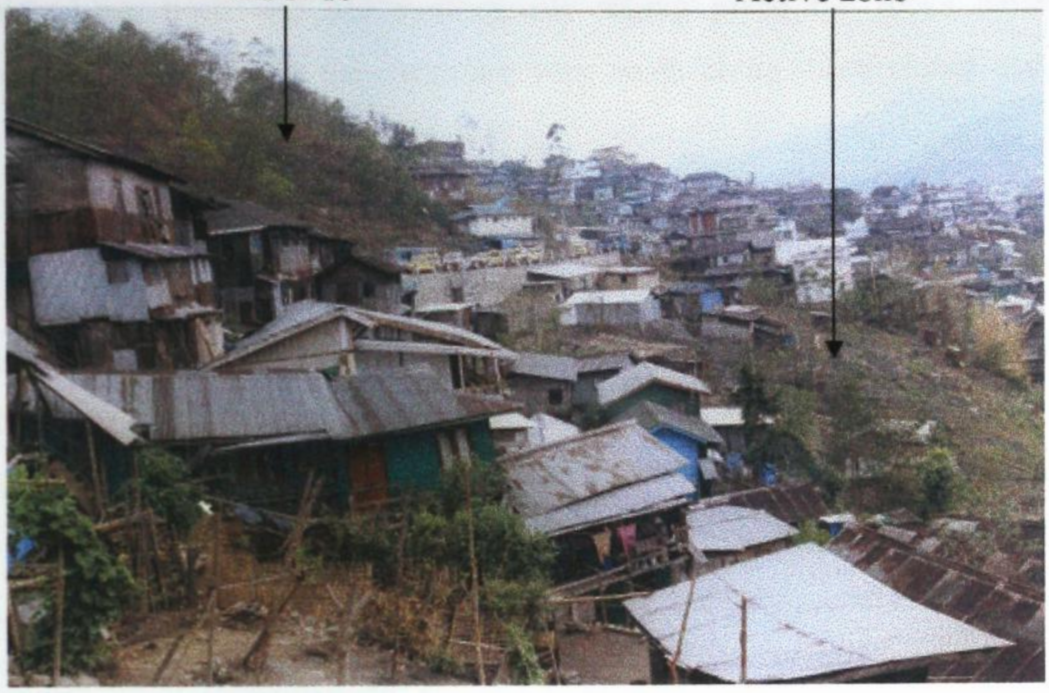
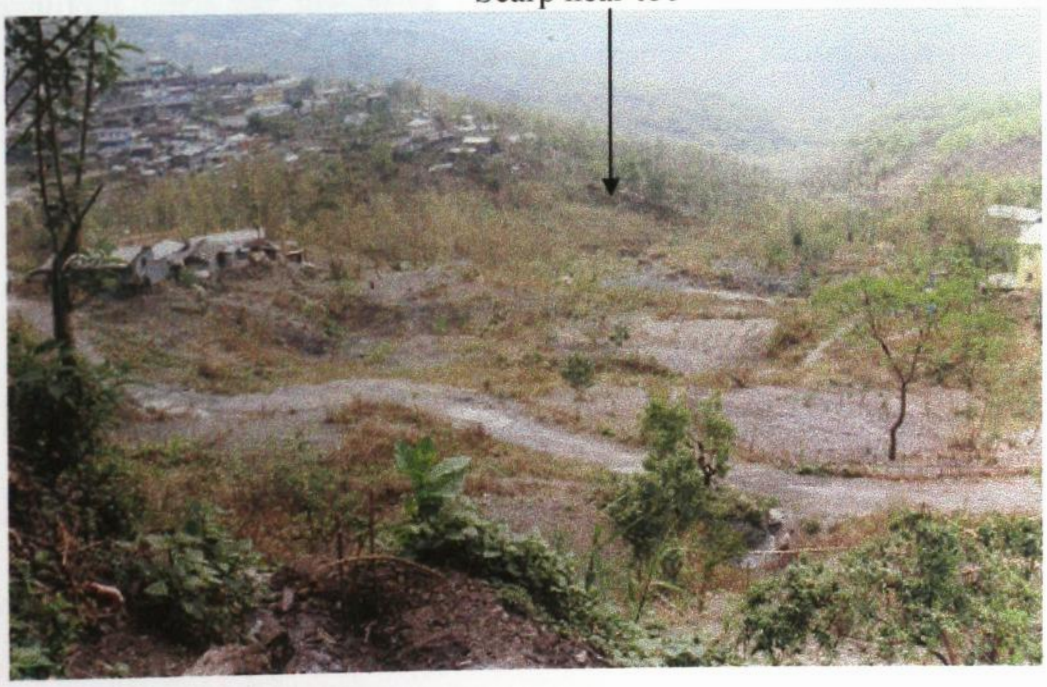


Fig. 7.2



Keziekie Slide Zone

Plate 7.2.1



Keziekie Slide Zone

Plate 7.2.2

and sheared. Three to four sets of joints are noted in the rocks of this area. Because mass movements have been and are continuously taking place the rocks have developed gaping fissures. Hence, the rocks are very weak along these planes and easily collapse.

7.2.4 Causes

The major cause of this slide is the lithology, structure, and high water concentration. Heavy rainfall triggered off the slide in this unstable area during the peak of monsoon. This area receives too much of rainfall which continues for many months due to which the ground gets totally saturated. The structures in this area include other lineaments besides faults, joints, and fissures. Satellite imageries of the area clearly show the disposition of the lineaments that have dissected the area. The possible movement amongst the blocks between the two faults in this zone has led to the general weakening of the area in the form of shearing, fracturing, etc. The rocks are also weathered to a considerable degree as a direct consequence of shearing and crumpling that has rendered them very weak. Another factor, though minor in the larger context, leading to the present creep is the poor drainage system. The density of settlement in this area is also very high. Population growth and expansion of settlements over potentially hazardous areas are increasing the impact of landslides (Perugia et al, 2002). This has led to the unplanned use of land resources, including haphazard construction and removal of vegetative cover of the slopes. This area also has a high concentration of subsurface water due to the inherent nature of the shale and its weathered product. The groundwater is responsible, particularly during the monsoon, for build-up of extreme pore pressure that leads to the total loss of shearing strength of the material.

7.2.5 Effects

This highway has been badly affected for many decades. The first landslide event recorded took place way back in 1934. The event destroyed the then Kohima-Wokha road which was at a lower plane from the road of today. This led to the diversion of the highway to the present position. The second event took place in 1942 affecting this highway. Both landslide events caused severe damage to the highway thereby affecting communication for many days. The extent and degree of damage is not accurately known as there are no proper records. Houses and other man made structures and vegetation was destroyed during the third major episode of sliding which took place in 1976.

7.2.6 Previous works

The highway is constantly being worked on by the state PWD to keep it functional. Retaining walls are also continuously being erected. However, these do not last long as the foundations of the walls are constructed within the slide debris. The drains constructed are shallow and ill maintained. Hence, they allow abundant water to percolate into the subsurface. Recently, however, large concrete retaining walls have been constructed in consultation with experts. The foundations of these walls have been placed on the bedrocks. However, these bedrocks are weak so it remains to be seen whether these walls will stand the test of time.

7.2.7 Recommendations

Taking into consideration the magnitude and intensity of damage some measures are proposed. The major cause is water. Seepage of water into the slide zone is to be prevented. For this catch-water drains should be constructed at suitable sites of the slide zone to divert surface run-off. Deep trench drains will help drain out subsurface water. Sewage and other domestic waste waters should also be properly drained. All exposed slopes should be covered with vegetation to prevent further soil erosion. Sausage-wire retaining walls at appropriate intervals should be constructed within the slide zone. Further construction of structures should be discouraged by the competent authority.

7.3 LERIE SLIDE

7.3.1 Introduction

This slide lies at 94°6'42" E longitude and 25°39'02" N latitude in Toposheet no 83 K/2 of the Survey of India. It is located about 2 kms southeast of Kohima Town. The length of the slide is about 750 m while the breadth is about 275 m. This slide has destroyed lanes and streets, and RCC buildings in the area. This has affected the NH 39 in the past and at present also poses a major threat as it is still active (Fig. 7.3). Plate 7.3 shows a portion of the slide zone.

7.3.2 Geology of the area

This area is predominantly made up of shale belonging to the Disang Group. They comprise black, buff, and brown colored shale with minor siltstone. The shale are highly weathered which make them very friable. Besides the siltstones they are intercalated with fine grained, brownish sandstones. The brown color of the sandstones is due to the oxidation of iron. The rocks dip in different directions due to local disturbances. The water table reaches the surface during the monsoon. During winter it is about 2 feet below the surface. This slide represents slow creep of material down slope.

7.3.3 Structure

This slide is structurally controlled by a major lineament. A fault runs almost E-W on the northern portion of the slide zone. Two streams, starting near the head of the slide on the western end flow through the slide zone almost parallel to the fault to merge on the northeastern corner of the slide. This stream cuts the fault at some distance below. At the crown a lineament cuts the fault in a NW-SE direction. The scarp of the slide zone lies near the lineament. Due to the presence of these structures the rocks are highly disturbed. Four sets of joints with varying trends are noted. The rocks are highly sheared and pulverised.

LERIE SLIDE

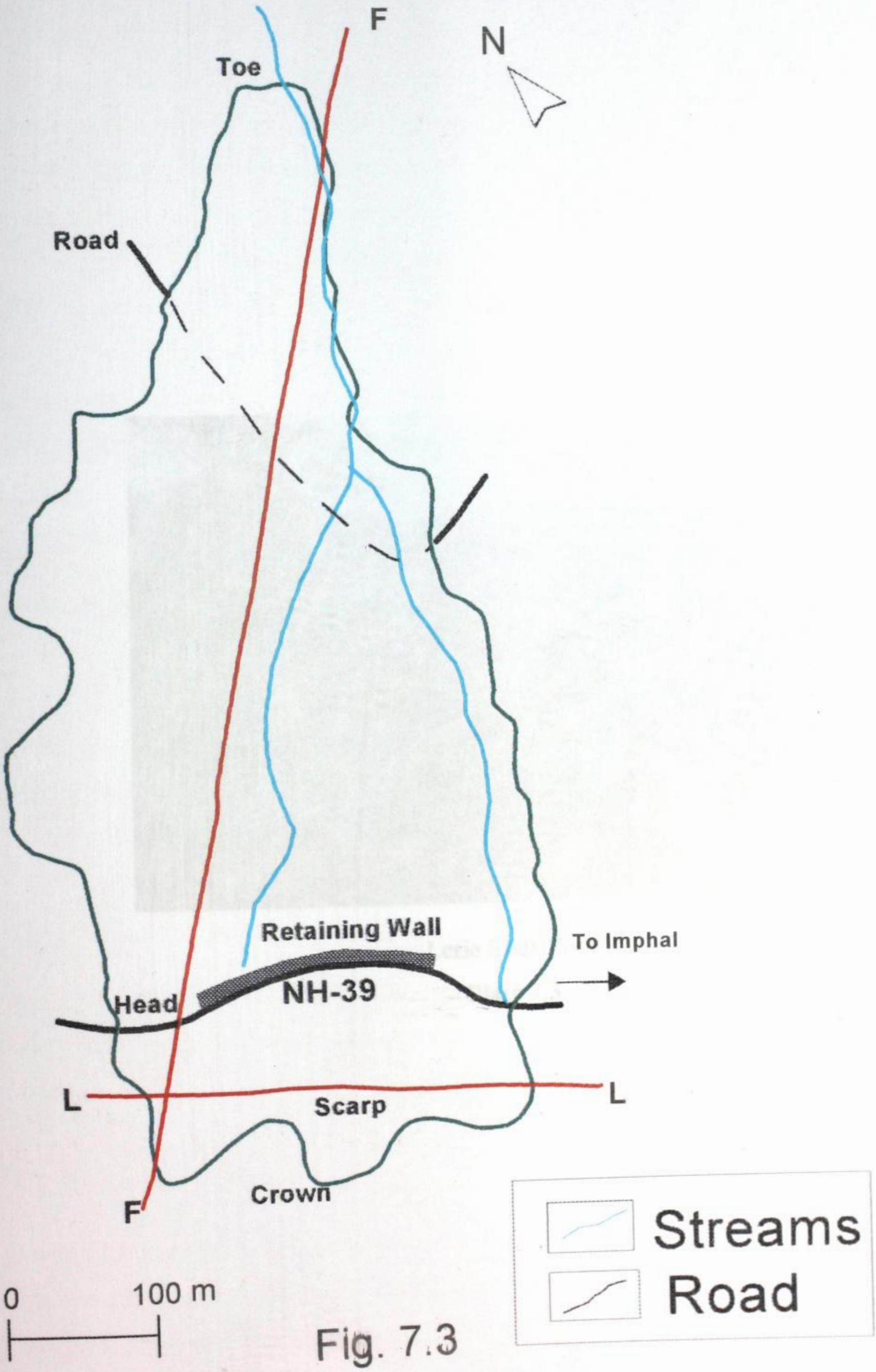
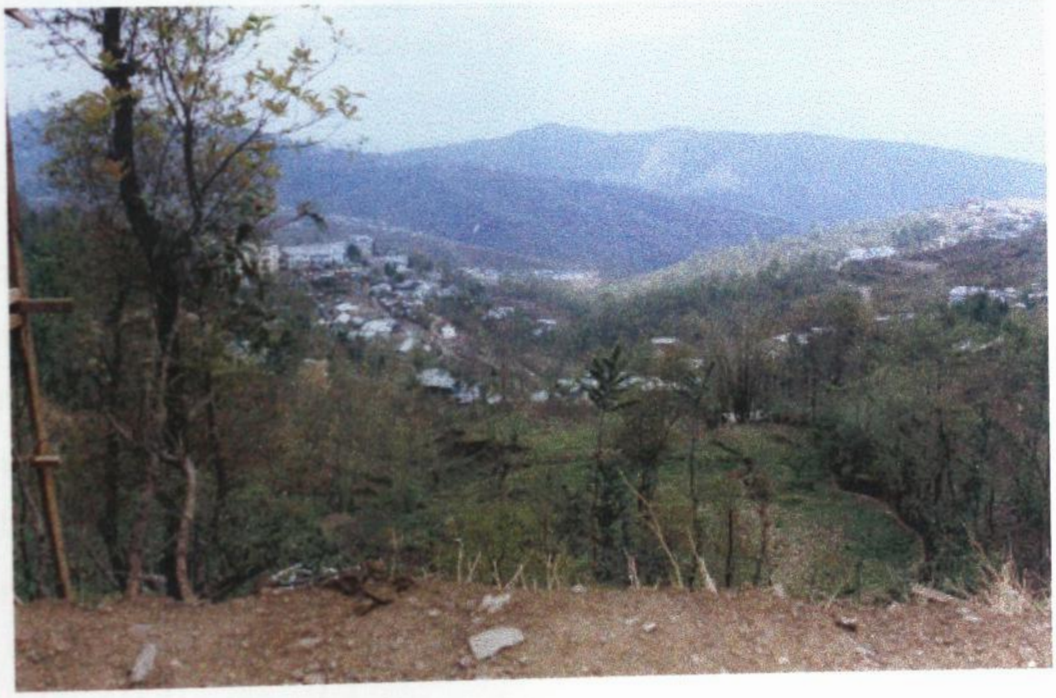


