LANDSLIDE HAZARD ZONATION OF THE BHILANGANA RIVER BASIN (UTTRANCHAL HIMALAYA)

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MASTER OF PHILOSOPHY

VIJENDRA KUMAR PANDEY

CENTRE FOR THE STUDY OF REGIONAL DEVELOPMENT
SCHOOL OF SOCIAL SCIENCES
JAWAHARLAL NEHRU UNIVERSITY
NEW DELHI-110067
INDIA
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जवाहरलाल नेहरू विश्वविद्यालय
JAWAHARLAL NEHRU UNIVERSITY
Centre for the Study of Regional Development
School of Social Sciences
New Delhi-110067

CERTIFICATE

I, **VIJENDRA KUMAR PANDEY**, certify that the dissertation entitled **"LANDSLIDE HAZARD ZONATION OF THE BHILANGANA RIVER BASIN (UTTARANCHAL HIMALAYA)"** for the degree of **MASTER OF PHILOSOPHY** is my bonafide work and may be placed before the examiners for evaluation.

(VIJENDRA KUMAR PANDEY)

Forwarded by

PROF. HARJIT SINGH
(SUPERVISOR)

21.7.05
DR. MILAP CHAND SHARMA
(SUPERVISOR)

29.7.05
PROF. M.D.VEMURI
(CHAIRPERSON)

Tel. : 6107676, 6167557 Ext. 2466, 2463 Gram : JAYENU Fax : 91-011-6165886, 6198234

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VIJENDRA KUMAR PANDEY

Dedicated to:

My Parents

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Chapter one

INTRODUCTION

INTRODUCTION

The problem of slope instability is a common phenomenon of high mountainous terrain across the world. Landslides is one of mass wasting processes, considered as a catastrophe, and always cause a major problem by killing human beings, damaging properties, as well as natural resources. Catastrophes are referred to as natural processes of destruction that are beyond control of human beings.

Landslides are a problem in India as well The Himalayan mountain belt comprises of tectonically unstable, younger geological formations, subjected to severe seismic activity. Every year number of landslide occurs causing number of casualties and huge economic losses, which are either induced by earthquakes or triggered by heavy downpour of rainfall. An earthquake of magnitude <6.5 (epicenter – Agora, near Uttarkashi, Uttaranchal) shocked the Garhwal Himalaya on October 1991, and caused extensive damage to human lives as well as properties and induced more than 200 mass movements[1]. Among various rainfalls triggered landslides, one has been occurred in the Malpa 1998, U.P. Himalaya (Uttaranchal) which killed more than 300 peoples including 60 pilgrims to Kailash – Mansarowar[2] .The Okhimandal landslide blocked the course of

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[1] Lewis, A. Owen, M.C. Sharma and R. Bigwood (1995), Mass Movement Hazard in the Garhwal Himalaya: The effects of 20 October 1991 Garhwal Earthquake and the July – August 1992 Monsoon season, In D.F.M.McGregor and D.A. Thompson (ed.) Geomorphology and Land Management in a changing Environment. Jhon wiley and Sons Ltd.pp.69

[2] NNRMS (2003): Landslide Hazard Zonation using remote sensing and GIS Techniques. ISRO, vol. (B) 28; pp. 65 –71.

Madhyamaheshwar Ganga, a tributary of Mandakini River, of U.P. Himalaya, which caused the formation of a huge artificial lake, besides killing about 37 people[3].

The varieties of eco-systems that it supports are therefore; fragile in such that even small disturbance triggers changes, which rapidly assume alarming proportion[4]. The Boundary Thrust that tectonically sub-divided the Himalayan provinces in to latitudinal zones is characterized by multiple splitting of rock formations, and are thus, particularly vulnerable to excess erosion and frequent landslides[5].

The Himalaya is bristling with landslides and other mass movement's processes today and in geological past. These areas are seismically very active since Alpine Orogeny, causing small to large-scale displacement of soil to rock mass, which are destabilized slopes as well as changed the flow direction of streams[6]. However in recent years, increasing exploitation of natural recourses, intensive construction activities and destabilizing forces of nature have combine together to generate a class of problems, large and complex.

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[3] Srivastava, S.K.; Bhattacharya, A.; Reddy, P.R.; Bhan, S.K. & Rao, D.P. (1998) Satellite Data captures Landslide around Malpa & Okhimandal, U.P., India. Interface, vol. 9(3); pp. 5-6

[4] Ganjoo, S.K. (1987): Landslide: A Case Study of Jammu- Srinagar National Highway. Dissertation submitted to CSRD/SSS/JNU; Supervised by Dr. S. Padmaja. pp. 6

[5] Chansarkar, R.A. (1975): Geological and Geomorphic factor in landslide investigation. In Proceeding of Seminar on landslide and Toe erosion problems with special reference to Himalayan region, Gangtok; pp.54

[6] Bhandari & Gupta (1985): Problems of landslides in Himalayas and Future directions, in Singh, J.S. (edt.) Environmental Preservation in Himalayas. Nainital, U.P.; Central Himalayan Environmental assessment, Gyanodaya Prakashan, Nainital. pp. 39 - 57

The irrational exploitations of natural resource of the Himalayas by humans, combined with its weak and tectonically active geology, heavy precipitation, and river action result a variety of landslides and other types of mass-movements[7].

It is observed that landslides do not occur in isolation; they are products of their environment and in turn, they influence its condition. There are various factors incorporated in occurrence of slope failures. Much of the literature on landslides has been event specific, often consisting of case studies for scientific and engineering purposes. The case studies have been instrumental in stimulating and complementing systematic research in to the geomechanics, physics of failure mechanism and controlling forces. As a result what goes during a landslide is reasonably well understood. The solution of this problem requires not only a knowledge of functional link between environmental and slope conditions, but equally an understanding of dynamics of environmental systems[8].

The construction of number of hydroelectric power projects due to massive needs of power supply to industrial as well as domestic use has become a fantasy of developmental process. Its implication on the hilly and fragile tract harnessing natural environment, destroying forests and land use, large scale rehabilitation of human population has compound problem. The more dangerous aspect of it is enhancing hydrostatic imbalance due to storage of water in un-natural state.

Other aspects are, rapid growth of population increasing pressure on fragile tract due to land use change, setting up of new industries, exploitations of forest produce boosting up agricultural growth, tourism, defense have further intensified road

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[7] Krishnaswami and Jain (1975): A review of the some of the major landslides in the Northern and Northwestern Himalaya. In Proceed. Indian society of Engineering Geology, pp. 5

construction activity on the high altitude zones. Since 1970s, India has built new roads and upgraded previous motarable ones to, many thousands of kilometers in the mountains. These activities have two motives. In parts it represents an attempt to accelerate the social and economic development of what traditionally have been isolated and underdeveloped backward areas. Another important aspect of rapid construction of roads on this fragile tract is necessity of military operation to protect our frontiers[9]. It becomes essential for the Government of India to deliver our border to defense forces with ready access to threatened areas. Creation of these roads have opened hillside to a large scale and often-illegal deforestation[10].

Rate of erosion has increased in Himalayan river catchments five times in a short geological past. The present rate of erosions is more than 1 mm. / year[11]. The rivers are carrying incredible large amounts of sediments at rate of 16.5 hectare meter per 100 km of catchment area per year[12].

The cause, of this massive erosion on slope due to clearing of protective vegetal cover which is now only 35%, against optimum of 60%, thus exposing about 65% of the area to the erosive forces. Cause of deforestation includes overgrazing, harvest for

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[8]Michal J. Crozier, (1986): Landslide; Cause Consequences and Environment. Croom Helm London. pp. 1.

[9] Mishra, P.N.and Aggrawal, P. D. (1982): Ecology and Roads in U.P. Himalaya. Indian Highway, Vol. 10 – 1; pp. 1-10

[10] Bhatt, C.P. (1980): Eco-system of Central Himalayas and chipko movement (S.S. kunwar Dashauli Gram Swaraj sangh, Gopeshwar, Chamoli, U.P.), pp.40

[11] Subramaniam and Dalavi (1978): Some aspects of Stream erosion in Himalaya. Himalayan Geology, vol. 8 (2) 1; pp. 822-34

[12] Singhal and others (1979): Sedimentation Problems of Tehri Dam; in proceeding workshop on Tehri Dam Project

timber, lopping of trees for fuel and fodder. The incidence of grazing is 2.5 to 4.5 times the supporting capacity of the forest[13].

Construction of 44,000 kilometers long roads in the Himalayan region has generated $2{,}650\times10^{6}$ cubic meter of debris. Each year, every kilometer of these roads produces 550 cubic meter of debris by landslides and rockfall. Every year about 24×10^{6} cubic meter of sediment slides down slope, destroying vegetation, smoothing springs and choking streams[14].

Slope instability processes, are not only product of local geomorphological, hydrological and geological condition but also due to other factors, which are play important role in occurrence of landslides. These are meteorological, or change in land use and land cover, agricultural practices and human intervention such as construction of roads, buildings etc. But problem of landslides becomes more hazardous in rainy season. Pores of rainwater increase shear stress, and accelerate slope failures. This has been also observed that landslides occur in presence of excess water.

The other most important aspect of planning for constructional works, one should consider local physical settings. For example when planning for construction of road networks in the hilly terrain detailed study of geological setting is essential.

The expansion of the transport network took place in whole India, but hilly region marks distinction in two respects. Firstly, roads are only important links of transport.

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[13] Singh, J.C. and Saxena, A.K. (1980): The grass cover in Himalayan region. In Proc. National seminar on resource development and Environment in Himalayan region, D.S.T. New Delhi.

[14] Valdiya, K.S. (1985): Accelerated erosion and landslides prone zones in the Central Himalayan region. In J.S. Singh (Edited), Environmental Regeneration in Himalaya. Nainital, U.P.; Central Himalayan Environmental assessment, Gyanodaya Prakashan, Nainital. Pp. 12 -38

Secondly, these regions have seen comparatively inferior and late development of transport infrastructure. Underdevelopment of the Himalayan region in India can be attributed to such an inadequate and late development of transport network[15]. It is in very recent past that expansion and upgradation of the Himalayan roads have been taken up. Consequently, length of roads in this region stood at 44,000 kilometers in 1985[16].

Second most important factor is land use practices. In the hilly regions it has been observed, that due to irrational land use practices, slope instability gets enhanced. Deforestation, drainage for irrigation etc. are such activities that make serious problems on the hilly terrain.

The hazardous character of landslide draws attention of scientific community to formulate strategy for minimizing loss of lives and properties. Most important task is preparation of landslide hazard zonation maps, making them available to concerned government vis-à-vis non -governmental agencies, local authorities to implement strategies.