Fig. 7.3



Lerie Slide Zone

Plate 7.3

7.3.4 Causes

From investigations it is ascertained that this slide is a reactivated palaeoslide. A fault traversing the affected area has resulted in shearing of the shales which are also badly crushed and weathered to a great extent that has rendered them susceptible to sliding. The construction of buildings and other developmental works in the area have further aggravated the situation and added tremendous load on this weak area. Agricultural practices such as farming and terrace cultivation have caused water logging that has led to slope failure. Such practices include random clearing of forest by the inhabitants and accumulation of water in the paddy fields. Clearing of forests has led to easy passage for the percolating waters thereby leading to build-up of undesirable pore pressure. Deforestation and developmental activities are responsible for soil erosion and destabilization of slopes (Naithani, 1999).

7.3.5 Effects

Past record show that the highway was so badly affected that communication was disrupted for many days. The recent slide caused more devastation which lead to huge losses. The lanes and streets within the area were washed away making even walking difficult. Fissures and cracks developed in the vicinity of the slide zone thereby affecting nearby buildings. The development of these fissures and cracks pose a threat to the highway as well in the near future.

7.3.6 Previous works

Nothing much has been done to control this slide or to provide mitigation measures except the construction of retaining walls to protect the highway and keep it motorable.

7.3.7 Recommendations

Thorough investigations have been carried out to determine the causes of weakness and to provide some mitigation and remedial measures. To prevent further movement of the mass, retaining walls using sausage wire and boulders should be constructed at the toe of the slide. Proper lined surface catch water drains should be constructed to convey water out of the slide zone. Pumping out water from the wells and using underground perforated pipes to remove excess water should be given priority so as to lower the water table. Such extracted water should be trained out of the slide zone through proper drainage in the area. Plants such as poplar, alder, willow, oak, birch, acacia, and certain species of eucalyptus should be planted to hold the soil and lower the water table. Certain species of grasses such as Peuraria hirsute (P. *thumbergiana*), lantana shrubs, and kukui grass should be planted as these plants prevent the seepage of water into the subsurface. These grasses have well matted root systems which help bind soils. The inhabitants should be discouraged from constructing heavy structures in the area. Further developmental work should be stopped to prevent further loading.

7.4 PARAMEDICAL SLIDE

7.4.1 Introduction

Investigations are carried out in this area to ascertain the factors responsible for the instability. This zone is situated near the 180 km stone of NH 39 at Kohima. It is located at 94°05'54" E longitude and 25°39'51" N latitude and is incorporated in Toposheet no 83 K/2 of the Survey of India. This is a very unstable area that was activated in the early 1970's and has continued to pose problems till date. Instances of highway blockage in the past have disrupted communication between Kohima and Imphal. The length of the slide zone is about 550 m while the breadth is about 310 m (Fig. 7.4). The type of failure in this zone is due to subsidence. This sinking zone is very active during the monsoon. Plate 7.4.1 depicts the area prior to slope treatment while plate 7.4.2 shows recent measures undertaken in the area.

7.4.2 Geology of the area

The area is made up of sediments belonging to Disang Group of rocks. The shale of this area are highly weathered and crumpled. Intercalations of sandstone and siltstone with shale are common. Gaping cracks or fissures are common in the sandstones. They are black to brown in colour, whereas the sandstones are reddish-brown due to oxidation of iron. The sandstones are usually hard, compact, and very fine grained.

7.4.3 Structure

The rocks are highly fractured and exhibit three to four sets of joints. Fracture gaps vary from less than one millimeter to more than one centimeter. Three prominent faults intersect. A wedge is very prominent on the satellite imagery of the area. One of the faults strikes E-W. The other two faults run NW-SE and NNW-SSE respectively. A stream runs almost parallel to the E-W fault which takes a bend and follows parallel to the NNW-SSE fault. Four sets of joints are noted. One of the joint sets dips towards the road. Out of the subsidence zone the rocks are vertically aligned. One set of vertical joints strikes parallel to the road. This set of joints is responsible for rock falls.

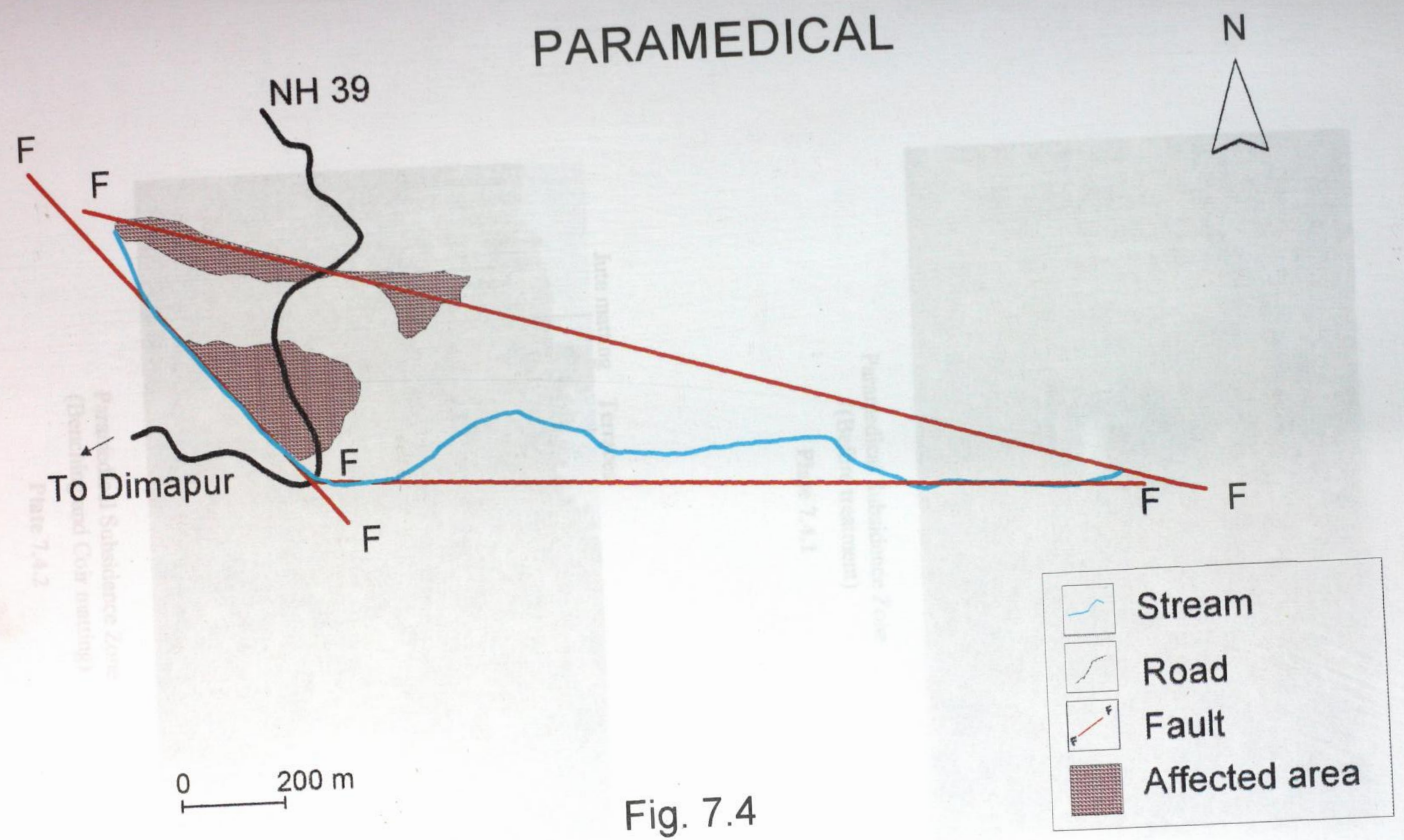

PARAMEDICAL
N
NH 39
F
F
F
F
F
F
To Dimapur
0
200 m
Stream
Road
Fault
Affected area

Fig. 7.4

Paramedical Subsidence Zone
(Before treatment)

Plate 7.4.1

Paramedical Subsidence Zone
(Benching and Coir matting)

Plate 7.4.2

7.4.4 Causes

The area is traversed by 3 faults which play an important role in the instability of this area. These faults are responsible for wedge failure due to which there is continued subsidence in the area. Faulting has also caused crumpling and shearing of the rocks. The rocks are highly jointed and fractured which has rendered them weak. At the head of the slide a number of wells are encountered. The water in these wells lies near the surface indicating high water tables. This zone is a part of NH 39 where continuous vehicular movement causes vibrations which may also be a contributory factor for weakness.

7.4.5 Effects

As this area is situated along the NH 39 vehicular movement between Kohima and Imphal is often disrupted for many days. The Border Roads Organisation (BRO) is constantly engaged during the monsoon in clearing the road to make it motorable. A number of houses have been destroyed even in the recent past. Tensional cracks are common in this weak zone.

7.4.6 Previous works

The Central Road Research Institute (CRRI) introduced some remedial measures that were adopted by the BRO. These measures have partially stabilized the slide zone for the last few years. The reduction of slope by bench cutting is effective. Retaining walls were also constructed on the uphill side of the highway. A drain constructed parallel to the retaining wall helps drain water into the streams on both sides of the slide zone. Check dams were constructed to prevent erosion by the stream. Coir nets were placed on the down slope side of the highway to hold the soil while grass was planted in the netted area.

7.4.7 Recommendations

Apart from the measures suggested by the CRRI some other measures are proposed. As water is the triggering factor, subsurface water should be properly drained. This can be done by introducing perforated pipes to dewater from the slide zone. Proper drainage should be constructed to help drain out surface runoff. For this proper lined surface drains on the uphill side, such as catch water drains are preferable. The uphill area should be covered by good soil binders such as grasses having good root systems. The slope on the uphill should be further reduced to some extent as the slope gradient is still too high at present. More material should be excavated so as to further reduce the load at the head of the slide.