1.1 INTRODUCTION TO AREA OF THE STUDY

The Bhilangana river basin lies between approximately 78° 28′ to 79° 00′ East Longitude and 32° 22′ to 30° 50′ North Latitude. It is a part of Garhwal Himalaya, (Fig. 1.1) occupies area in Tehri Garhwal District of Uttaranchal. Uttar Kashi bounds district

[15] Neeraj Kumar Singh (1998): Geoenvironmental Appraisal of landslide- A Case study of Chamba-Mossoori road. Dissertation submitted to CSRD/SSS/JNU; Supervised by Prof. Harjeet Singh. pp. 1.

[16] Valdiya, K.S. (1985) Accelerated erosion and landslides prone zones in the Central Himalayan region. In J.S. Singh (Edited), Environmental Regeneration in Himalaya. Nainital, U.P.; Central Himalayan Environmental assessment, Gyanodaya Prakashan, Nainital. Pp. 12 -38

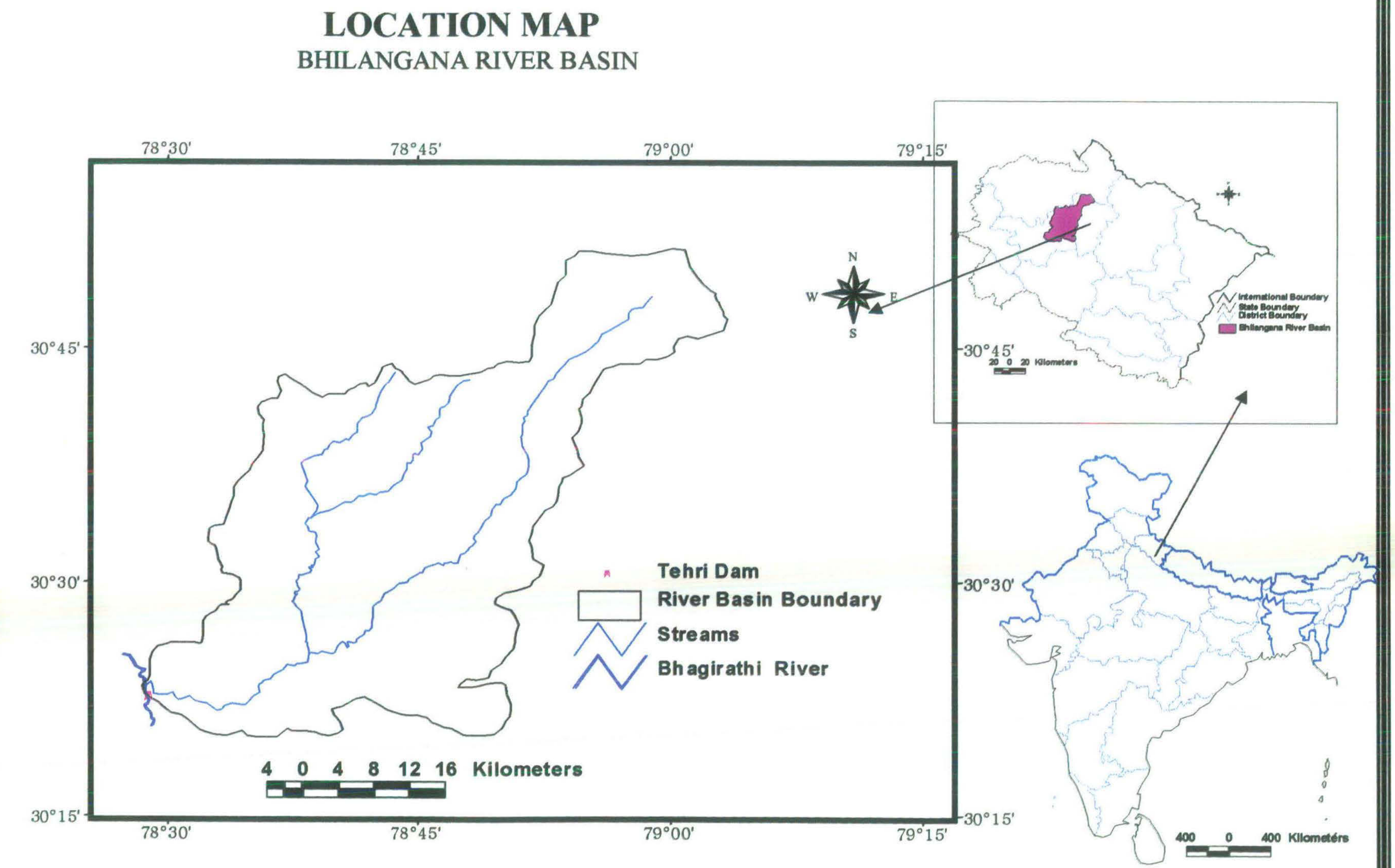
LOCATION MAP
BHILANGANA RIVER BASIN
78°30'
78°45'
79°00'
79°15'
30°45'
30°30'
30°15'
N
W
E
S
Tehri Dam
River Basin Boundary
Streams
Bhagirathi River
4 0 4 8 12 16 Kilometers
International Boundary
State Boundary
District Boundary
Bhilangana River Basin
20 0 20 Kilometers
400 0 400 Kilometers

Fig. 1.1

on the north, Chamoli in the east, to its south lies Pouri Garhwal district and on the west is Dehra Dun district.

The Bhilangana river basin occupies area of Pratapnagar Tahsil, and some stretch of Devprayag Tahsil, in Tehri-Garhwal district. The Bhilangana River is a left bank tributary of river Bhagirathi; join near the Tehri town (altitude 768 meter m.s.l.) above the site of Tehri Dam, which is still under construction. Catchments area covers the part of lesser Himalayas and Great Himalayan ranges, marked by high peaks and deep roaring gorges. The two important glaciers Khatling Bamak and Dudhganga Bamak feed the Bhilangana River.

Tehri Garhwal district can reasonably be divided into three distinct geological zones: The Great Himalaya Range, the narrow window zone along the Bhagirathi valley and the southern synclinal zone of Mussoorie-Sirkanda-Banali Range[17]. The district contains some mineral deposits such as dolomite, limestone, gypsum, rock phosphates, marbles etc.

Fairly long and severe winter season is main climatic feature of study area, but climate in different locations varies according to change in altitude and aspect. As insolation at high altitude is intense, temperatures are much higher in open than shade in summer, while in valleys stagnant pool of cold air causes large diurnal variation of temperature. June is the warmest month with a mean maximum temperature of about 37°C in the valleys with altitude less than 1,069m., 26°C at 2000 m., and still lower with increasing altitudes[18].

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[17] District Gazetteers, Tehri Garhwal District, U.P. 1990, pp. 3.

[18] District Gazetteers, Tehri Garhwal District, U.P. 1990, pp. 4-5.

In the study area, over the 70 percent rain occurs during monsoon months, i.e. June to September; July being rainiest month. There are two rainfall minima, one in the April and another is November. December to March this area receives the rain from the western disturbances, which is about 20 to 30 percent of total precipitation. The climate of district varies from sub-tropical monsoon to the alpine.

The natural vegetation varies from subtropical forests to alpine grasses. Some of dominant species are chir, oak, deodar, haldu, fir, spruce etc.

1.2 LITERATURE REVIEW

Landslide is a very complex environmental phenomenon. Therefore a multidisciplinary approach is required for a better understanding. To get a better understanding of slope instability process, review of available literatures is necessary.

The available literatures mostly deal with event specific studies of landslides. Various geologists, civil engineers and geomorphologist have worked on Landslides, treating various aspects.

For a better understanding of slope instability processes, available literatures have been grouped in to two broad classes. First includes those studies, which are broadly dealing with nature of slope instability process. Second class includes those studies that are event specific analysis. These are:

- Literature, which deals with landslides problems within theoretical framework and do not involve any empirical study, and
- Studies, which deals with field observations of landslides and are based on case studies.

Some studies pertain to slope instability analysis through tools, such as Remote Sensing and Geographic Information Systems (GIS).

Veder, (1981)[19] in his book "Landslides and their stabilization" deals theoretical aspect of landslides. In the introduction part of book author have very clearly define landslides. Discuss about the types of slope failure, types of debris at slope. He was also discussing about causes of Landslides.

This book was written with objective of providing geotechnical engineers with a practical guideline on how to cope with landslides as well as of acquainting them with present state of physical fundamentals and scientific explanations for phenomena of landslides. The book was based on personal experiences of author, gathered over decades of work as Geotechnical engineer on construction sites of Austria and many other parts of the world.

After, details definition of landslides he was discussed about economic importance of landslides. How it could destruct wealth and killing human beings. In the next chapter author concentrated on the providing detail information of characteristics, types of landslide and alternative for their stabilization. Third chapter was cover the whole aspect of factors which causing landslides. In this section author has given very detail information about factor causing landslides. The factors are grouped in five categories. These are first deals with geological cause like stratagraphy, dip, type of rocks etc. Second part cover the morphological cause, third deals geomorphologic cause, fourth physiochemical properties of lithology, and last one with hydromorphological

[19] Veder, Christian (1981). Landslide and Their Stabilization. Springer-Verlag New York Inc., U.S.A.

characteristics of rocks and action of water. Author in the book verifies these factors by primary data collected by different scientific instruments.

Remaining, section author was discussing about theoretical basis of calculation of slope safety factors analysis. In this parts author has given details knowledge of geometric and mathematical formulas. He was also talk about the applicability of these equations and their limitations. And also given a detail knowledge of different types of field observation, and how could we improve of these formulas. Then author was given different methods of field and laboratory investigation, such as Aerial photography, Geodetic surveys and Geological (Seismicity, geoelectric) investigations.

In the last Veder has given methods of slope stabilization. Author ~~was~~ produced different scientific and conventional methods for slope stabilization. He ~~was~~ has given details of different sites of landslides prone areas, and how there was a slope instability phenomenon was controlled across the world. Author, ~~was~~ also has been developed a scientific instruments 'short – circuit conductors' for controlling landslides.

Finally, author has made great efforts in book. This book is providing a framework for Geotechnical engineers; students to have a clear understanding about slope instability phenomena, theoretical as well as practical.

Zaruba and Mencl (1982)[20] in their book 'Landslides and their Control' deals with geological and geotechnical aspects of landslides. This book provides much valuable knowledge of collecting of information, with new methods of field investigation and the

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[20] Zaruba, Q. and Vojtech Mencl (1982). Landslide and Their Control. Elsevier Scientific Publishing Company, New York, U.S.A.

application of computing techniques. This book has been brought much progress with respect to theoretical analysis and data handling of slope instability phenomena. In the first section of the book authors has briefly defined landslides and then after giving economic significance of landslides. How it could go to the damage properties and unvaluable lives of human beings. They have been made a list of structures that could be damaged by slope instability phenomena. In they next section discuss the relationship of various destabilizing and triggering factors causing landslides. After the brief introduction of classifications of slope movement's phenomena, they have produced detailed knowledge of mechanics of slope failure.