7.5 MIDLAND SLIDE

7.5.1 Introduction

This area is located at 94°06'29" E longitudes and 25°39'46" N latitudes and is part of Toposheet no 83 K/2. The length of the slide zone is about 615 m while the breadth is about 260 m (Fig. 7.5). It represents a rotational failure that is accompanied by soil creep. This slide lies between two streams. Creep has been continuing for many years. This slide zone may be divided into three pockets of instability. High degree of shearing and weathering is noted near the stream channel. The two stream channels are probably fault planes. This is a debris slide made up of partially weathered shale and abundant clay (Plate 7.5).

7.5.2 Geology of the area

The rock types include highly pulverized and crumpled shale and siltstone. The shale and siltstone are weathered to a great extent. They are black to brown in color. Spheroidal weathering is common. The rocks are highly jointed as a result of which they exhibit a splintery nature.

7.5.3 Structure

Two faults are noted in this area. These faults lie within the slide zone which has a NNE-SSW trend. A stream follows the trend of the NNE-SSW fault and turns to the right and follows the trend parallel to the NE-SW fault. A number of joint sets are noted in the rocks. The course of the streams is structurally controlled. Due to faulting the rocks are sheared and crushed, and weathered to a considerable extent. This particular slide appears to have stabilized now but may possibly be reactivated.

7.5.4 Causes

Investigations have revealed that a number of factors have contributed to slope failure. Faults have sheared the rocks to a considerable degree thus making them friable and weak and highly susceptible to weathering. The weathered products of these rocks, the

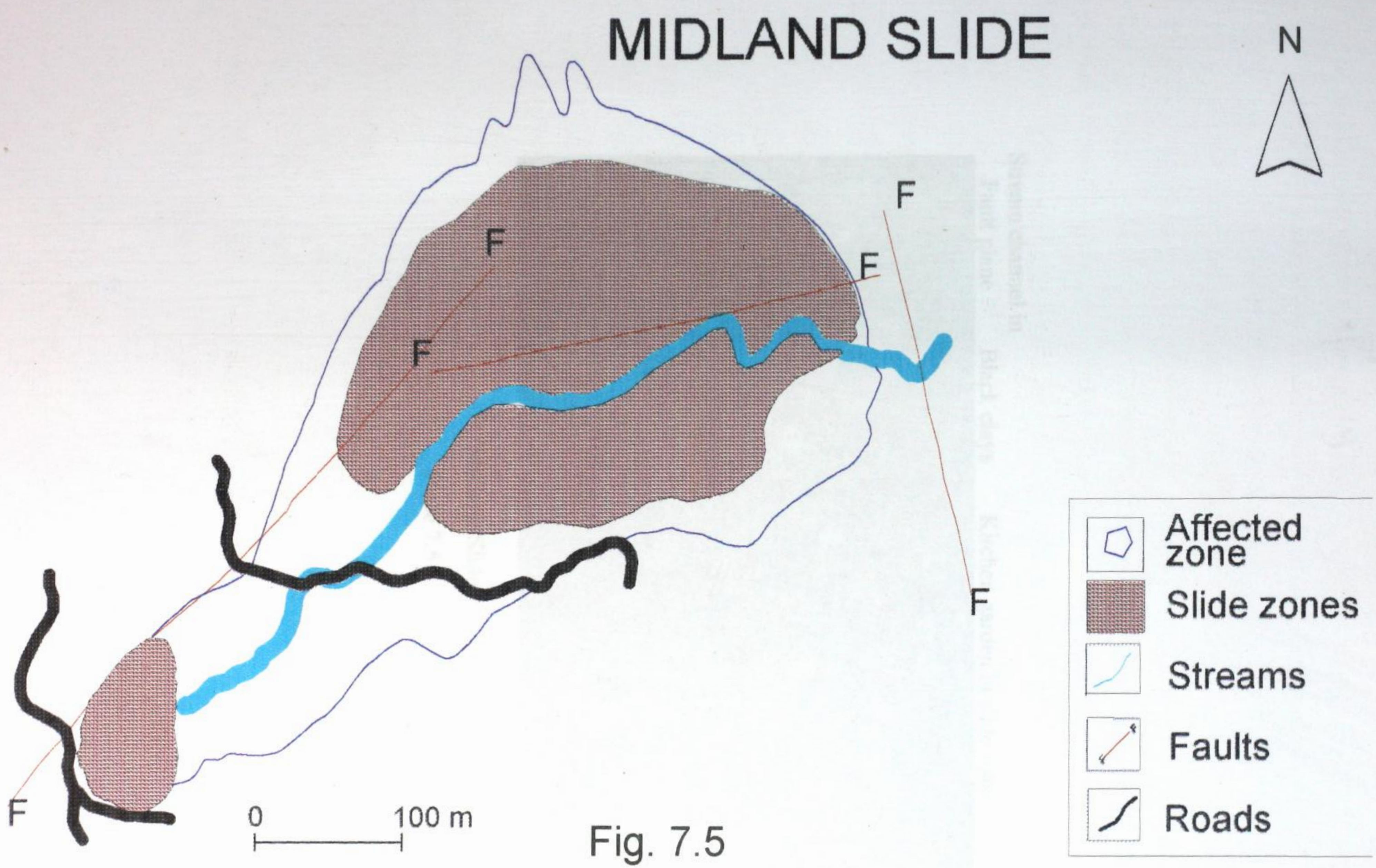

MIDLAND SLIDE
N
F
F
F
F
F
F
0
100 m
Affected zone
Slide zones
Streams
Faults
Roads

Fig. 7.5

Midland Slide

Plate 7.5

black and brown clays, are very weak and highly plastic. Hence, they tend to flow in the presence of water or on application of loads. A number of wells dug in this area show very shallow water tables. Water levels reach the surface during the monsoon. Terrace cultivation for paddy practiced in the landslide zone leads to water logging. This in turn puts tremendous pressure on the soils by increasing the pore pressure. Residential buildings are being constructed in the slide zone. The weight of these structures appears to have a negative impact on the soils which may be very conducive for slope failure. The southern stream also is very active against its weak bank. This has lead to toe erosion and collapse of the soil structure at places. If this stream is not controlled the southern bank area are in danger of total collapse. The two streams meet at a lower level. At the meeting point also toe erosion is very prominent. These two streams are also involved in vigorously cutting the weak sheared rocks thereby quickly deepening the river bed.

7.5.5 Effects

This slide zone marks the boundary between two colonies, namely the Lower PWD and the Midland. Footpaths in this slide zone connecting the two colonies are constantly destroyed. This event takes place more or less, every monsoon. Two small bridges connect the two sides over the two small streams. However, the southern bridge needs to be repaired or replaced every couple of years. This is because of constant damage to the structure. It was presumed that this damage to the bridge is due to toe erosion by the stream. But investigations have revealed that the problem lies elsewhere. Creep of the mass of the slide is one of the reasons. The other reason is that the fault on this side may be very active. So, due to movements the bridge position is constantly changed. Even man made structures are constantly moved even up to a few meters away from the original site. Many houses are tilted. On the basis of the movement and orientation of these structures it is concluded that failure of the rotational type is taking place along the southern bank of the slide zone.

7.5.6 Previous works

So far no agency has done anything to stop or mitigate the weakness in this slide zone except to construct small retaining walls to place the small bridge on the southern bank of the slide.

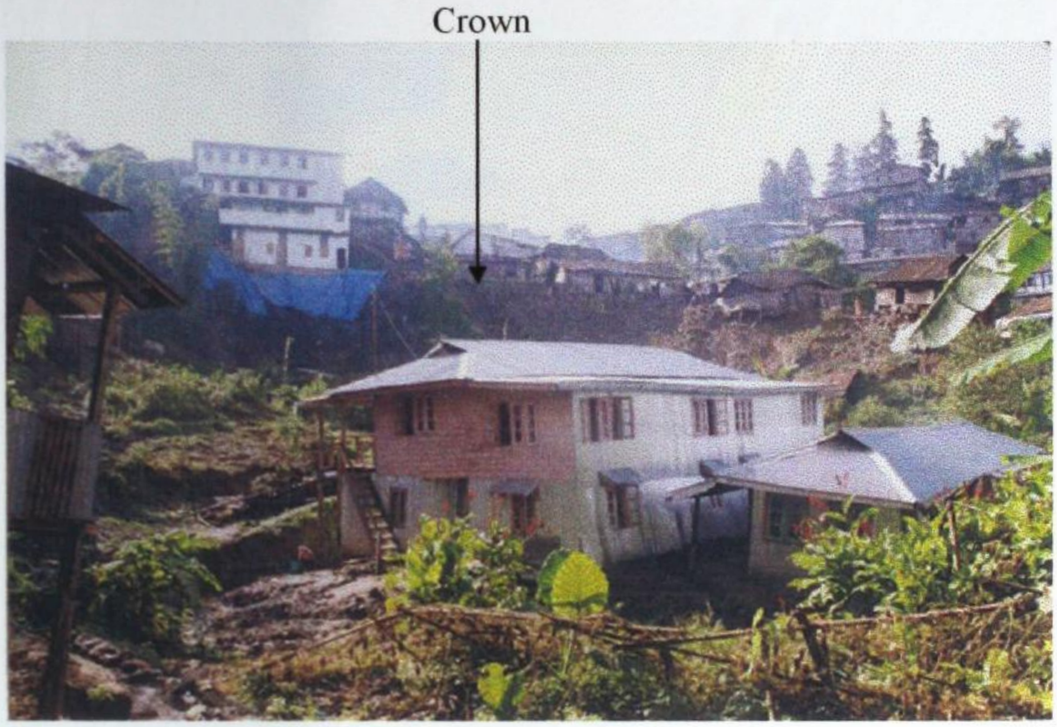
7.5.7 Recommendations

To prevent further movement of the slide proper retaining walls should be constructed. To control erosion and check the velocity of running water check dams should be constructed on the river bed of both streams. At the meeting point of the streams proper retaining walls should be constructed to stop further toe erosion. Proper drainage at appropriate places should be made to check surface run-off. Subsurface water should be removed by pumping out through wells or through internal drains to reduce the excessive accumulation of groundwater from the affected area. Construction of heavy structures and the practice of paddy cultivation within the slide zone should be discouraged. As the area is poor in vegetative cover, plantation of some species of plants and grasses that are good soil binders should be introduced.

TABLE 7

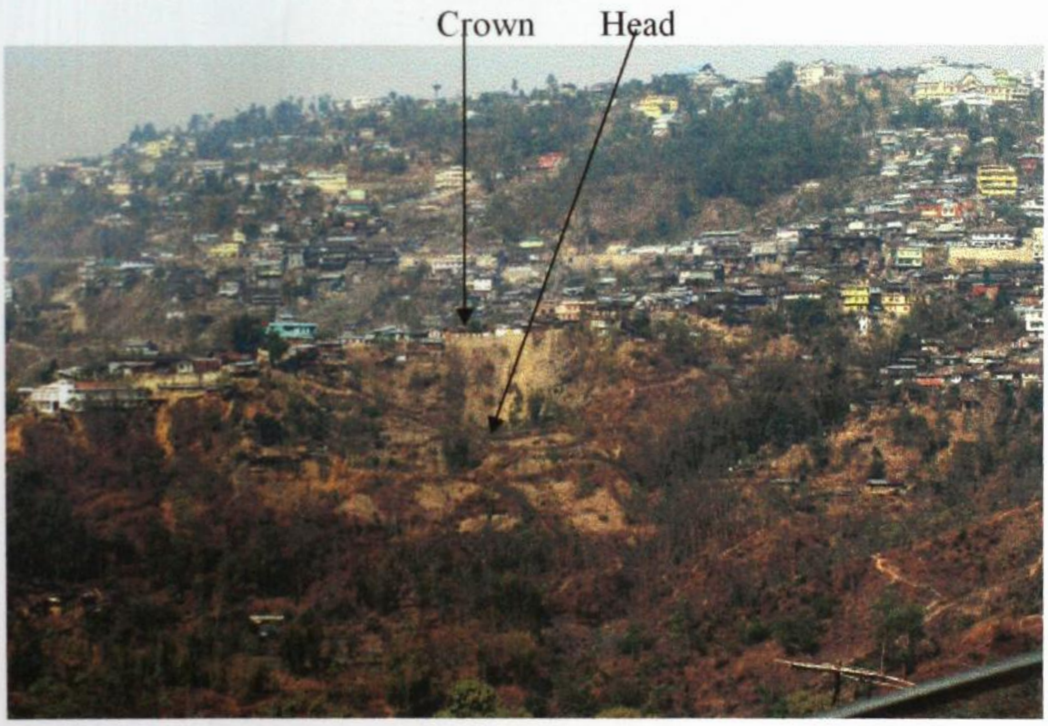
SUBSIDIARY LANDSLIDES: CAUSES AND REMEDIAL MEASURES

Name of slide/ subsidence	Causes	Remedial Measures
TCP Gate	Weathered shale, shear zone, subsurface water	Removal of subsurface water, retaining wall
New Market (Plate 7a)	Shear zone, lithology, water, high settlement density	Removal of subsurface water, avoidance of construction
Naga Bazaar (Plate 7b)	Palaeoslide, lithology, water, topography, high settlement density	Removal of subsurface water, avoidance of construction
BRTF Camp (Plate 7c)	Subsurface water, rainfall, high settlement density	Subsurface drains, retaining walls
Forest colony	Palaeoslide, water, settlement	Improvement of drainage system, avoidance of construction, minimize water seepage
PR Hill	Shear zone, water, heavy structures	Subsurface drains, avoidance of construction
Merhülietsa	Heavy structures, water	Reduction of load, minimize water seepage, retaining walls
Upper Officers' Hill	Shear zone, toe erosion, subsurface water, topography	Retaining wall, minimize water seepage, vegetation cover
Lower Officers' Hill	Exposed surface, topography	Vegetation cover, retaining wall
Phezhu	Thrust, shear zone, slope, water, human activity	Retaining walls, minimize water seepage
Porter Lane	Slope, lithology, structure	Slope reduction, minimize water seepage
Assam Rifles (Plate 7d)	Slope, lithology, structure	Retaining walls, minimize water seepage
Lower Chandmari	Shear zone, toe erosion	Retaining walls, check dams, minimize water seepage
AG Road	Shear zone	Minimize water seepage, grouting



New Market Slide

Plate 7a



Naga Bazaar Slide Zone

Plate 7b

BRTF Slide Zone

Plate 7c

Assam Rifles Debris Slide

Plate 7d

7.6 DESCRIPTION OF REMEDIAL MEASURES

7.6.1 Water control methods

Landslides and other mass movements may be significantly reduced by improving drainage. There are a number of approaches to effective surface and subsurface drainage for better stability, the choice being governed by geomorphology of the terrain, hydrological conditions including intensity and distribution of rainfall, permeability of the slope-forming materials, vegetation, natural drainage, construction activity, and sliding mechanism.

Catch-water drains, trench drains, etc. are commonly adopted to improve slope drainage (Bhandari, 1987). Removal of water from slide prone areas is one of the most important mitigation measures, particularly in sheared zones. The following water control methods have been found to be useful:

Surface water

It is very important to drain off all water on the ground. Cracks and other openings should be grouted or sealed properly by other means to prevent water percolation into the regolith or bedrock. Concrete drains should be constructed from top to bottom at regular intervals. The outlet of water could be connected to a nearby drain.

Subsurface water

The earth materials should be dewatered at regular intervals to lower the water table and pressure head. This may be achieved by pumping out water from wells to a certain limit or appropriate measures be taken to allow water to flow out naturally into surface drains.

7.6.1.1 Catch-water drain

It is recommended that a number of surface drains in the form of catch-water drains be constructed for certain slide zones. They should be interconnected to intercept and divert surface waters along hill slopes. Such drains should be properly lined. The gradient should be such that the velocity of water is not too great as to cause erosion of the drain. In such cases the drains may have gradients ranging from 1 in 20 to 1 in 25. Water from the catch-water drains may be trained into natural hillside drains or waters flowing along such drains should be led into properly lined culverts at road level from where the same can be led into surface stream channels.

7.6.1.2 Deep trench drain

Subsurface drainage in the form of deep trench drains is equally important. Such a trench may be of a definite size and filled with rounded gravel of sizes varying between 50 and 60 mm. The preference for the size and shape is that such material has large voids which would help to drain out water easily. Suitable geotextile should be used to cover the gravel so as to prevent the fine soil particles from entering the voids between the gravel and thereby blocking it (Fig. 7a).

Where streams cut across the highway cross drainage is necessary. Waters from side drains also should be led into these cross drains and finally into surface stream channels. Such drains, if properly and adequately placed, will prevent water from flooding the roads.

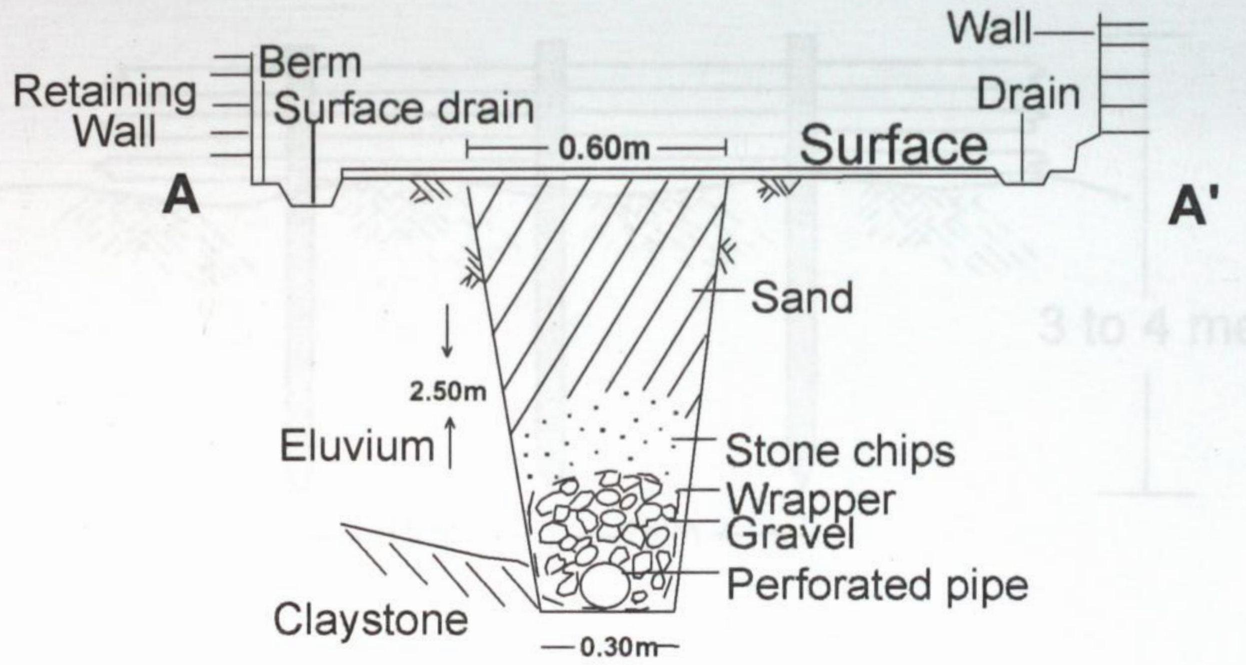
7.6.2 Bamboo/wooden nail reinforcement

The stability of slopes can be improved by installation of bamboo or wooden stakes into the loose sliding mass. Such measures are purely temporary and are to be used for short term benefits only. Such nails or stakes help in stabilizing slopes by preventing surface erosion of slide areas. Shallow movements of sliding masses are effectively arrested. The stakes may vary from 10 to 15 cms in diameter. They may be hammered at intervals of 1 to 1.5 metres. Horizontal runners must to be nailed to the stakes. The function of the runners is to check the flow of debris downhill (Fig. 7b).

7.6.3 Retaining walls

Retaining walls are used to increase the resistance to slide movements and are generally installed at or near the toe of unstable areas. These features have been found

FILTER FABRIC TRENCH



CROSS SECTION ALONG A-A'

Fig. 7a

Ballie/bamboo piling

Front elevation

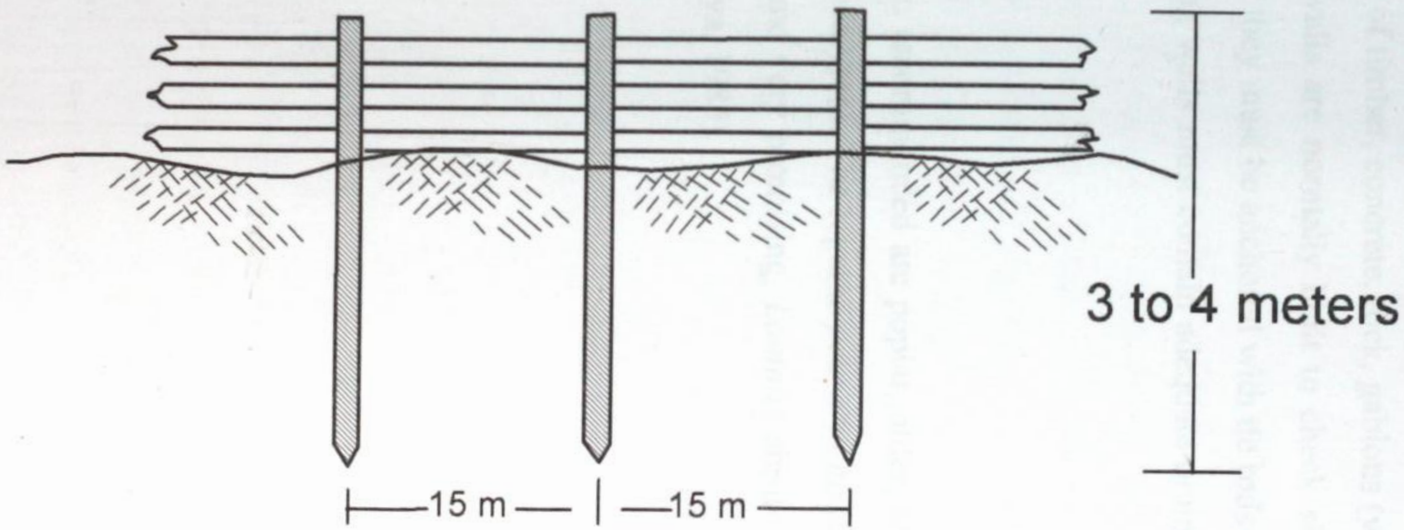


Fig. 7b

to be suitable particularly in cases of slip-out type of slides. Such structures should have deep foundations with weep holes for smooth passage of water. There are numerous designs that use different material to check the down slope movement of earth material in landslide zones. Such structures are variously called dykes, cribs, bulkheads, walls, etc. Their purpose is to impede motion of an unstable area. There are different types of retaining walls such as cantilever, gravity, grip, buttress, etc. They may be composed of timber, concrete, rock, gabions (wired networks filled with rocks), etc. Retaining walls are normally built to check sliding in small areas. To increase their efficiency they must be anchored with tie rods to adjacent stable terrain. The backside of retaining walls must contain adequate drainage to divert water build up.

7.6.4 Vegetation

Among the trees that are recommended are poplar, alder, willow, birch, oak, acacia, and certain species of eucalyptus. The legume *peuraria hirsute* (p. thunbergiana) with deep roots has been found very promising. *Lantana* shrubs and *kikui* grass are also good soil binders (Valdiya, 1985).

CHAPTER 8

DISCUSSION AND CONCLUSION

Kohima Town and its surroundings are made up of a young geologic terrain with pervious soils and unstable rocks. Landslides and mass movements are very common particularly during the monsoon. They occur due to adverse geology, heavy and prolonged rainfall, indiscriminate cutting of slopes, unplanned developmental activities, and deforestation. Increasing population and rapid urbanization has added to landslide incidences that has lead to huge loss of property. Therefore, it is necessary to determine the causative factors by analyzing the geological and geomorphologic parameters, and human activity. Many integrated studies have been carried out on the impact of population density, urban growth, and land use/land cover changes on landslides using remote sensing and GIS. The present study is carried out to evaluate the factors responsible for land instability and to generate a LHZ map. This will help assess the vulnerability and risk.