In this part authors discuss about the condition on which at a particular sites landslides could occur. They have discussed so many conditions such as failure arising at the toe of the slope, failure arising at the top of the slope, slope movements in weak rocks etc.

In the following section this discussions has been extended to geological definitions of landslides, methods of landslides investigation. They have talked different methods of field investigations such as survey of landslides area, the use of aerial photographs, the use of geological map, hydrological research, surveying the slide movement, and field shear tests. Authors have also talk about the laboratory investigations.

Remaining part of this book deals with stability analysis and corrective measures of landslides. They have present different methods of slope stabilization, and problems facing with their applicability in the field. In order to minimize the risk the authors have also discuss the geotechnical aspects of different developmental scheme such as mass movement with dams, roads, urban planning and mass movements and the exploitation of mineral deposits.

This book deals with many aspects of landslides such as geological, geomorphic and hydrological. This book is serving as basic framework for geologist, civil engineers and students for their scientific investigation of landslides. Due to the scientific nature of this book, the utility of this book is limited to only professional researchers and scientists.

Crozier, (1986)[21] in his book 'Landslides: causes, consequences and environment' started with the definition of landslides and raise the issue related to internal working of slopes. How the process of slope failure related to present environmental condition. After the having the brief introduction of different classificatory schemes of landslides, authors present a few multiple objectives classificatory scheme.

In order to understand the nature of slope failure, author has given details of factors causing landslides. He have discuss different factors and set a model to find out commutative causation among these causative factors. Author has also given the details of using the formulas of safety factor analysis of slope. Further to see the influenced of various destabilizing factors on inherent strength and slope instability analysis, quantification of these factors and based on these quantitative analysis has been proposed.

Following section of the book deals with the environmental and geomorphic models for the development of unstable terrain. In this part, author has given details of the geological properties of rocks, morphological characteristics of the slope. He has

[21] Crozier, M. J. (1986). Landslide, Cause Consequences and Environment. Croom Helm, London.

discussed about the condition of development of slope failure such as regional instability, fluvial downcutting of the river, change in the slope, etc.

Last section author has been discussing about the significance of rainfall. He is emphasized rainfall as triggering factor of landslides. He was also talk about the threshold limit of and its use in predicting intensity and frequency of landslide events. Then author has discussed damaging nature of landslides. He has made lists under different subtopics such as personal cost, economic costs and environmental costs.

Finally this book provide a basic knowledge to research scholars and student to have a clear understanding about the slope instability phenomena, due to its simple and effective presentation of information. This book is most useful book for the students among those available today.

Singh and Pandey (1996)[22] in their paper focused on the pattern of spatial distribution of landslides and their impact on local communities. In this research paper they has been find out that increasing anthropogenic activities along the slopes have altered the existing land use pattern posing risk from different type of hazards. Also they have mention that the nature of landslides event in Indian Himalaya is more hazardous than the Canadian Rockies due to varying concentration of population and community awareness along with the difference in the level of technical expertise.

In this paper authors have used the methods of field investigation. They have visited both selected areas and collected the field data, of general terrain information. They have surveyed the areas where landslides had been occurred, noted the nature of

[22] Singh, R.B. & Pandey, B.W. (2002) Landslide hazard in Himachal Himalaya (edited by V. Subramaniam - Environmental Hazard in south Asia). Capital publishes co. New Delhi; pp.55 – 64.

failures. One most important thing that they have conducted interviews to local people to gathered historical information about the occurrence of landslides, and impact of that on their livings.

This is a very good research paper, presented all the information in very simplified forms. It's very useful for the student to conduct fields' works and collects information about the landslide events.

Higaki and Yoshida (1996)[23] in their paper raised the issue that geological structure and chemical action of water induced the slope failure events. In their research they find out that many landslide events occurred due to geological structure.

In the paper authors have visited the area and marked the geological Features such as cracks, faults, escarpments, dip, strata and weathering characteristics of rocks. They have find out association that the maximum numbers of the geological structure mentioned above, the probability of slope failure is maximum.

Sarkar and Kanungo (2000)[24] in their paper raise the issue that, deterministic approaches are applicable for landslides hazard mapping only when the geomorphic and geologic conditions are fairly homogenous

over the entire study area and landslides types are simple. In the paper they have used white box model for the calculation of quantitative value of stability in terms of factor analysis.

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[23] Higaki, D. and Yoshida, K. (1996): Geological structure and movement of landslide slopes from the viewpoint of slope evolution process in Proc. Of the 8th International Conference and Field Trip on Landslides, Granada, Spain 27-28 September, by Chacon, J. and Clemete, I. (ed.) Landslides, pp. 153-162

[24] Sarkar, S. & Kanungo, D.P. (2000) Landslide hazard zonation and risk assesment (Natural Disaster and their mitigation, Remote sensing and GIS perspective, edited by P.S.Roy et al.). IIRS, Dehradun December, pp. 102 – 109.

Authors have been done a critical analysis of applicability of remote sensing and geographic information technique for the landslide hazard mapping. As it's proved that landslide occurrence depends on complex interaction among a large number of partially interrelated factors. They have find that remote sensing technique is very useful for the geomorphologic mapping and detecting the landslide areas where landslides have been occurred in the past. With the GIS technique we can derive the slope, aspects and could be generated useful information. But they have make cleared that reliability of information is depends up to users.

Ray (2000)[25] analyzed the applicability of computer software models in his paper. They have given details knowledge of the Decision space software package provides a framework for integrating spatial data with analytical models, graphic display and the expert knowledge. This is ideal analysis of spatial data with analytical hierarchy process (AHP), ideal point analysis, Factors of importance methods, fuzzy logic etc., built within the ARC/INFO.

Authors have grouped the factors causing the landslides; make the priority and analysis through this software. They have prepared different layers form these data, integrated these layers, and classified the susceptibility class of landslide. It's a very good package for slope instability analysis but there is limitation's only that selection of parameters and making priority of that.

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[25] Ray Champati, P.K. (2000), Operationalisation of Cost-effective Methodology for Landslide Hazard Zonation using Remote Sensing and GIS: IIRS initiative, In P.S.Roy et al. (ed.) Natural Disaster and Their Mitigation: A Remote Sensing and GIS prespective, IIRS, Dehradun, pp. 95-101

Pal (2002)[26] in his paper focussed on the issue of tectonic movements is the main cause of natural hazards in the Garhwal Himalayas. In the present paper author has been emphasized that most of the natural hazards of Garhwal Himalaya are associated with geological event. He was discussed the extension of Arawali ridge down to Himalaya as Delhi- Hardwar- Harsil ridge. This particular ridge is an underground ridge, which is posing through the Dehra Dun. It is 70-75 km in width and is expected at a depth of 2 to 2.5 km below Dehra Dun City, which is situated on its crest. Due to presence of the ridge several time tectonic activity, causing various types of hazards. Along the Main Central Thrust and Main boundary fault, disastrous landslides are occurring every year.

In this paper, author has presented all geological aspect about natural hazards in very effective manner. This paper is very useful for the understanding of environmental hazards in Garhwal Himalaya.

Basu and Ghatowar (1988)[27] raised the issue that intensity and magnitude of slopes instability phenomenon increasing with increased human intervention in the study area. They have historical records of the area, as numbers of landslides occurring in that particular area. Authors are found that in their research that due to increasing human intervention in the area these instability phenomena is tremendously increased.

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26 Pal, Devendra (2002), Extension of Arawali Basement below Garhwal Himalaya and Geological control over the occurrence of Natural Hazards in Uttaranchal State, In National Seminar on Geodynamic, Nainwal, H.C. and C. Prasad (ed.) Geodynamic and Environment Management in Himalaya, Dehradun, India.

27 Basu, S.R. and Ghatowar, L. (1988), Landslides in the Lish Basin of the Eastern Himalayas and Their Control, In Singh, S. and R.C. Tiwari (ed.) Geomorphology and Environment, The Allahabad Geographical Society, Allahabad, pp.428-433

Authors are emphasized, that due to increase in population of the hilly regions of the country as well. Become the most important in hilly area due to their direct interface with natural environment. They have found that tree plantation on the slopes (tea), extensive needless deforestation, shifting cultivation, quarrying and constructions works, inadequate drainage, led to worst landslide phenomena of the area. The methodology adopted in this study was rationalistic one, comprising of the quantitative determination of the instability factors of slope. Analysis of soils, mapping the composition and orientation of geological structure and the examination of geomorphological processes involved in sculpturing land surfaces together with the study of the nature and extent human interference.

Pande (1988)[28] in his paper selected a small area of Lesser Himalaya. He was finding out that increasing human activity, such as unscientific land use and land covers, deforestation of the lesser Himalaya region is the major cause of slope instability. In this paper field observations method has been employed. He was collected all types required data about the studies in the fields through different instruments.

Pande was found a critical relationship between the land use and Land capability of the selected region. He was noted that in those areas slope instability phenomena is most hazardous, where land use is against the land capability. Author has also prepared the assessment mapping of slope instability phenomena.

[28] Pande, R.K. (1988), Land Use and Slope instability in Kafura-Bhaunra Nala of Lesser Himalaya, India, In Singh, S. and R.C. Tiwari (ed.) Geomorphology and Environment, The Allahabad Geographical Society, Allahabad, pp.444-454

Alcantara-Ayala and Thornes (1996)[29], they have selected an area and sort out the problems of slope instability related to geological structure and morphology. They have examined evolution processes of an entire landslide slope and find

out that the slip plane of present landslide and landslide displacement distribution chemical composition of ground water. In the present research authors have emphasized that slope evolution process could induce by the relationship between the geology and quality of water. Due to different chemical composition of water and chemical reaction with the respect to lithology, different types of weathering processes are active.

Irigary, et al. (1996)[30], in their research paper explore the means of Geographic information system (GIS) to identify the factors causing slope failure. They have selected an area and surveyed the whole area; used different instruments collected the all kinds of data such as slope angle, lithology, fault, fracture, landuse etc. Then after used the GIS prepared the different required layers for susceptible of landslides. For the assessment of the degree of significance of the observed relationships the P coefficient, the Godman-Kurshkal coefficient "G" and the Kolmogorov-Smirnov test (K-S) were used. The determinant factors showing the highest degree of association with rockfall are lithology,

[29] Alcantara-Ayala, I. and J.B. Thornes (1996): Structure and hydrology in controlling mass failure in space and time-The case of the Guadalfeo failures in Proc. Of the 8th International Conference and Field Trip on Landslides, Granada, Spain 27-28 September, by Chacon, J. and Clemete, I. (ed.) Landslides, pp. 153-162

[30] Irigary, C. and Chacon, J. and T. Fernandez (1996): Methodology for the analysis of landslide determinant factors by means of a GIS: Application to the Colmenar area (Malaga, Spain) in Proc. Of the 8th International Conference and Field Trip on Landslides, Granada, Spain 27-28 September, by Chacon, J. and Clemete, I. (ed.) Landslides, pp. 153-162

morphological units, elevation and illumination coefficient, until flows are related to elevation and slope angle.