The rock types of this area include the argillaceous sediments of the Disang Group and some arenaceous Barail sediments. These rocks trend NNE-SSW to NE-SW. The Disang Group of sediments is the oldest in the study area. They are a monotonously thick sequence of splintery shales that are usually dark grey in colour. They exhibit concretionary structures and box-work weathering. They are also highly jointed, folded, and faulted. The shale alternate with minor siltstones and fine grained sandstones. Reddish brown colour is noted at places which are due to leaching of iron oxide. The dark grey and black shales that are organically rich are weathered to clays at numerous places. On saturation with water these clays become slimy and act as lubricants. This also leads to the building up of high pore water pressure that reduces inter-grain friction. This causes loss in their shearing strength and collapse of the soil structure. Sharda and Bhambay (1980) opine that the shear strength of the saturated Disang shale and soils of Kohima is very low. Crumpling of the shale and excessive saturation generates conditions favourable for shear failure of slopes due to in of pore pressure and consequent decrease in shear resistance of the slope material. Lithology, structure, and slope play an important role in causing weakness in the area. The drainage system in the area is also poorly developed. Surface runoff is very high because of the impervious nature of the shale and their weathered products, the clays. This causes the erosion of the top soil, particularly along those slopes with unconsolidated overburden. However, in areas of mixed soil and highly jointed and fractured rocks abundant percolation of rain water is noted. The shale in the area are highly puckered and fissile due to which, on exposure to air, they disintegrate and weather easily. On saturation, they start flowing to cause debris and mud flows. Soil creep is a very common phenomenon in the Disang. This is observed by the curved trunks of trees, bulging retaining walls, etc.

not a single photo

There must be crooked windows and door frames

The Disang Group is conformably overlain by the Barail Group of rocks that consist of well bedded greywacke. The Barail, as a whole, are made up of sandstones with alternations of siltstones and occasionally, papery shale. They are confined to a small patch on the southern part of the area. As sandstones are tough in nature landslides are not frequent in this area. However, due to the presence of prominent joint planes and vertical rock faces caused by road cutting, etc., rock falls occur in the steeper areas.

or fractures

A number of faults are noted in this area. Many thrusts too probably cut through the Disang. However, due to the monotonous nature of the Disang sediments it is difficult to map such thrusts. The fault zones are marked by the presence of crushed material and displacement of beds. Deposits of dark grey clay are noted along some fault zones in the Disang.

is this a lake sediment ?

Structure and lithology are the main geologic factors contributing to landslide incidences in Kohima town. Rocks of the area have been affected by small-scale folding and faulting and are intensely sheared. Most of the rocks of this area have also been rendered weak due to three to four sets of joints. Many of the slides in this area are deep-seated, multiple rotational slumps of old surfaces of weathered and jointed rocks. The joints are responsible for giving the Disang shale its splintery nature. Extensive leaching of limonite along the joint planes of shales and thin-bedded siltstones and sandstones are noted. The fissile nature of the shales coupled with the joint planes have made this terrain highly susceptible to mass wasting. Crushed zones are numerous in this area. These consist of colluvial debris comprising rocks of various sizes mixed with clayey and sandy soils. These crushed zones, in a number of cases, have been identified as palaeoslide sites. Landslides commonly occur in areas where the rocks are intensely fractured and sheared. As most thrusts, faults, and shear zones are associated with the presence of breccia and other crushed material, the shearing strength of such material is reduced in the presence of water.

Investigations have revealed numerous faults in the Disang sediments. Numerous well-defined lineaments are very prominent in the satellite images of the area. Most of these are faults that occur in parallel groups. Numerous streams have cut deep channels along some fault and other planes of weakness. Vuichard (1986), while studying the lower vegetated areas of the Nepal Himalayas, has observed that fracturing caused by the intersection of folds and faults are often responsible for steeply cut gullies. During the monsoon, these youthful streams vigorously erode the highly jointed Disang sediments and transport the debris to lower lying areas. Streams frequently run through shear zones in the Disang. These are responsible for some of the slides and general sinking of these areas.

Geological structures control stream channel configurations in the area of investigation. The higher order streams commonly follow major joint patterns and fault traces. These channels meet larger streams at various angles forming irregular branches. The drainage pattern includes dendritic, parallel, trellis, and intermediate forms. Zernitz (1932) opines that, development of dendritic patterns is due to the uniform resistance of rocks on a regional slope. A number of deep gullies have dissected the hill slopes. Toe cutting by streams is active at the lower levels. The area experiences heavy rainfall which causes abundant percolation of rain water through the soils and highly jointed shale. Because of high saturation the weathered Disang shale is unstable. This leads to mud and debris flows. Such material, made up of slurries of soil, rock, and organic matter combined with air and water, flow very rapidly. In movement they resemble viscous fluids. Such flows are facilitated by the steep gullies in this area.

Rising groundwater tables, particularly during the monsoon, unlined gullies, and naked slopes together allow rainwater to saturate the subsurface. This results in the development of undesirable pore pressure that reduces the shear strength of slope forming material. Hence, it is imperative that the naked slopes be covered by vegetation. Priority should be given to stabilise slopes by improving the surface and subsurface drainage conditions. Undesirable surface waters should be drained into natural stream channels using lined drains. The area should also be reshaped so as to control surface runoff. Tension cracks and other permeable zones at and around the crests of slopes may be temporarily or permanently sealed by mortar, asphalt, etc.

The two triggering factors of landslides include human activity and excessive rainfall. The frequency of natural disasters seems to have greatly increased in recent decades due to environmental degradation (Vincent, 1997). The magnitude of disasters is dependent on the susceptibility of land and vulnerability of society (Verstappen, 1995). In Nagaland the age long practise of jhum or shifting cultivation still continues rampantly. Agricultural practices of any given area have determined the degree of mass wasting, soil erosion, siltation, and other ecological imbalances. In any area faulty land use practices such as jhum cultivation, water storage in paddy fields and lower areas, constructional activities on steep slopes, etc. have caused irreparable loss to the environment and aggravated the problem of landslides. Anthropogenic activity has helped bare the slopes thereby aiding the natural processes to cause landslides. The sharp increase in population aided by rapid unplanned constructional activities has also contributed in destabilising the area. Most road constructions are substandard and have greatly increased landslide incidences. The combined effect of erosion of the steep slopes, weight and vibrations caused by vehicular traffic on the semi-consolidated mass, and build-up of pore pressure are major factors that contribute to slope failure. The existing vegetation cover too has been disrupted by landslides and gullying in areas where erosion is initiated or accelerated by activities including road constructions and depletion of natural vegetation by clearing, grazing, and burning. Thus, any activity that increases hillside gradients, undercuts earth materials, adds weight to the slopes, or produces more water, can lead to instability and set the stage for land sliding. Road constructions have directly or indirectly caused landslides. The soil cover in the area can support a luxuriant growth of vegetation, but the rapid growth of population and other activities of man have disturbed the natural processes thereby exposing the soil to water action which ultimately results in extensive erosion and slope instability. Terrace cultivation along slopes where shale is predominant have a disastrous effect upon soil stability. This is because the water stored in paddy fields generates great pore pressure on the soils thereby inducing landslides. It is noted that most areas under terrace cultivation are actually palaeoslide zones.

Water action on soils is the major factor for initiation of landslides. However, the presence and action of water is frequently overlooked in soil exploration and safety calculations. The absence of water during a certain period does not rule out the damage that may be caused at a later date. It often takes many years until water becomes active (Bishop, 1957; Skempton, 1977; Bauer et al, 1980). Its control and removal are thus very important in the stabilization of slopes. The stabilization of active landslides by controlling drainage has been carried out with full success at numerous landslide zones (Veder and Hilbert, 1980). The size, permeability, and transmissivity of pervious zones and orientation of discontinuities will determine the effectiveness of drains. Dry surfaces are not indications that favourable groundwater conditions exist as groundwater evaporates rapidly, especially in dry climates.

Intense monsoon precipitation sometimes accompanied by cloudbursts is a factor that has initiated most of the landslides in the area. The downpour is so heavy that large-scale devastation occurs during cloudbursts. Occasionally they are noted to continue for up to two hours in the region (Aier, 2005). Investigations of the phenomena have revealed that this damage is worse than that inflicted by the combined effect of rainfall of the whole year. Continued rainfall of lesser intensities has also triggered off landslides at numerous places. Because of the high amounts of rainfall and the occasional cloudbursts, surface run-off is very high as also the case with waters percolating into the subsurface.

Under different geological, meteorological, and hydrological conditions rocks and soils behave differently. The reduction of the impact of landslides is possible with careful monitoring of the behaviour of material under adverse conditions. Bhandari (1984) has given importance to instrumentation and field monitoring of landslides and other mass movements. The emphasis is on multi-functional monitoring instruments that are capable of measuring movements ranging from slow creep to rapid sliding of material, as well as direction of movement and vertical subsidence.

Bhandari (1987) insists that planners must now be able to recognize and appreciate the problems of hilly regions and that authorities should ensure that no plans are cleared unless adequate provisions are made for fullest investigation and protective measures. In landslide prone areas it is necessary to determine whether the driving forces that seek to change hillside equilibrium exceed the resisting forces that operate to maintain slope stability. This means that rock excavation should be minimised. In the investigation of sites for townships, highways, mines, etc. geologists and engineers should be able to compute the safety factor of material and predict rock and soil behaviour along slopes. Brazil passed National decrees as early as in 1955 that stipulate the requirement of investigations to determine the stability of sloping land before any construction. The rational design of rock slopes is particularly important where slopes are steep and cost of slope design is optimum. The resultant long-term savings would probably justify the greater initial investments in time and money, in as much as maintenance and repair costs for land sliding and landslide-caused damage have been shown to be high and commonly recurrent (Nilsen and Brabb, 1972; Taylor and Brabb, 1972). According to Alcedo (1998) well implemented disaster mitigation programs will effectively contribute to reduce the physical, social, and economic vulnerability of disaster prone areas.

CONCLUSION

The present investigation is an attempt to create a landslide database based on field investigations and using topographical maps and satellite data in a GIS environment as there is lack of information on landslides. A landslide database is necessary for proper planning and coordination, the ultimate aim of which is to reduce the impact of this natural phenomenon. GIS is an effective tool that provides for proper planning, and policy and decision making through data integration and modeling. It is suitable to use these models in this rugged terrain which can be analyzed and viewed in 3-D perspective. The landslide hazard maps generated for this area using GIS can serve as management tools. Such data can be replicated for use elsewhere under similar environs.

Landslide investigations should be aimed to the promotion of disaster preparedness to establish a network for efficient operation for all disaster related activities in the pre-disaster period, during an actual disaster, and afterwards. From the Landslide Hazard Zonation maps generated the highly susceptible areas identified should be marked clearly. These areas must be considered in terms of possible risk to property and human lives. Management programs must be planned for both short and long term remedial measures for the areas identified as high risk zones. Thus it is necessary to have implement-able plans in place and for which resources are available. Disaster preparedness is necessary for protection of lives and property from immediate threats. Disaster mitigation techniques are important to reduce the impact of landslides in the long run and to anticipate future situations and requirements.

Geotechnical investigations are very important for the prediction of landslides. Such investigations will help device appropriate control and preventive measures. Geotechnical investigations should aim at analyzing the shearing strengths of the various clays and soils. The safety factor for all types of soils should be calculated before the execution of any developmental work. Investigations should include detailed analyses of slope stability characteristics of the terrain and incorporate such factors as the size and shape of unstable masses, the nature and composition of rock types, detailed attitude of joint and bedding planes, and the water conditions of the area. Thus, a combination of geologic, geomorphic, and hydrologic studies with soil and rock mechanics is necessary. Such data should be evaluated in terms of a total benefit-cost ratio.

With adequate weather forecasting and careful analyses of cumulative rainfall patterns it may be possible to predict to a reasonable degree of accuracy the potential hazards due to landslides. The threat of an oncoming storm well into the monsoon that may be disastrous in terms of landslide hazards should be viewed seriously and public warnings should be issued of the potential danger. Structures situated in areas of former slide zones and adjacent areas are in great risk. People in such areas should be evacuated without delay during intense monsoons.

In the present investigation an attempt was made to correlate landslides with rainfall. However, the exact temporal relation could not be derived due to the lack of landslide data. Moreover, rainfall data is available from just one station. In this area the monsoon is a long and monotonous event that continues for several months. Long spells of rain are broken with very short dry intervals. However, such dry intervals are not enough to dry out the ground which remains fully saturated. For efficient investigations leading to better planning it is necessary to install more rain gauges at various places to obtain more accurate and detailed data.