The authors have found out that, when a large area could consider for risk assessment morphological units, elevation and lithology result the more dominant between the considered factors.

1.3 OBJECTIVE OF THE STUDY

In the present study landslides investigation has been taken up in the Bhilangana River Basin of the Uttranchal Himalaya. Considering the importance of slope instability process, attempt has been made to identify the factors that cause slope instability, as well as to find out interrelationship among these variables. The study also aims to prepare landslide susceptibility map of the study area, suggest mitigation plans to stabilize the slopes. Some broad objectives are follows:

- To identify the causative factors of landslides occurrence in the Bhilangana River Basin, and find out the interrelationship among these factors,
- To identify the most susceptible locations of landslide occurrence in Bhilangana River Basin,
- To divide the landslide areas into zones according to their degree of susceptibility, and
- Find out their mitigation mechanism.

1.4 HYPOTHESES

Slope instability is a complex geomorphic process. Study concentrates on verifying the research findings in the light of the available data and information. Environmental variables vary over space and time. Therefore it is necessary to evaluate these factors with a natural limit. Present study includes to test the following hypotheses:

- Higher the slope angles maximum the probability of slope failure,
- High altitudes with weak lithology, produce more slope failures,
- Roads excavations causes the maximum slope instability,
- Any incision on toe of slope will have more slope failure,
- High proportions of forest cover on the slopes, lower the probability of failure,
- Heavy and prolonged spell of rainfall determines the nature and extent of slope failures

1.5 DATABASE AND METHODOLOGY

In order to meet the objective of the study and test the hypothesis appropriate data and information are required. Following sources of data have been used:

➤ Secondary sources:

- Topographic map, 1:150,000 scale (Survey of India), ? 1:50,000
- Climatic data, pertaining - temperature and precipitation (IMD),
- Geological Maps, NATMO
- Satellite imagery (Digital), and
- Land use and Land cover data by NATMO

It is important to choose appropriate methodology for the landslide hazard zonation. Keeping in the view that various factors are interrelated in causing landslides, it is necessary to authenticate results with statistical techniques. Some methods used are as follows–

- Digitization of contours of topographic map to prepare digital elevation model (DEM), derive slope map, hillshade and aspects etc in Arc View 3.2.
- The study area segmented in to grids of 1.5×1.5 km2 for morphometric analysis,
- Landuse and Landcover classification from satellite imagery, techniques is to get the results, supervised classification is used in Erdas Imagine 8.4,
- Heuristic approach has been used to assign weightages to the factors which results to instability and Principal component analysis has been done taking grid Id as independent variable and slope, relative relief, dissection index, ruggedness index, land use and land cover, road density, fault/ thrust density, and lithology as dependent variables, and
- In order to prepare landslide hazard susceptibility map the following maps has been used: Slope, relative relief, dissection index, ruggedness index, lithology, land use and land cover, road density, and fault/ thrust density.

The methodology for preparation of landslides hazard zonation map is shown in the Fig. 1.2.

1.6 ORGANIZATION OF MATERIAL

The nature of slope instability process is varying over space and time. The introductory chapter of the present dissertation has been devoted to placing of the landslide problems in the Bhillangana River Basin. Apart from the introduction of the study area, comprehensive literature review has been done of the available literatures, to have a clear understanding about the slope instability phenomena. The rationale behind the literature review to get information about what kinds of research has been done on the

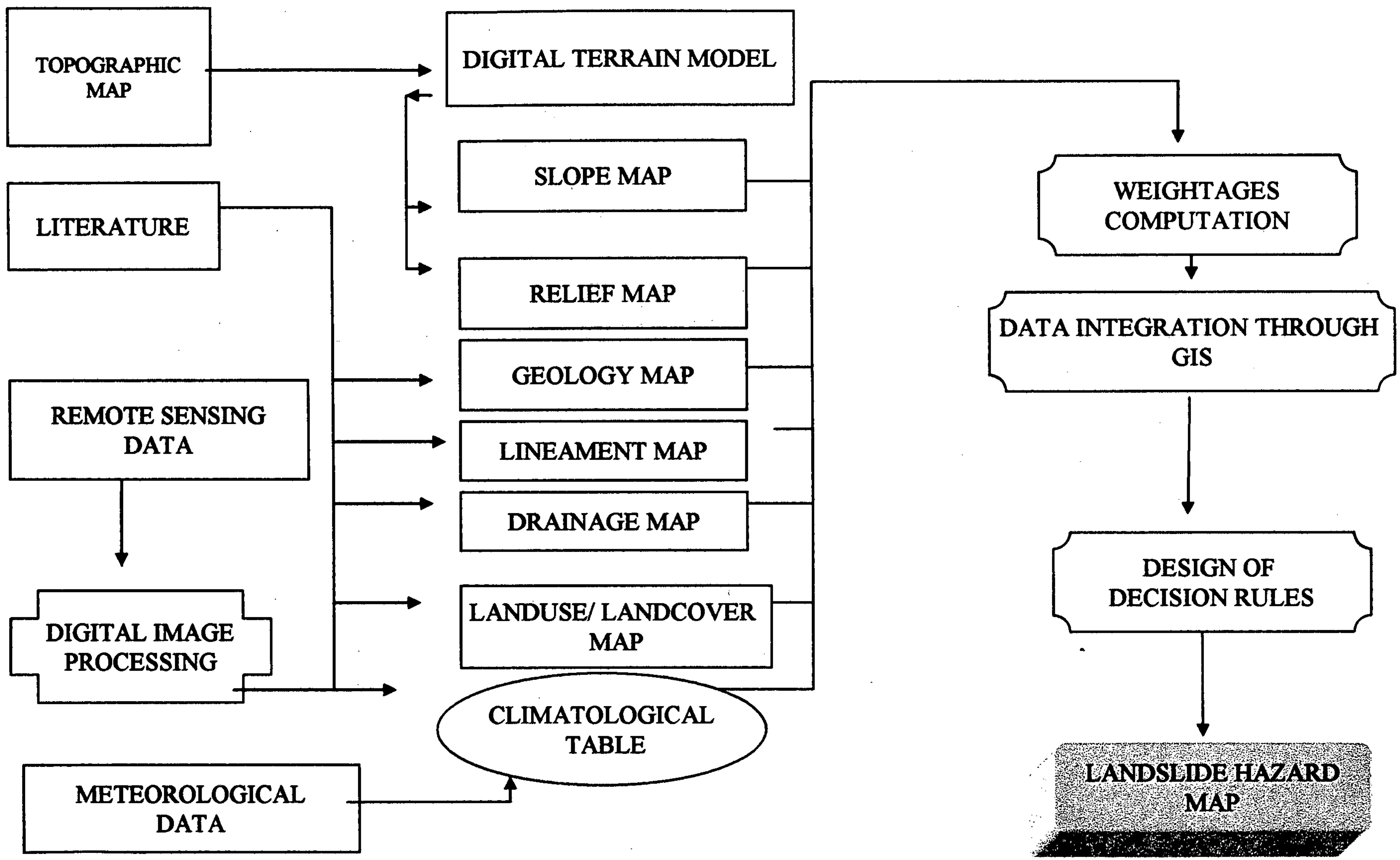


Fig. 1.2 Flow chart of Methodology of Landslide Hazard Zonation Mapping.

landslide and methodology that involve. Also this chapter cover, objective of the study, data sources and methodology that have been used in the present study.

Any research is supposed to strike proper balance between theoretical understandings of the phenomena with empirical reality. Theoretical pursuit, therefore of various aspects of landslides have been discussed in the following chapters. Second chapter of the present study deals with defining slope instability phenomenon, characteristics, types and classification, according to the frequency and magnitude of occurrence. Chapter third of the present study, covers the factor that are causing slope instability. Theoretical analyses of the available mathematical formulae for the calculation of slope safety have also been done in this chapter.

After having the theoretical understanding of the slope instability phenomena, fourth chapter of the present study devoted to present the physical setting of the Bhilangana River Basin. Physiography, geology, climate and other aspects have been discussed in this chapter. Chapter five covers the landslide hazard zonation and management practices required to minimize the frequency and magnitude of the slope instability phenomenon.

In the last this study also has come up with some conclusions.

Chapter two

CHARACTERISTICS TYPES AND CLASSIFICATION OF LANDSLIDE

CHARATERISTICS TYPES OF LANDSLIDE

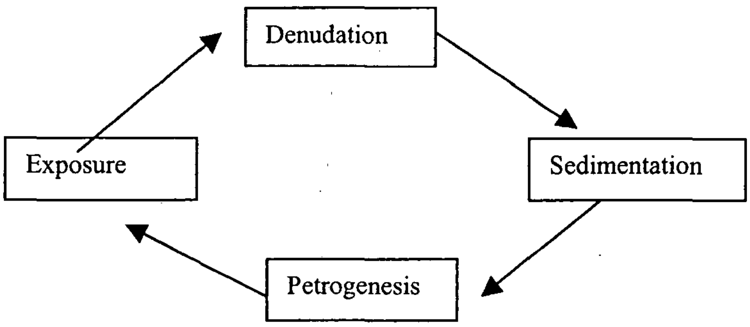
The problem of the instability of slopes, both natural and excavated, has to be dealt with in natural sciences for a better understanding and safer human activity. When slope stability is disturbed, a great variety of sliding movement takes place[1].

Scientist who studied the landslides dynamics, have identified it by different terms according to size, shape, magnitude and nature of occurrence. Some time these occurrences are termed as mass movement and slope movement, which are synonyms to one another. An acceptable definition for the term and identification of the event certain criterion needs to be developed to understand the phenomena.

2.1 DEFINITION:

Slope movement constitutes a part of denudation process which involves mechanisms, to weaken the rock (weathering process), and carry it away from source area (erosional process). Denudation is generally referred to as wearing away of the landmass through geological times. Davis (1902) considered the 'denudation' is active removal of regolith or waste rock from the slope[2]. Five groups of processes (Figure 2.1) has been recognized as because to the external to 'exogenic forces'.

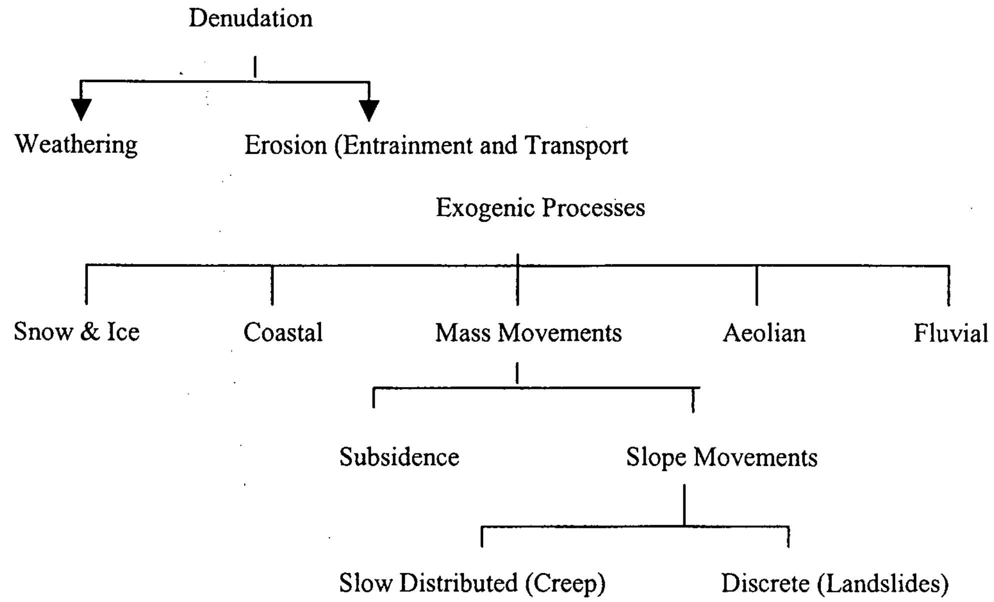
a. ROCK CYCLE



[1] Zaruba, Q. and Mencel, V. (1982): Landslide and Their Control. Elsevier Scientific Publishing Company, New York, U.S.A. pp. – 13

[2] Davis, W.M. (1902): Base level, grade, and peneplain. Journal of Geology, Vol.10; pp.-77-111

b. DENUDATIONAL CYCLE



c. NORMAL EROSION

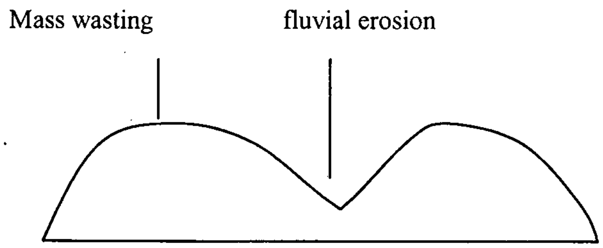


Fig: 2.1 Classifications of Major Geomorphic Processes (Adopted from Crozier, 1986, pp.-5.)

Among these five erosion agents, mass movements is distinguished from the others by being the process evolved in the outward and downward gravitational movement of the slope/ slope materials without the aid of running water as transporting agent. In other words it is a product of variations between the two forces active over the slope, i.e. shear strength and shear stress. It is important to note that mass movement process does not deny the importance of the water in either its solid or liquid state as destabilising factor nor does it exclude subsidence and other movement on flat ground.

It is necessary to differentiate between the term mass movement and mass wasting, used synonymously. It is a broader geomorphic concept commonly used in conjunction with the erosion cycle to refer to the mass reduction of the interfluves as opposed to the degradation by streams. It must include all the action of non-linear erosional processes working on the slope between streams[3].

The slope instability is another important term, which is generally referred to as predisposition of a slope to mass movement. This condition gives rise to slope movements. On the slope two principal types of forces exist, one tends to promote slope movement (shear stress) and another resist this force (shear strength).

Landslides due to its hazardous nature, has attracted many scholars of various natural sciences, offering challenging issue of the study. In some regions slope instability occurres rarely, whereas some region it is very frequent. Similar slope characteristics in two different areas may show varying results due to different environmental factors. Therefore these have varying properties of slope causes failure, which many scholars have identified differently. Some commonly encountered terms are: Slope failure (Ward 1945), mass wasting (Yatsu 1966), mass movement (Hutchinson 1968), landslides (Varnes 1958) and slope movement (Varnes 1978)[4].

Scientific community has most commonly used the term landslide as universal accepted terms for the various types of slope movements. It has been generally seen as a

[3] Gouddie, A. and others (1990): Geomorphological Techniques. Unwin Hyman Ltd. London; pp.71-80

[4] Crozier, M.J. (1986): Landslide, Cause Consequences and Environment. Croom Helm, London pp. - 8

category of mass movement, excluding creep and subsidence. Skempton and Hutchinson (1969) stated "the generic term landslide embraces those downslope movement of soil or rock mass as a result of shear failure at the boundaries of the moving mass"[5]. However, the term could also include many types of movements where nearly all types of displacement occurs other than by slide. Vernes advocated the term slope movement for mass movement restricted to the slope[6].

Landslides, especially in soils, are gravitational downward and outward movements of soil masses that may be set off by the liquefying effects of water or induced by the earthquakes[7].

Another definition of landslides incorporates all varieties of mass movements or slope including, rock fall, topples and debris flow that involves little or no true sliding. According to the 5th International symposium on landslide (1988), "landslide is the movement of the rock mass of the earth or debris down a slope"[8].

The general definition of landslide is "sudden collapse of a large mass of hillslope. It may be set off either by the earthquakes are or saturation of surface by rainstorm". Further these have grouped into different categories according to the size, magnitude and nature of occurrence.

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[5] Skempton and Hutchinson (1969): Stability of natural slopes and Embankments foundation. State of the Art Volume, 7th International Conference on soil Mechanics and foundation Engineering, Mexico, pp. – 291-240

[6] Vernes, D.J. (1978): Slope movement and types and Process. In: Landslides – Analysis and Control. Edited by R.L. Schuster and R.J. Krizek, Transportation Research Board special Report 176, National Acedamy of Sciences, Washington DC., pp. 11 - 33

[7] Veder, C. (1981): Landslide and Their Stabilization. Springer-Verlag New York Inc., U.S.A., pp.- 2

[8] Popsecue, M.E. (1996): Form landslide causes to landslide Prediction. In sennest (Edited), Landslide. Balkema Rotterdam

2.2CLASSIFICATION OF SLOPE MOVEMENTS

Landslide activity has been grouped in to different categories according to the nature, frequency and magnitude of the event. Classifications of slope movement often have different titles; in some cases these reflect only a semantic difference but in others they indicate variations in the slope of treatment. To understand differences implied, it is necessary to clarify terminology and to place slope movements in the context of the other earth – forming processes[9].

The classification of slope movement has been considered as the first step for any scientific investigation. The great variety of slope movement offers much scope for different systems of classification. Landslide can be classified on the basis of mode and rate of movement, the shape of the slide surface, the types of materials involved and a number of other criteria.

A classification should have certain parameters on which classification could be practiced. Also it is designed to reduce multitude of different but related processes to a few easily recognized and meaningful groups on the basis of common attributes. It should not only involve investigation to the development of model building, development of formulae, but it is required to produce satisfactory explanation of the event. Classifications are also consistently evolving mediate with new findings and minimum structural change in the scheme.

It has been always a matter of critical concern, what types of criteria one should adopt with the landslide investigation. Some time one have to clearly identify the failure events, taking into consideration the principal cause of the slope movements.

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[9] Crozier, M.J. (1986): Landslide, Cause Consequences and Environment. Croom Helm, London, pp. - 4

Many authors have developed an appropriate classification of slope movements. Among these are Terzaghi (1950), Campbell (1951), Hutchinson (1978), Vernes (1978) and Crozier (1973, 1978). These authors have adopted different sets of parameters, in which most important list of parameters have been produced by Vernes (1978)[10]:

1- Types of movement (Five types have been recognized as – Falls, Topples, Slides, Lateral Spreads and Flows)
2- Types of materials
3- Quality of materials; degree and orientation of structural discontinuities
4- Morphometric characteristics
5- Degree of displacement of materials from its **in situ** position
6- Degree of disruption of displacement mass
7- Orientation of slide geometry to geological structure and landform
8- Degree of potential hazards
9- Causes of movements
10- Geological settings
11- Rate of movements, and
12- Water, air and ice contents.

The other most important things, which must be considered, are the motive behind the classification. Mostly these classifications are practiced on the basis of the case studies. It is important to note the motive of classification scheme. Different authors have given Numbers of classification scheme. Some important classification schemes are as follows.

[10] Crozier, M.J. (1986): Landslide, Cause Consequences and Environment. Croom Helm, London, pp. 8.

Campbell (1951) attempted to provide a scheme for the evolving problem of erosion. The scheme (Table 2.1) highlights the issue of the mass movement and issues of soil conservation.

Table 2.1 **Mass Movements and Soil Erosion** (Campbell 1951)

Simple types	Compound types
1- Creep erosion	
Soil creep	
Scree creep	Sheet and Creep
Solifluction	Terracettes
2- Slip erosion	
Soil slip	
Earth slip	Slip and earthflow
Slump	Slump and earthflow
Subsidence	
3- Flow erosion	
Earthflow	
Debris avalanche	Creeping erthflow
Mudflow	
Associated erosion	
4- Sheet erosion	Sheet and wind erosion
5- Gully erosion	Gullied earthflow
Gullied slip	
Tunnel – gully	
6- River erosion	
Bank erosion	
Sedimentation	
7- Wind Erosion	Wind and sheet erosion

This scheme is very useful for the soil conservation practices particularly in New Zealand, and across the world. The classification gives little attention to parameters such as failure geometry, strength properties or types of materials, which might assist in analytical woks of mass movement.

In the 1978, Hutchinson provided a geotechnical classification scheme for landslides investigation. In this method he used stability analysis of the slope. Because many landslides event occur as a result of a sudden increase in ***shear stress*** which cause by steep slopes and increase height of the slope through excavation. Stability analysis is carried out by determining the differences between amount of shear stress being exerted within the slope and amount of resistance that can be mobilized against that stress by the material involved.

Table 2.2 **Mass Movements on Slopes** (Hutchinson 1977) 1978

ELASTIC REBOUND

1. Inward movement of valley sides
2. Vertical round of valley floor

   a. Valley anticlines
   b. Raised valley rims and upward flexure valley

A. CREEP

Generally not leading to a landslide

1. Shallow, predominantly seasonal creep; Mantle creep

   a. Rock creep
   b. Soil creep
   c. Talus creep

2. Deep – seated continuous creep; Mass creep

Generally leading to a landslide

3. Pre-failure creep, progressive creep (primary, secondary, tertiary)

Post Slide

4. Post – failure creep

B. LANDSLIDES

Table: 2.2 Continued.........