Surface water should be efficiently dealt with as it is one of the important slide inducing factors. Water should be prevented from entering present and old landslide zones as far as possible. The present study has revealed that most landslides occur in very hazardous zones most of which are palaeoslide areas. The loss of shearing strength of the material in such zones causes failure. Thus, such zones including the palaeoslides should be thoroughly mapped as they are highly disaster prone. Water should not be allowed to penetrate into the subsurface but must be drained into proper lined surface channels particularly around the crown of slides to prevent sheet-wash from entering slide zones. The water table should be lowered to reduce the pore-water pressure below that which can cause failure. For this it is necessary to remove excess water from the subsurface.

Terrace cultivation and horticulture may be practiced on slopes ranging from 15°-35°. The area should be properly afforested through proper schemes with suitable fast growing, deep rooted trees like eucalyptus, alder, and willows including *Salix tetrasperma* and *Salix ichnostachya Lindl.* For the other areas the type of activities to be carried out should be clearly defined. Activities that could be hazardous should be prevented. Slopes that are greater than 35° should be left undisturbed as far as possible. Construction and allied activities in the high hazard areas should be regulated and monitored. The techniques of road construction in high hazard zones should be improved. In such areas it would be worthwhile to avoid earth cutting for new roads. In badly deformed areas realignment of roads may be a better option.

Innovations are essential to reduce cost, improve speed of construction, and promote utilization of slope waste to the extent practicable so that strain on scare materials and the need for their long distance transportation could be reduced or even eliminated.

ADDITIONAL RECOMMENDATIONS

The frequency and adverse effects due of landslides can be minimized to a great extent by adopting certain additional remedial measures. Based on the analysis of the results certain additional recommendations are made.

Legal / Regulatory Approach

1. It is necessary that the Government set up a Landslide Management and Regulatory Board. This Apex Committee should be supported by regional committees and subcommittees with online networking systems.
2. The Government should establish research programs for landslide assessment, landslide hazard zonation mapping, and collection and dissemination of information using modern technologies such as Geoinformatics.
3. Real-time monitoring of active landslides by GPS networking methodology is a must.

Environmental Approach

4. For any management plan an Environmental Impact Assessment (EIA) must carried out before execution of works.
5. Buffer zones should be created around landslide sensitive areas to prevent any human activity. This will effectively help land use and EIA planning activities simultaneously.

Land Use Planning Approach

6. Biotechnical slope stabilization should be encouraged as it is cost effective as compared to the use of structural elements. This will increase environmental compatibility and allow the use of locally available materials.

Engineering Approach

7. Loose debris should be removed from the head of weak zones to reduce the dead load. Terracing or benching may be taken up for slope reduction.
8. The drainage system should be improved by constructing catch-water drains at the crown, body, and toe of slide zones to channelise rainwater. The drainage system should be so planned that surface runoff should be led to such sites where running water will not affect the area. Subsurface waters should be properly drained so that the soil is not allowed to saturate. Water from above the slide should be channelised along drains on either side of roads.
9. Toe and surface erosion must be controlled by constructing grip walls at the lower reaches of slide zones.
10. The drainage at the feet of fault scarps and at the heads of slide zones should be carefully diverted. Water should be prevented from seeping through. Surface and subsurface drainage are important to divert undesirable surface flows.
11. It is recommended that impermeable material such as mortar or asphalt be sprayed at the crown and head regions to seal or plug tension cracks and other permeable zones that provide avenues for excessive water infiltration. Polythene sheets have been successfully used as temporary measures.
12. Affected slopes have unconsolidated overburden which offer easy access to percolating waters. Surface runoff easily saturates such slope forming material thereby leading to instability. Grasses and bushes on slopes should not be removed as far as practicable to keep the area covered with natural vegetation.
13. Catch-water and deep trench drains are effective in certain slide zones as they help prevent further sliding and erosion of debris. They should be interconnected to intercept and divert surface waters along hill slopes. Such drains should be properly lined. Waters flowing along such drains should be led into properly lined culverts at road level from where waters can be led into surface stream channels.
14. The stability of affected slopes can be improved by installation of bamboo or wooden stakes. Such measures are purely temporary and are to be used for short term benefits only. Such nails or stakes help in stabilizing slopes by

preventing surface erosion of material in slide areas. Bamboo-check-dams help check the downhill slide of material.

15. Retaining walls increase the resistance to slide movements. Such structures should have deep foundations with weep holes for smooth passage of water. To increase their efficiency they must be anchored with tie rods to adjacent stable terrain. The backside of retaining walls must contain adequate drainage to divert water build up. Retaining walls of appropriate design should be constructed to protect slopes.

16. Retaining walls should be constructed along the sides of roads to prevent debris from flowing down. Such structures should penetrate beyond the surface of sliding. Provisions should also be made to allow excess groundwater to flow out thereby lowering the water table during the monsoon. This may also be achieved by siphoning out excess water. This will considerably increase the shear resistance of soils.

17. Most landslides are directly related to flowing water including surface flows and underground seepage. Construction of watertight drains to collect surface and seepage water and their release through culverts or diversion into nearby streams can be undertaken.

18. Construction of heavy structures, particularly on unstable slopes should be avoided in order to reduce the load on slopes. Care should be taken at excavations so that slopes are made gentle.

19. Mitigation measures and maintenance should be cost effective. Economic feasibility should take into account the cost of the remedial action to the benefits.

Social Approach

20. Awareness should be created amongst the people about the hazards.
21. Warning should be given to the public of potentially hazardous areas.
22. The public should be educated about landslides so that personal safety measures may be taken.
23. Public participation in disaster management programs is necessary.

BIBLIOGRAPHY

Abdullah, A. and Ali, F.H., 1994. Strength and suction-moisture characteristics related to slope stability. Intl. Conf. Landslides, slope stability and the safety of infrastructure, Malaysia.

Agarwal, N.K. and Shukla, R.C., 1996. Kohima urban area. Contri. Environ. Geol. GSI Sp. Pub., vol. 43, p. 150.

Aier, I., 2005. Landslides along the Kohima-Dimapur road: their causes and possible remedial measures. Unpublished Ph.D. thesis, Nagaland University, Kohima.

Ajalloeian, R. and Nikzad, K.M., 2000. Investigation of land use in relation to landslide by using GIS. Proc. 21st Asian Conf. Rem. Sens., Taipei.

Alcedo, T., 1998. Disaster preparedness and planning. Proc. Intl. Conf. Dis. Man., Guwahati, pp. 73-86.

Aldridge, C.H., 1999. Discerning landslide hazard using a rough set based geographic knowledge discovery methodology. 11th An. Coll. Spatial Info. Res., Dunedin.

Anand, R., 1988. Preliminary geological investigations of landslides along Dimapur-Mao road, Nagaland state, India. Ind. Geol. Assoc. Bull., vol. 21, pp. 199-205.

Anbalagan, R., 1992. Landslide hazard evaluation and zonation mapping in mountainous terrain. Engg. Geol., vol. 32, pp. 269-277.

Arunachalam, A., 1998. Shifting cultivation and soil degradation at lower altitudes of Arunachal Pradesh. Proc. Intl. Conf. Dis. Man., Guwahati, pp. 163-173.

Barata, F.E., 1969. Landslides in the tropical region of Rio de Janeiro. Proc. Intl. Conf. Soil Mech. Found. Engg., Mexico, vol. 2, pp. 507-516.

Bartarya, S.K. and Valdiya, K.S., 1989. Landslides and erosion in the catchment of the Gaula River, Kumaun Lesser Himalaya, India. Mount. Res. Dev., vol. 9, pp. 405-419.

Bauer, G.E., Deschamps, G.P., and Scott, J.D., 1980. The effect of shear strength and pore pressure distribution on the stability of natural slopes. Intl. Symp. Landslides, New Delhi, vol. 1, pp. 297-302.

Beguería, S., Lorente, A., and García-Ruiz, J.M., 2003. Comparing statistical and process based methods for landslide hazard assessment. Geophy. Res., vol. 5, pp. 580.

Bhandari, R.K., 1984. State-of-the-art report on simple and economical instrumentation and working systems for landslides and other mass movements. Proc. 4th Intl. Symp. Landslides, Toronto, pp. 251-273.

Bhandari, R.K., 1987. Slope instability in the fragile Himalaya and the strategy for development. Ind. Geotech. Jour., vol. 17, pp. 1-77.

Bhan, S.K. and Champati Ray, P.K., 1998. Remotely sensed and ancillary data integration techniques for landslide zonation: a review. In: Kumar, N.T. and Bajpai, V.N. (Eds), Remote sensing in geoscience. Anmol Publication, pp. 1-77.

Bhattacharjee, C.C., 1991. The Ophiolites of northeast India: a subduction zone Ophiolite Complex of Indo-Burman Orogenic Belt. Tectonophysics, vol. 191, pp. 213-222.

Bhattacharjee, C.C., Rahman, S., Sarmah, R.N., and Thong, G.T., 1998. Landslides and road instability along NH 39, between Kohima and Chumukedima, Nagaland. Proc. Intl. Conf. Dis. Man., Guwahati, pp. 556-568.

Bishop, A.W., 1957. Some factors controlling the pore pressure setup during construction of earth dams. Proc. 4th Intl. Conf. Soil Mech. Found. Engg., London.

Bishop, D.M. and Stevens M.F., 1964. Landslides in logged areas in Southeast Alaska. For. Ser. Res. Paper, Nor., vol. 7, p. 18.

Blanc, R.P. and Cleveland, G.B., 1968. Natural slope stability as related to geology, San Clemente area, Orange and San Diego Counties, California. Cal. Div. Mines & Geol., Sp. Rep., vol. 98, p. 19.

Blight, G., 1977. Slopes and excavations in the residual soils. Proc. 9th Intl. Conf. Soil Mech. Found. Engg., Tokyo, vol. 2.

Bonham-Carter, G.F., 1994. Geographic Information Systems for geoscientists: modeling with GIS. Comp. Meth. Geos., vol. 13, pp. 398.

Brabb, E.E., 1984. Innovative approaches to landslide hazard and risk mapping. Intl. Symp. Landslides, Toronto, vol. 1, pp. 307-323.

Brabb, E.E., Pameyan, E.H., and Bonilla, M.G., 1972. Landslide susceptibility in San Mateo County, California. USGS Misc. Field Studies Map, MP - 360.

Brand, E.W., 1981. Some thoughts on rain induced slope failures. 10th Intl. Conf. Soil Mech. Found. Engg. Stockholm, vol. 3.

Brown, C.B. and Sheu, M.S., 1975. Effects of deforestation on slope. Jour. Geotech. Engg., vol. 101, pp. 147-165.

Burroughs (Jr), E.R. and Thomas, B.R., 1977. Declining root strength in Douglas fir after felling as a factor in slope stability. US Dept. Agri. For. Ser., Res. Paper, vol. 190, p. 27.

Caine, N. and Mool, P.K., 1982. Landslides and the Kolpu Khola drainage: middle hills, Nepal. Mount. Res. Dev., vol. 2, pp. 157-173.

Cardinali, M., Reichenbach, P., Guzzetti, F., Ardizzone, F., Antonini, G., Galli, M., Cacciano, M., Castellani, M., and Salvati, P., 2002. A geomorphological approach to the estimation of landslide hazards and risks in Umbria, Central Italy. Nat. Haz. Ear. Sy. Sc., vol. 2, pp. 57–72.

Carrara, A., Cardinali, M., Detti, R., Guzzetti, F., Pasqui, V., and Reichenbach, P., 1991. GIS techniques and statistical models in evaluating landslide hazard. Ear. Surf. Proces. Landforms, vol. 16, pp. 427-445.

Central Road Research Institute, 1989. Report on use of Coir Geogrid for surface erosion control of slopes. Coir Board, Govt. India.

Central Road Research Institute, 2000a. Preliminary report on correction of landslide at km-174 and km-180 on NH-39 in Nagaland, pp. 1-6.

Central Road Research Institute, 2000b. Correction of landslides on NH-39 in Nagaland. Supple. Rep.

Chattopadhyay, B., Venkataramana, P., Roy, D.K., Bhattacharya, S., and Ghosh, S., 1993. Geology of Naga Hills Ophiolites. GSI Rec., vol. 112, pp. 59-115.

Chenniah, G., Clemences, S.P., and Thurairajah, A., 1994. Slope stability in residual soils: an overview. Intl. Conf. Landslides, slope stability and the safety of infrastructure, Malaysia.

Chi, Kwang-Hoon, Lee, Kiwon, and Park, No-Wook, 2002. Landslide stability analysis and prediction modeling with landslide occurrences on KOMPSAT EOC imagery. Kor. Jour. Rem. Sen., vol. 18, pp. 1-12.