1. Rotational slips/slides (each unit approximately circular)

   a. Single rotational slips (single event)

   b. Successive rotational slips (usually retrogressive, occasionally progressive)
   c. Multiple rotational slips (all retrogressive)
   i. in stiff, fissured clays
   ii. in soft, extra-sensitive (quick) clays; clays flows

2. Compound slides (markedly non-circular)

   a. Graben slides (single event)
   b. Progressive non – circular slides

3. Translational Slides (usually single event or retrogressive)

   a. Rock slides

      i. Planar slides; block glide (two dimensional)
      ii. Wedge failure

   b. Slab, or fake slides

   c. Spreading failure (all retrogressive)

   d. Debris (detritus) slides

   e. Mudslides (generally retrogressive)

   f. Bog slide, bog flows, bog bursts

   g. Flow slides (involving collapse of loose structure)

   h. Catastrophic debris flows

   i. Mudflows

      i-climatic
      ii-volcanic (lahars)

Classes (e) to (f) may be referred to as debris flow by some classification

4. Troppling failures

Table: 2.2 Continued...

5. Falls
6. Sub-aqueous slides
    a. Under-consolidated clay slides (slumps)
    b. Flows slides

C. FREEZE- THAW PHENOMENA

1. Stone Stripes (a form of patterned ground)
2. Periglacial Solifluction
    a. Sheets
    b. Lobes
    c. Stone streams
3. Cambering and valley bulging

Crozier (1973) carried out a study of various characteristics of slope movement in South Island of New Zealand and provides a morphometric classification for landslide studies. He used the parameters of slope geometry, characteristics, types and flow movement by using simple morphometric analysis. Crozier also developed morphometric indices, which could also be applicable to distinguish various classes of movement recognized by the others.

Table 2.3 Morphometric Indices (Crozier 1973)

Index	Calculation
Depth	D/L*100%
Dilation	Wx/Wc
Tenuity	Lm/Lc
Flowage	|Wx/Wc-1| Lm/Lc*100%
Viscos Flow	Lf/Dc
Displacement	Lr/Lc
Fluidity (water content) ranked residuals from regression of flowage on slope.	

On the basis of these indices, Crozier provided the most useful morphometric classification of landslide studies. The scheme is given in Table 2.4.

Table 2.4 **Process Groups used in Morphometric Analysis** (Crozier 1973)

Process Group	Class of Movement
Fluid – Flow	Mudflows, debris flows, debris avalanches
Viscous – flow	Earthflows, bouldery earthflows
Slide- Flow	Slump\flow
Planar Slide	Turf glide, debris slides, rock slides
Rotational Slide	Earth and rock slumps

The three-classification system discussed above represents widely divergent approaches to the way in which slope movements may be characterized and classified. Each of the classification schemes is problem oriented with specific case. Campbell classified the soil conservation; Hutchinson provided basic information for the geotechnical engineering. Crozier's classification scheme is based on the geomorphological studies. However, where an initial assessment is being made of slope movements or where studies have multiple objectives, a general classification (Table 2.5) is required.

Table 2.5 **Abbreviated Classification of slope Movements** (Varnes 1978)

TYPE OF MOVEMENT			TYPE OF MATERIAL		
			BEDROCK	ENGINEERING SOILS	
				PREDOMINANTLY COARSE	PREDOMINANTLY FINE
FALLS			ROCK FALL	DEBRIS FALL	EARTH FALL
TOPPLES			Rock Topple	Debris Topples	Earth Topples
SLIDES	ROTATIONAL	FEW UNITS	Rock slump	Debris slump	Earth slump
	TRANSLATIONAL	MANY UNITS	Rock Block slide Rock slide	Debris Block slide Debris slide	Earth block slide Earth slide
LATERAL SPREADS			Rock spread	Debris spread	Earth spread
FLOWS			Rock flow (deep creep)	Debris flow	Earth flow (Soil creep)
COMPLEX			Combination of two or more principal types of movement		

On the basis of comprehensive studies of the above three-principle classification scheme, Crozier presented a comparative studies of these classification scheme (Table 2.6).

Table 2.6 **Correlation of Classification for Landslides in Engineering Soils** (Crozier, M. 1986)

Hutchinson (1977)	Varnes (1978)	Campbell (1951)
Fall	debris fall	
	Earth fall	
Toppling failure	debris topple	
	Earth topple	
Single rotational slip	debris slump	slump
Successive rotational slip	earth slump	
Multiple rotational slips		
Spreading failure	earth lateral spread	
Graben slide	earth block glide	
Progressive non-circular		
Slide		
Debris slide	debris slide	earth slip
	Debris block slide	
Mudslide		
Bog slide	earth slide	soil slip
Catastrophic debris flow	debris flow	debris avalanche
Mudflow	earth flow	earth flow
Flow slide		mudflow
Bog flow		
Bog burst		

2.3 TYPE OF SLOPE MOVEMENTS

A wide range of variations in terms of rate, direction and movement is noted in mass movements at different places, having varying vis-à-vis equal environmental condition. On the basis of materials involved at slopes direction and size of movement and rate of movement these are identified. Some important mass movement their mode of occurrence and properties are discussed below.

Table 2.7 Types of Landslide/ Mass Movement

I- Slides		
i. Slump		
a. Rock slump	b. Debris slump	c. Earth slump
ii. Slides		
a. Rock slide	b. Debris slide	c. Earth slide
II- Fall		
a. Rock fall	b. Debris fall	c. Earth fall
III- Flows		
a. Rock flows	b. Debris flows	c. Soil/Mud flows

➢ **SLUMP**

Slump refers to the downward sliding of a rock mass or unconsolidated materials moving as a unit along a curved surface (Fig. 2.2). Generally the slumped material does not travel spectacularly fast. This is a common form of mass movement process especially in thick accumulations of cohesive materials such as clay. Although the rock mass slides in a crescentic shape -scarp are created at head and the block at upper surface is some times tilted backwards. In many cases water percolates in to the base of rock mass through the rupture and cracks and promotes instability and additional movements.

Most probably slump occurs due to overstepened slopes. The material on the upper portions of a slope is held in a place by the materials at the bottom of the slope. As this anchoring material at the base is removed, the materials above are become unstable and react to the pull of gravity. One relatively common example is valley walls that become overstepened by downcutting of the river. Slumping may also occurs when a slope is overloaded causing internal stress materials on the below. This type of slumps also occurs when week, clay-rich materials underlay a layer of stronger and more resistant rocks.

➢ **ROCKSLIDE**

Rockslide occurs when a block of bedrock breaks loose and slides down a slope (Fig. 2.2). If the material is largely unconsolidated the term debris slides is used instead. Such events are faster and the most destructive types of mass movements. Generally rockslides takes place in geological settings when the rock strata are inclined, or where joints and fractures exist parallel to the slope. When such a rock unit is undercut at the base of the slope, it looses support and rockslide occurs. The landslide event is most prolonged during the rainy season, because water lubricates the underlying surface to the point that friction may take place.

The other most important causative factors that induce rockslide event are by an earthquake. In the Himalayan region there is a long history of landslide events after the earthquakes.

> **ROCK FALL**

It refers to down slope collapse of weathered rock materials including rock blocks. The sizes of rock fragments depend upon the size and pattern of rock joints. These types of movements involve vertical displacement of materials without aid of water. This is the most hazardous type of mass movement. On the basis of mode of occurrence and materials involved, its subdivided into rock fall, debris fall and earth fall.

The causes of rock fall vary with lithology and environmental conditions. Rock fall is facilitated by granular and block disintegration of rocks under the process of physical and mechanical weathering and limited action of oxidation in sandstone. Generally, hydrofracturing, stress release, the wedging action of tree roots and other weathering processes promote rock fall. A common cause of rock fall is undercutting of the base by river or more rapid weathering of an underlying weak rock layers.

> **DEBRIS FLOW**

Debris flows is relatively rapid types of mass wasting process, which involves a flow of soil and regolith containing a large amount of water. Because of their fluid properties debris flow frequently follow the streams channels.

Earth flow is most common on hillside during the period of heavy rainfall. When water saturates the soil and regolith, due to pore water pressure these loosened materials flow down slope (Fig. 2.2). Distinction between the earthflow and debris flow is, much faster and fluid than the earthflow, and often follows the stream.

Special type of earthflow, known as liquefaction some times occur in association with earthquakes. Pores, clay- to sand sized sediments that are saturated with water is most vulnerable.

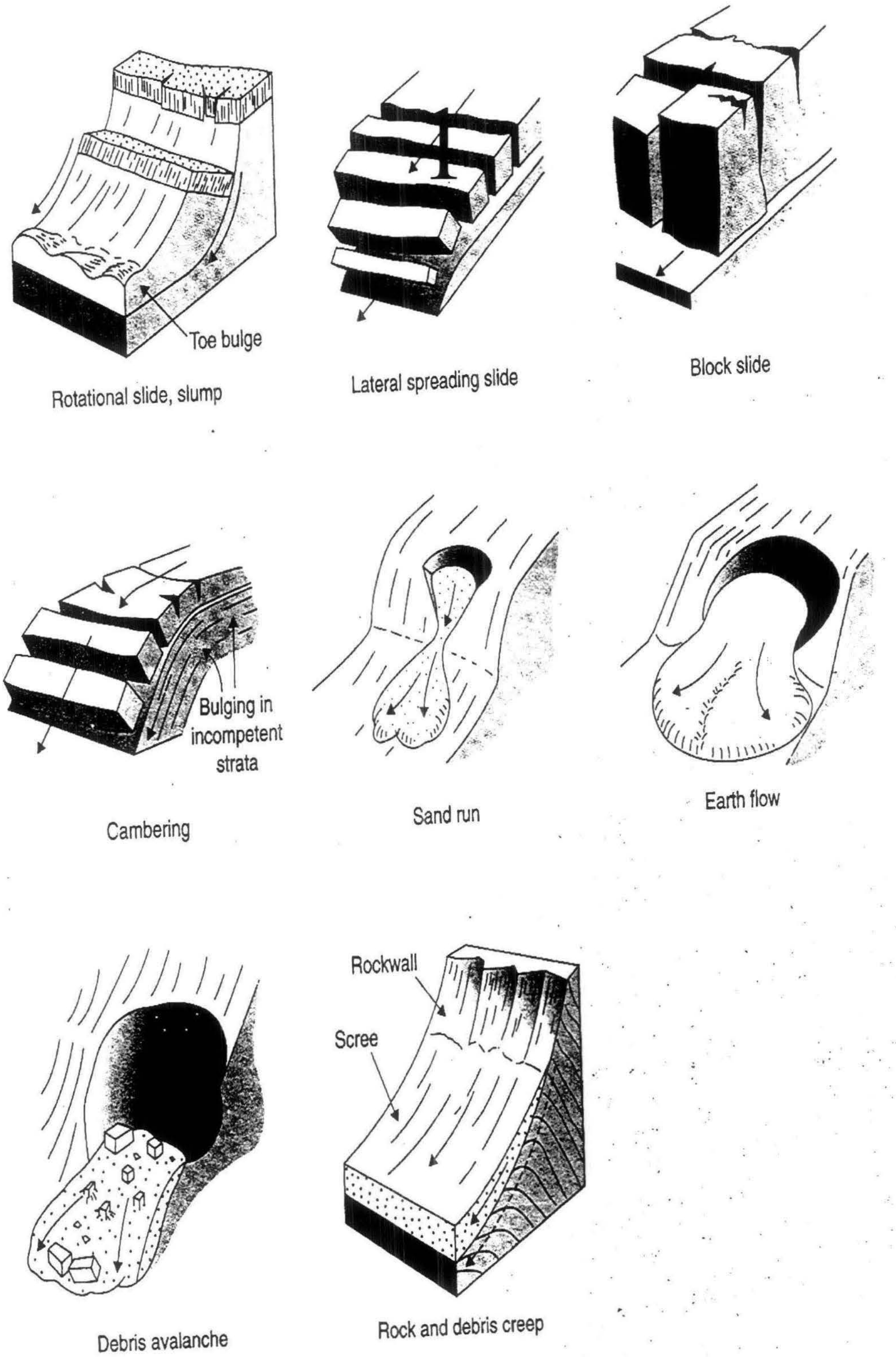


Fig. 2.2 Different Types of slope failures.

➢ **CREEP**

Creep refers to the slow downslope movement of the upper layers of regolith. In the mechanism of mass movements, creep is more widespread and is responsible for the movement of the greatest mass of the materials.

Creep is caused by a number of factors. In the humid temperate regions the combination of the chemical and physical weathering process results more or less continuos layers of regolith covering the bedrock surface. This also occurs in the lower slopes.

2.4 DEFINATION OF SOME IMPORTANT TERMS

The important definitions of terms concerning hazard is given by Varnes (1984):

- **NATURAL HAZARD:** Natural hazard means the probability of occurrence of a potentially damaging phenomenon within a specific period of time and within a given area.
- **RISK:** Its means the expected number of lives lost, person injured, damage to property or disruption of economic activity because of particular natural phenomenon.
- **ZONATION:** Zonation refers to the division of land into homogenous areas and the ranking of these areas according to their degrees of actual of potential hazard caused by mass movement. In common practices landslides hazard zonation maps display the spatial distribution of hazard classes.

Chapter three

FACTOR CAUSING SLOPE INSTABILITY

FACTOR CAUSING LANDSLIDE

As soon as rocks are exposed at the earth's surface, they come under attack by the combined process of erosion; they are loosened, and worn away. In all cases, the force responsible for this leveling of gradation is the relentless downward pull by gravity. The first geologic process to operate is usually weathering, which convert rocks into regolith. Once regolith forms, the process of erosion begins to move it downslope, ultimately to the base level (Fig.3.1).

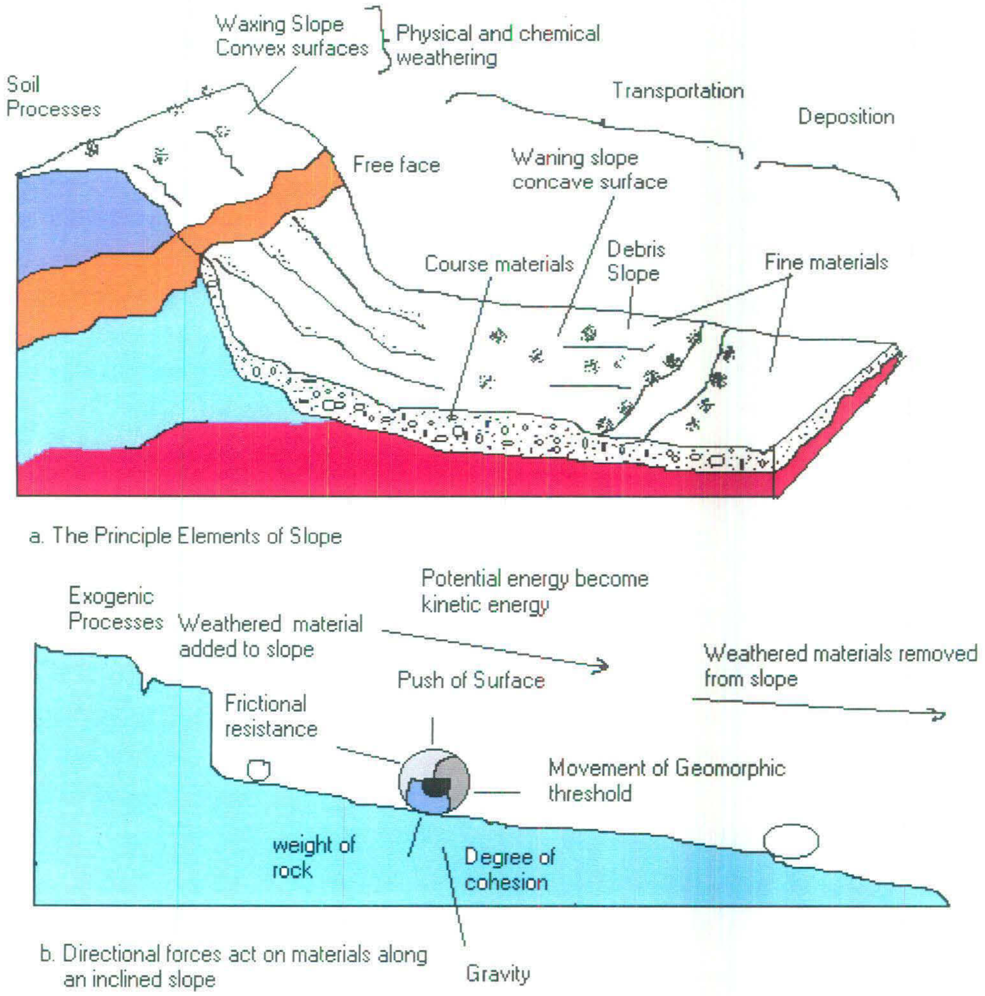


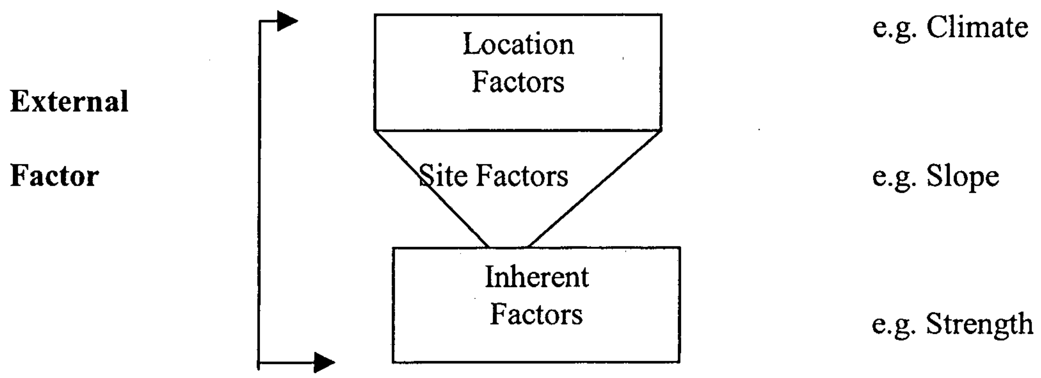
Fig. 3.1 Slope form and mechanics (Adopted from –Summerfield, 1997).

There are number of causative factors for slope instability, which affect and induce mass movements. Because this is one of the complex geomorphic phenomena, it does not occur in isolation. At each landslide event, group of factors play important role to wear down the regolith from slopes vis-à-vis the hard rock masses as well.

Unfortunately, the distinction between stable and marginally stable states in these terms is more easily made in theory, which is in large practice. Besides the problems of establishing accurately the stress condition within slope, the main difficulty lies with determining the full range of stress changes that can be brought about by transient factors. Transient factors, such as climate and earthquakes, vary greatly with time and thus a long record is required to predict probability of failure[1].

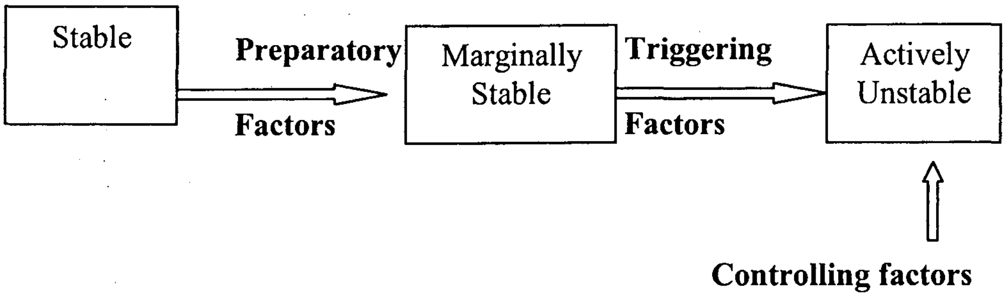
Slope stability of particular location is a reflection of geographic location, climate and geological process. These three factors are very useful frameworks for understanding the causes of instability (Fig. 3.2). These factors are active over each location on the slope, according to their geological and geomorphic properties. Taking into consideration the critical importance of slope movement process, the major causative factors are categorized in two broad groups:

a. Place of operation



[1] Crozier, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp. 33

b. Function



c. Rate of Change

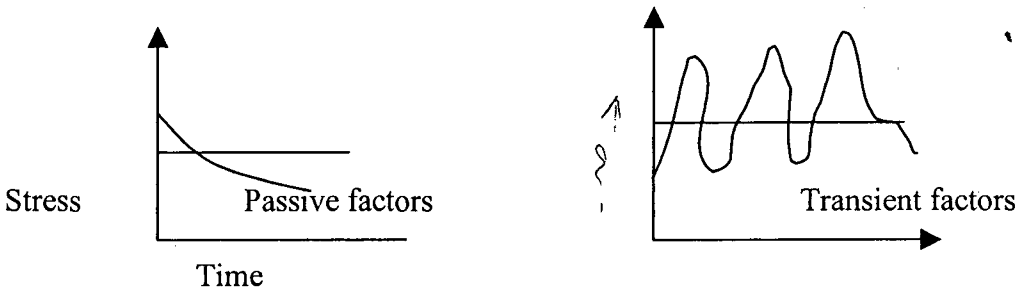


Figure 3.2 Types of Causative factors (Adopted from Crozier, 1986).