Choubey, V.D. and Lallenmawia, H., 1987. Landslides and other mass movements in Aizawl, NE India, Mizoram State. 5th Intl. Conf., New Zealand, pp. 113-120.

Choubey, V.D. and Lallenmawia, H., 1989. The structural evolution of Northeastern Himalayan zone with special reference to Mizoram region. Current Trends in Geology – XI. Himalayan mountain building. Today & Tomorrow Publishers, N. Delhi, pp. 147-162.

Choubey, V.D. and Litoria, P.K., 1990. Terrain classification and Land hazard mapping in Kalsi-Chakrata area, Garhwal Himalaya, India. ITC Jour., pp. 58-66.

Chung, C.F., Fabbri, A.G., and Westen Van, C.J., 1995. Multivariate regression analysis for landslide hazard zonation. In: Carrara, A., and Guzzetti, F. (Eds), Geographical Information Systems in assessing natural hazards. Kluwer Publishers, pp. 107-133.

Chung, C.F., Kojima, H., and Fabbri, A.G., 2002. Stability analysis of prediction models for landslide hazard mapping. In: Allison, R.J. (Ed), Applied geomorphology: theory and practice. John Wiley & Sons, New York, pp. 3-19.

Conklin, H.C., 1957. Hunwnoo Agriculture in the Philippines. FAO, Rome.

Corominas, J., Copons, R., Vilaplana, J.M., Altimir, J., and Amigó, J., 2003. Integrated landslide susceptibility analysis and hazard assessment in the principality of Andorra. Nat. Haz., vol. 30, pp. 421–435.

Crozier, M.J., 1986. Landslide: causes, environments, and consequences. Croon Helm, London, 252 p.

Crozier, M.J., 1989. Landslide hazard in the Pacific islands. In: Brabb & Harrod (Eds), Landslides: extent and economic significance. Balkema, Rotterdam, pp. 357-366.

Crozier, M.J. and Vaughan, E.E., 1990. Relative instability of colluvium-filled bedrock depressions. Ear. Surf. Proces. Landforms, vol. 15, pp. 329-339.

Cruden, D.M. and Varnes, D.J., 1996. Slope movement types and processes. In: Landslides - investigation and mitigation. Spl. Rep. Natl. Acad. Press, Washington, vol. 247, pp. 36-75.

Dai, F.C., Lee, C.F. and Ngai, Y.Y., 2002. Landslide risk assessment and management: an overview. Engg. Geol., vol. 64, p. 65.

Department of Science and Technology, 1994. Methodology for landslide hazard zonation.

Desikachar, S.V., 1974. A view of tectonic and geological history of Eastern India in terms of plate tectonics theory. Jour. Geol. Soc. Ind., vol. 15.

Directorate of Geology and Mining, Nagaland, 1978. Misc. Pub., no. 1.

Directorate of Geology and Mining, Nagaland, 1996. Feasibility studies for groundwater development in the hilly terrain in and around Kohima Town, Nagaland. Tech. Rep.

Emelyanova, E.P., 1977. The influence of geological and climatic conditions on the distribution of landslides on Russian Platform. Bull. IAGE., vol. 16, pp. 6-27.

Endo, T., 1970. Probable distribution of amount of rainfall causing landslides. Ann. Rep. Hokkaido Br. Govt. For. Exptl. Stn., Sapporo, pp. 123-136.

Evans, P., 1964. The tectonic framework of Assam. Jour. Geol. Soc. Ind., vol. 5, pp. 80-96.

Fugita, T., 1980. Slope analysis of landslides in Sikoku, Japan. Proc. 3rd Intl. Symp. Landslides, New Delhi, vol. 1, pp. 169-174.

Fugita, T., 1994. Characteristics of landslides in southwest Japan based on slope analysis. 7th Intl. IAEG Cong., Lisbon, Portugal, vol. 3, pp. 1415-1424.

Fugita, T., Hirano, M., and Hada, S., 1976. The structural control of landslides in the Kawai area, Tokushima Prefecture, Shekoku, Jisuberi. Jour. Jap. Landslide Sci., vol. 13, pp. 25-36.

Galster, R.W. and Laprade W.T., 1991. Geology of Seattle, Washington, USA. Bull. Assoc. Engg. Geol., vol. 28, pp. 235-302.

Gray, D.H., 1973. Effects of forest clear-cutting on the stability of natural slopes: Results of field studies. Ntl. Sc. Found., Washington, p. 119.

Gudehus, G., Kolymbas, D., and Leninenkugel, H.J., 1976. Zeitverhaltan von Böschungen and Einchnitten. In: Weichem and Steifem (Eds). Proc. 6th Eur. Conf. Soil Mech. Found. Engg., Vienna, vol. 1, pp. 1-51.

Guidicini, G. and Iwasa, D.Y., 1977. Tentative correlation between rainfall and landslides in Mattumid Tropical Enviroment. Proc. IAEC Symp. Landslides and other Mass Movements, Prague, pp. 13-18.

Gupta, R.P., 1991. Remote sensing geology. Springer Verlag, Berlin.

Gupta. R.P. and Joshi. B.C., 1990. Landslide hazard zoning using the GIS approach - a case study from the Ramaganga Catchment, Himalayas. Engg. Geol., vol. 28, pp. 119-131.

Haigh, M.J., 1988. Dynamic systems approaches in landslide hazard research. Z. Geomorph. N.F. Berlin. Stuttgart. Supple. Bd. 67, pp. 79-91.

Heller, P.L., 1981. Small landslide types and controls in glacial deposits: Lower Skagit river drainage, Northern Cascade range. Washington. Environ. Geol., vol. 3, pp. 221-228.

Hansen, A., 1984. Landslide hazard analysis and slope instability. Wiley, UK, pp. 423-602.

Ives, J.D., 1987. The theory of Himalayan environmental degradation: its validity and application challenged by recent research. Mount. Res. Dev., vol. 7, pp. 189-199.

Jworchan, I. and Nutalaya, P., 1994. Characteristics of landslides in residual soil in Khao Luang Mountain range in southern Thailand. Proc. Intl. Conf. Landslides, slope stability and the safety of infrastructure, Malaysia.

Kandpal, G.C. and Pant, G., 1995. Geological evaluation of instability along Balia Nala, Dist. UP, Symp. Rec. Adv. Geol. Studies, NE Himalayas, Lucknow, pp. 21-23.

Kawakami. H. and Saito. Y., 1984. Landslide risk mapping by quantification method. Proc. Intl. Symp. Landslides, Toronto, pp. 535-540.

Kemas, K., Thong, G.T., and Walling, T., 2004. Chokidzü debris slide – a case study. Naga. Univ. Res. Jour., v. 2, pp. 89-94.

Koirala. N. and Watkins. A.T., 1988. Bulk appraisal of slopes in Hong Kong. Intl. Symp. Landslides, Lausanne.

Kumar, B., Virdi, N.S., Sahe, M.P., Bartarya, S.K., and Gupta, V., 1995. Landslide hazard zonation between Rampur and Wangtu, H.P. Symp. Rec. Adv. Geol. Studies on NE Himalayas, Lucknow, pp. 324-326.

Kumar, S., Babu, G.L., and Mukesh, M.D., 2002. Landslide analysis in GIS. Proc. Int. Conf. Map Ind., New Delhi.

Lopez-Tello, L.F., 1977. Stabilising effects of plants on slopes. Rev. Obras. Publicas, Madrid, pp. 659-668.

Lotha, K.A., 1994. A note on the geotechnical investigation on landslide at Cheipfutsiepfe, Lower AG colony, Kohima Town, Nagaland. Unpubl. Rep. Geotech. Geoenvir. Cell, DGM, Nagaland.

Lotha, K.A., 1999. A note on the preliminary geotechnical investigation of the site of the Naga hospital Kohima, Nagaland for upgradational construction works. Rep. DGM, Nagaland.

Malkawi, A.H., Saleh, B., Mohammed Al-Sheriadeh, S., and Hamza Mufid, S., 2002. Mapping of landslide hazard zones using remote sensing and GIS. Jour. Urb. Plng. Dev., vol. 126, p. 17.

Mantovani, F., Soeters, R., and Westen Van, C.J., 1996. Remote sensing techniques for landslide studies and hazard zonation in Europe. In: Harvey A.M. and Vitek J.D. (Eds), Geomorphology 15. Elsevier, Netherlands, pp. 213-225.

Mathewson, C.C. and Clary, J.H., 1997. Engineering geology of multiple landsliding along 1-45 road-cut near Centerville, Texas. In: Coates, D.R. (Ed), Landslides. Geol., vol. 3, pp. 213-223.

Mathur, L.P. and Evans, P., 1964. Oil in India. Intl. Geol. Cong. (22nd Session), N.Delhi.

Matula, M., 1969. Regional engineering geology of Czechoslovakia Carpathians. Slovak Acad. Sc., Bratislava.

McElhinny, M.W., 1973. Paleomagnetism and plate tectonics. Cambridge University Press, 230 p.

McKean J., Buechel, S., and Gaydos L., 1991. Remote sensing and landslide hazard assessment. Photogram. Eng. Rem. Sens., vol. 57, pp. 1185-1193.

McKenzie, D.P. and Sclater, J.G., 1971. The evolution of the Indian Ocean since the Late Cretaceous. Royal Astro. Soc. Geophy. Jour., vol. 25, pp. 437-528.

Mehrotra, G.S., Sarkar, S., and Dharamraju, R., 1992. Landslide hazard assessment in Rishikesh-Tehri area, Garhwal Himalaya, India. Proc. 6th Intl. Symp. Landslides, New Zealand.

Mehrotra, G.S., Sarkar, S., and Kanungo, D.P., 1993. Lithotectonic evaluation of landslide and mass movements in Garhwal, Kumaon Himalaya. Jour. Engg. Geol., vol. 22, pp. 19-33.

Muller, L., 1964. The stability of rock bank slopes and the effect of rock water on same. Intl. Jour. Rock Mech. Min. Sc., vol. 1, pp. 475-504.

Nabil, Al-Daghastani, S., 1989. Remote sensing in geomorphological mapping and mass movement study of the Sinjar anticline, Northwestern Iraq. ITC Jour., vol. 2, pp. 92-103.

Nagarajan, R., Mukherjee, A.R.A., and Khire, M.V., 1998. Temporal remote sensing data and GIS application in landslide hazard zonation of part of Western Ghat, India. Intl. Jour. Rem. Sens., vol. 19, pp. 573-585.

Naithani, A.K., 1999. The Himalayan landslides. Emp. News, vol. 23, pp. 1–2.

Nakamura, H. and Lang, Yu-Hun, 2001. Prediction of hazard area of landslide induced by earthquake. Proc. Int. Conf. Nat. Haz: mitigation and management, Amritsar, India. p. 25.

Nandy, D.R., 1976. The Assam Syntaxis of the Himalaya: a re-evaluation. Sem. Rec. Geol. Study, Him., Misc. Pub., GSI, vol. 24, pp. 363-368.

Nilsen, T.H. and Brabb, E.E., 1972. Preliminary photo-interpretation and damage maps of landslide and other surficial deposits in northeastern San Jose, Santa Clara County, California. USGS Misc. Field studies Map MF 361.

Nilsen, T.H., Taylor, F.A., and Brabb, E.E., 1976. Recent landslides in Alameda County, California. USGS Bull., no. 1398, pp. 1-21.

Nilsen, T.H. and Turner, B.L., 1975. Influence of rainfall and ancient landslide deposits on recent landslides (1950-1971) in urban areas of Contra Costa County, California. USGS Bull., no. 1388, pp. 1-18.

Nishida, Y., Yagi, N., and Futaki, M., 1979. The theoretical analysis of the pore pressure due to rain water permeation in the ground. Proc. 6th Asian Reg. Conf. Soil Mech. Found. Engg., Singapore, vol. 1, pp. 241-244.

O'Loughlin, C.L., 1974. A study of tree root strength deterioration following clear felling. Can. Jour. For. Res., vol. 4, pp. 107-113.

Panigrahi, R.K. and Bhagwan, J., 2002. Landslide hazard zonation using remote sensing in GIS environment - a new approach. In: Rao, K.S. and Srivastava, R.K. (Eds), Geotechnical engineering: environmental challenges. Proc. Ind. Geotech. Conf., pp. 615-618.

Perugia, P.R., Carrara, A., and Guzzetti, F., 2002. Assessing and mapping landslide hazards and risk. Nat. Haz. Ear. Sys. Sc., vol. 2, pp. 1-2.

Petley, D.N. and Reid, S., 1999. Landscape sensitivity and change at Taroko, eastern Taiwan. In: Smith, B. J., Whalley, W.B., and Warke, P.A. (Eds), Spl. Publ., Geol. Soc. London, vol. 162, pp. 179-195.

Pichler, E., 1957. Aspectos geologicos dos escorregamentos de Santos (Portuguese). Bull. Sociedade Brasilerado Geologia, vol. 6, pp. 69-79.

Pilgrim, K. and Nicholas, K., 1999. Landslides: risk and decision-making in Kinnaur District: bridging the gap between science and public opinion. Disasters, vol. 23, p. 45.

Piteau, D.R. and Peckover, F.L., 1989. Engineering of rock slopes. In: Goodman, R.E. (Ed), Introduction to rock mechanics (2nd ed). John Wiley & Sons, 576 p.

Radbruch, D.H., Colton, R.B., Davis, W.E., Skipp, B.A., Lucchitta, I., and Varnes, D.J., 1976. Preliminary landslide overview map of the conterminous United States. USGS Misc. Field Studies Map, MP 771.

Radbruch, D.H. and Crowther, K.C., 1973. Map showing areas of estimated relative amounts of landslides in California. USGS Misc. Inv. Map, pp. 1-747.

Rao, D.P., 2000. Disaster management. Proc. Int. conf. Map India, New Delhi.

Rengers, N., Soeters, R., and Westen Van, C.J., 1992. Remote sensing and GIS applied to mountain hazard mapping. Episodes, vol. 15, pp. 36-46.

Rodriguez, O.J.M., Hinojosa, J.A., and Prieto, C., 1978. Regional studies on mass movements in Spain. Intl. Assoc. Engg. Geol., 3rd Intl. Cong., vol. 1, pp. 267-277.

Romana, M., 1985. New adjustment ratings for applications of Bieniawski classification of slopes. Intl. Symp. Rock Mech., Zacatecas, pp. 49-53.

Sabins, F.F. (Jr), 1986. Remote sensing principles and interpretation. Freeman & Co., New York, pp. 246-260.

Saha, A.K., Gupta, R.P., and Arora, M.K., 2002. GIS-based landslide hazard zonation in the Bhagirathi (Ganga) Valley, Himalayas. Intl. Jour. Rem. Sens., vol. 23, pp. 357-369.

Sahai, B., 1993. Application of remote sensing for environmental management in India. Spa. Envi. Rep. Sp. Plen. Ses., Intl. Astro. Fed., 44th Congress, Garz, Australia.

Sarmah, R.N., 1989. Clay minerals in Disang-Barail Groups of sediments from Kohima, Nagaland. Bull. Ind. Geol. Assoc., vol. 22, pp. 107-111.

Schuster, R.L., 1997. Landslides: effects on the natural environment. Proc. Symp. Engg. Geol. Env. Intl. Assoc. Engg. Geol., Athens, vol. 5.

Schuster, R.L. and Highland, L.M., 2001. Impact of landslides and innovative landslide mitigation measures on the natural environment. USGS Open File Rep. 01-0276, pp. 29-36.

Serafim, J.L., 1968. Influence of interstitial water on the behaviour of rock masses. In: Zienckiewicz, O.C. and Staag, K.G. (Eds), Rock mechanics in engineering practices. Wiley, New York, pp. 55-97.

Seshagiri, D.N. and Badrinarayan, S., 1982. The Nilgiri landslides. GSI Misc. Publ. No. 57.

Shah, A.N. and Jadhav, P.C., 1987. Control of slope stability in the Bhinj Rao basin area, Pauri Garhwal Himalaya (UP). Jour. Engg. Geol., vol. 16, pp. 13-22.

Sharan, R.B., 1995. Landslide hazard zonation in Salal area of Chenab River Valley, J&K State, India. Symp. Rec. Adv. Geol. Studies, NE Himalayas, Lucknow, pp. 21-23.

Sharda, Y.P. and Bhambay, G.C., 1980. Kohima Town, Nagaland: a decade of environmental geoscientific studies. GSI Sp. Publ. Series, No. 9, Calcutta.

Sharma, V.K., Sharma, A., and Attre, J.K., 1996. Slope mass rating (SMR) technique in landslide susceptibility evaluation in parts of Nainital area, Kumaon Himalaya. Jour. Engg. Geol., vol. 25, pp. 289-295.

Singh, R.P., 2001. Use of remote sensing in natural disaster. Proc. Intl. Conf. Nat. Haz. Miti. Mana., Amritsar, p. 3.

Skempton, A.W., 1977. Slope stability cuttings in Brown London Clay. Proc. 9th Intl. Conf. Soil Mech. Found. Engg., Tokyo, vol. 3, pp. 261-270.

Soeters, R., Rengers, N., and Westen Van, C.J., 1991. Remote sensing and Geographical Information Systems as applied to mountain hazard analysis and environmental monitoring. Proc. 8th Them. Conf. Geol. Rem. Sens., Denver, pp. 1389-1402.

Soeters, R. and Westen Van, C. J., 1996. Slope Instability - recognition, analysis and zonation. In: Turner, A.K. and Schuster, R.L. (Eds), Landslides - investigation and mitigation. Transp. Res. Board, Nat. Res. Council, Spl. Rep., vol. 247, pp. 129–177.

Sondhi, V.P., 1941. A note on landslips on the Dimapur-Manipur road, Assam. GSI Unpubl. Rep., Strategic Br.

Starkel, L., 1972. The role of catastrophic rainfall in the shaping of the relief of the lower Himalaya (Darjeeling Hills). Geog. Polonica, vol. 21, pp. 103-160.

Swanston, D.N., 1974. Slope stability problems associated with timber harvesting in mountainous regions of the western US. US For. Ser. Gen. Tech. Rep., PNW-21, 14 p.

Swanston, D.N. and Dyrness, C.T., 1973. Stability of steep land. Jour. For., vol. 71, pp. 264-269.

Swanston, D.N. and Dyrness, C.T., 1975. Impact of clear cutting and road construction on soil erosion by landslides in the Western Cascade Range, Oregon. Geol., vol. 3, pp. 393-396.

Swanston, D.N. and Swanson, F.J., 1977. Timber harvesting, mass erosion and steep land forest geomorphology in the Pacific northwest. In: Coates, D.R. (Ed), Geomorphology and engineering. Hutchinson & Ross, Stroudsburg, pp. 199-221.

Takei, A., 1982. Limitation methods of hazard zones in Japan, Kyoto Univ. Lab. Erosion Control, Res. Bull., vol. 1, pp. 7-25.

Taylor, F.A. and Brabb E.E., 1972. Maps showing distribution and cost by counties of structurally damaging landslides in the San Francisco Bay region, California, winter of 1968-69, USGS, Misc. Field studies Map MF 327; scales 1:500,000 and 1:1,000,000.

Terlien, M.T.J., Asch Van, Th. W.J., and Westen Van, C.J., 1995. Deterministic modeling in GIS-based landslide hazard assessment. In: Carrara, A. and Guzzetti, F. (Eds), Geographical Information Systems in assessing natural hazards. Kluwer Academic Publishers, pp. 57-77.

Ter-Stepanian, G., 1974. Depth creep of slopes. Bull. Intl. Soc. Engg. Geol., vol. 9, pp. 97-102.

Terzaghi, K., 1950. Mechanism of landslides. In: Paige, S. (Ed), Application of geology to engineering practice. Geol. Soc. Amer. Mem., pp. 83-123.

Terzaghi, K., 1962. Stability of steep slopes in hard unweathered rock. Geotechnique, vol. 12, pp. 251-270.

Thapliyal, B.K., 1998. Disaster management – preparedness planning. Proc. Intl. Conf. Dis. Man., Guwahati, pp. 55-65.

Thigale, S.S., 1999. Recommendation on landslide and water scarcity problems of Nagaland with special reference to Kohima. Report.

Thigale, S.S., Khandge, A., Thigale, M., Bhokare, M., and Sawarkar, A., 1998. Causative factors of landslides as applicable to GIS: a case study of western mountain chain of Maharastra, India. Proc. Intl. Symp. Rem. Sen. GIS to Disaster Reduction, Tsukuba, Japan. Geol, Surv. Japan, pp. 197-213.

Thong, G.T. Aier, I., and Walling, T., 2004. Preliminary geological report of Mao slide. Report submitted to BRO.

Tiziano, C., 2003. Landslide hazard evaluation: the landslide hazard curves. Jour. Geotech. Geoenviron. Engg., vol. 129, p. 520.

Valdiya, K.S., 1985. Accelerated erosion and landslide prone zones in the Central Himalayan region. In: Singh, J.S. (Ed), Environmental regeneration in Himalaya - concept and strategies. Prakashan.

Valdiya, K.S., 1987. Environmental geology: Indian context. Tata-McGraw Hill, New Delhi., 583 p.

Vargas, M., 1971. Effects of rainfall and groundwater levels. Proc. 4th Pan Amer. Conf. SMFE, New York, pp. 135-141.

Varnes, D.J., 1980. Landslides hazard zonation. Review of principles and practices. Bull. IAEG.

Varnes, D.J., 1984. Landslide hazard zonation: a review of principles and practice. Nat. haz., UNESCO, vol. 3, pp. 63.

Varshney, R.S., Prakash, S., and Sharma, P.C., 1987. Rock slides in Alakhnanda valley. Jour. Engg. Geol., vol. 16, pp. 1-12.

Veder, C. and Hilbert, F., 1980. Landslides and their stabilization. ISBN, USA.

Verma, R.K., 1985. Gravity field, seimicity, and tectonics of the Indian Peninsula and the Himalaya. Allied Publishers, New Delhi, pp. 155-189.

Verstappen, H.T., 1995. Aerospace technology and natural disaster reduction. In: Singh, R.P. and Furrer, R. (Eds), Natural hazards: monitoring and assessment using remote sensing techniques. Elsevier, New York, pp. 3-15.

Vincent, R.K., 1997. Fundamentals of geological and environmental remote sensing. Prentice Hall, New Jersey.

Vuichard, D., 1986. Geological and petrographical investigations for the mountain hazards mapping project, Khumbu Himalayas, Nepal. Mount. Res. Dev., vol. 6, pp. 41-52.

Wadge, G., Wislocki, A.P., and Pearson, E.J., 1993. Spatial analysis in GIS for natural hazard assesment. In: Good, D., Parks, B.O., and Steyaert, L.T. (Eds), Environmental modeling with GIS. Oxford University Press, pp. 332-338.

Wagner, A., Raymond. O., and Leite, E., 1987. Rock and debris slide risk maps applied to low volume roads in Nepal. Transportation Res. Board. 4th Intl. Conf., Low-volume Roads, Ithaca, USA, pp. 255-267.

Westen, Van, C.J., Rengers, N., and Soeters, R., 2003. Use of geomorphological information in indirect landslide susceptibility assessment. Nat. Haz. 30. Kluwer Academic Publishers, Netherlands, pp. 399-419.

Westen, Van, C.J., 1994. GIS in landslide hazard zonation: a review, with examples from the Andes of Colombia. In: Price, M.F. and Heywood, D.I. (Eds) Mountain environments and geographic information systems, pp. 135-166.

Westen, Van, C.J., 1993. Remote sensing and Geographic Information System for geological hazard mitigation. ITC-Publ., no. 15, ITC, Enschede, pp. 393-399.

Yin, K.L. and Yan, T.Z., 1988. Statistical prediction model for slope instability of metamorphosed rocks. Proc. 5th Intl. Symp. Landsides, Lausanne, vol. 2, pp. 1269-1272.

Yuan, R.K.S. and Mohd. I.S.M., 1997. Integration of remote sensing and GIS techniques for landside applications. Proc. 18th Asian Conf. Rem. Sen., Malaysia.

Zêzere, J.L., Reis, E., Vieira, G., Rodrigues, M.L., Garcia, R., Oliveira, S., and Ferreira, A.B., 2003. Integration of spatial and temporal data for landslide hazard assessment - a case study in the area north of Lisbon (Portugal). Geophy. Res., vol. 5, pp. 39-73.

Zaruba, Q. and Mencl, V., 1969. Landslides and their control. Elsevier, Amsterdam, 205 p.

Zernitz, E.R., 1932. Drainage pattern and their significance. Jour. Geol., vol. 40, pp. 498-521.

Zhang, J., Jiao, J.J., and Yang, J., 2000. Insitu rainfall infiltration studies at a hillside in Hubei Province, China. Engg. Geol., vol. 57, pp. 31-38.