- ❖ Geological/ Topographic Factors
- ❖ Triggering Factors

The search for any cause of an individual landslide or an attempt to designate the state of instability may be promoted by a need to find an efficient method to solve the problems. Further, these factors are classified into different classes according to their nature and magnitude of process evolved (Table. 3.1).

Table: 3.1 **Factors Causing Mass-Movements**

1. Principle Causes	**2. Triggering Causes**
➢ Geological Factors	* Seismic events
• Types of rocks	* Precipitation

Table: 3.1 Continued...

• Structures (Faults, Cracks, Lineaments etc.)	*Anthropological Factors
• Dip, incline, Strata, Bedding	-Construction of roads
➢ Morphological Factors	-Landuse pattern
• Excessive steepening of slope	-Rapid urbanization
• Stream excavation/ undercutting	-Constructions of dams, bridges etc.
• Removal of lateral support by weathering	
• Weakening of slope Toe	-Deforestation of slopes
• Removal of Vegetation	-Blocking of natural drainage
• Slope Aspects, Hillshade	
• Drainage pattern and density	-Loading of slopes
➢ Physical factors	-Artificial vibrations
• Decay of cohesion with time	
• Dilatancy of slopes	
• Weathering of rock	
• Soil depth and texture	
• Progressive failures	
➢ Hydrological factors	
• Compaction of soil	
• Permeability of rocks	
• Presence of voids, joints in the rocks	
• Ground water fluctuations	

3.1 GEOLOGICAL CAUSES

In the landslide investigation, geology is principal field, which study critical condition that causes mass movements. Some geological features such as dip, strata, angle of the inclination of deformation, layering pattern of the rocks are very important.

3.2 MORPHOLOGICAL CAUSES

The formation of terrain and its inclination play a critical role to understand instability status of a slide area. Due to the developmental activities on the hillside, it is human beings that disturb the equilibrium of slope by cutting through them and constructing embankments, bridges for transportation routes etc. But landslides may also occur without human force, by undercutting the toe by unregulated rivers or overloading head of slopes. Some important morphological causes are:

3.2.1 EXCESSIVE STEEPING OF SLOPE GRADIENT

These may be caused by the excavation for land development or in response to fluvial downcutting. In exceptional case the angle of slope is steepened as a result of tectonic processes, such as subsidence or uplift. An increase in slope gradient produces a change in the internal stress of the rock mass and equilibrium conditions disturbed by the change in shear stress. Even if other slope parameters remain constant, increase in the slope angle in any circumstance may be sufficient to initiate slope movements.

Another important cause is increase in the slope height. It is noted that increase in height may result in increase in weight over a potential shear plane. Thus, a constant shear plane angle increase in height may cause failure in a cohesive slope, but not cohesiveness of slope. Many scholars have used the term critical height (H'c) above which failure will occur, when analyzing hard rock. They argue that the processes, which create slope relief invariably, involve the removal of materials from the slope face and thus a reduction in lateral support for the slope. This reduction in support creates vertical cracks in the slope according to the tensile strength of material due to tension extending for some distance in the slope. Terzaghi (1943) [2] has shown that on a vertical slope assuming Rankine's active state of stress, the depth of the cracks (Zo) is equal to:

$$Zo = 2c/\gamma \tan (45° + \phi/2) \qquad ...3.1$$

Where, the term c denotes cohesion with respect to effective normal stress γ is bulk density of slope materials and ϕ is angle of internal friction (shearing stress) with respect to effective normal stress. Rankine assumption also dictates that with a vertical slope any failure plane would pass through the toe of the slope at an angle to 45° from the horizontal plus half the angle of internal friction. In many rockslides, rocks avalanches and slab failures, the failure plane is seen to intersect a tension crack at the back of landslides. However, with a better understanding of slope geometry it is also difficult to distinguish critical height and determine the optimum slope angle that protects slope instability. This is the one of the complex geomorphic process, which varies over space. Even in the same rock group, response varies with different environmental conditions. There is also a limitation of application of these mathematical formulae in the determining slope angle. This is the core problem for the geotechnical engineers for any constructional works in the hilly terrain.

3.2.2 WEAKENING OF SLOPE TOE

The weakening of the slope toe have various causes, such as flowing water may erode and undercut the toe of slope. In this case, the best measure to protect the toe is

[2] Crozier, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp.52

either by a carefully carried out rockfill or by a retention wall. The other important cause is the toe of slope move downward through the action of water streaming in the subsoil. It may seem that flow of ground water moving parallel to the slope reduces stability as compared to the slope without ground water flow.

The cutting of the slope for roads on the steep slopes disturbs the equilibrium. It is, required to construct retaining walls to provide lateral support to the slopes.

3.3 PHYSICAL FACTORS

Environmental process do not have distinct boundary that one could state it is a particular type of causative factor. There are overlapping entities, which have complex geomorphic consequences. Physical factors deals with the overall process, which are active on the earth's surface. The exogenetic forces cause physical changes to the landform pattern, their evolution process and wearing away of landless features.

3.3.1 WEATHERING OF ROCK

The rocks at earth surface and to some depth below it, are prone to weathering processes. Weathering processes disintegrate both surface and sub-surface rocks into mineral particles or dissolve them. Weathering processes are both physical and mechanical.

The nature and magnitude of weathering are vary over space and time. Weathering of surface is also controlled by lithological and structural characteristics of rocks, relative relief, slope, aspects etc. besides the climatic condition, topography, vegetation covers. For example, disintegration of rocks is more effective in tropical semi-arid regions due to frost action, while chemical weathering is more pronounced in hot and humid temperate regions.

The disintegration and decomposition of rocks, nature and intensity is directly affected by mineralogical composition of rocks, joints and fractures, layering systems, folding and faulting. Carbonate rock is more vulnerable to chemical weathering due to soluble minerals, while well-jointed sandstones are subjected to physical weathering. Rocks having vertical strata are easily loosened and broken down due to temperature changes, frost action, water and wind action. Durgin (1977) presented a combination of weathering processes in granitic terrain causing landslides[3] (Table 3.2).

Table 3.2: Influence of Weathering on Landslides Type in Granitic Terrain (after Durgin, 1977)

Weathering stage	Weathering Product	Landslides Types	Slide Surface
Fresh rock	<15%	rockfalls, rockslides, blockglides	joint- surfaces
Corestone	15% - 85%	rockfalls, rock avalanches	sheeting joints bedrock surface
Decomposed Granitoid	85% - 100%	debris flows, debris avalanches, debris slide	bedrock surface
Saprolite	100% +laterite	rotational slides	residual joints

A slope is an open system seeking an angle of equilibrium. Conflicting forces work simultaneously on slopes to establish an optimum incline motion. Rocks in the region of steep hillslopes are easily disintegrated due to mechanical weathering and the weathered material is instantaneously removed down the hillslope. Continuous removing

[3] Crozer, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp. 90

of weathering product allows prolonged exposures of rocks to latter weathering processes.

The nature of weathering is largely determined by the presence of vegetation. It is noted that vegetation may protect surface from exposure to weathering, but also becomes a factor of weathering process. In fact, vegetation binds the rock through their network of roots and thus protects them from weathering and erosion. But some times the penetration of roots weakens the rocks by breaking them in to several blocks.

3.3.2 DECAY OF COHESION WITH TIME

Cohesive forces bind up the loosened regolith of the bedrock. Moist sand is held together by the surface tension by water and this cohesion disappears at the moment when sand is soaked or dried out. In the course of the Earth's history, clay wash was sedimented and then consolidated under growing load. At a later stage of geological evolution, their deposits were removed and over consolidated clay with a distinct cohesion remained. Overconsolidated clays are further distinguished by their ability to regain deferability, depending upon the consolidation pressure and increasing with their plasticity[4]. After the load is removed the clays expand in volume parallel to the surface, which will increase the shear stress.

The uppermost layers is most exposed to weathering, changing temperatures and alternate soaking and drying, which disturb the soil to a degree that eventually losses its cohesion altogether. In addition, it undergoes certain chemical changes such as oxidation and decomposition due subjacent zones of ground water fluctuations and temperature changes. These processes work with gravitational forces and the stress reflection parallel

[4] Veder, C. (1982), Landslide and Their Stabilization. Springer-Verlag New York Inc., U.S.A., pp.11

to the surface may cause slope movements that reduce shear strength causing rockslides, soil slides, etc.

3.3.3 DILATANCY OF PEAK STRENGTH

Dilatancy is the process of volume increase experienced by certain materials when they are disturbed and sheared. Volume increase may also result simply from unloading pressure. In the soil, this process is led by water content, densely packed frictional materials, jointed rock, silt and consolidated over clays, which all exhibit same degrees of Dilatancy.

During shear testing, dilatancy is recorded as axial strain in a direction opposed to the normal load. Prior to maximum expansion, the materials initially offer peak resistance to shear stress, followed by decline to a residual resistance as dilatancy occurs[5].

3.3.4 PROGRESSIVE FAILURES

Slopes are open system seeking to the state of equilibrium. Frequently, slides occur at particular sites where shear strength required for the stability of the slopes is lesser than the shear stress. These could be experienced of presence of the weak zone at the slope where, through movements, peak strength is surpassed and shears strength decreased below peak strength. In extreme cases at such weak zones progressive failures occur, where by slip surface will progress from bottom to top in the direction opposite to the soil movements.

A progressive failures could occurs at the particular time and space only if the soil shows marked difference between peak strength (τf) and residual strength (τr) and only if

[5] Crozier, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp. 104 - 105

the mean strength required for the stability of the slope is larger on only insignificantly smaller than the residual strength. Further, it become clear that susceptibility to progressive failures could be the greater, the smaller the displacement (v) required reduces shear strength from peak strength to residual strength.

Bishop (1967) introduced the brittleness index $Ib = (\tau f - \tau r) / \tau f$. Greater is brittleness of the soil, higher it tendency to develop progressive failures[6].

3.3.5 EFFECT OF SEISMICITY

Seismic events are most important accelerator of slope failures. There is a long history of mass movements in the slopes of the Himalayas due to severe earthquake events. It is understood that earthquake events are reduce stability of the slopes by imparting both shearing stress and reduction in resistance to slope materials.

Earthquake wave propagation has the direct mechanical affect on horizontal acceleration, which at high soaking intensity may exceed acceleration due to gravity. This will provide temporary increment in the shearing stress, which is capable to trigger landslide events. The reduction of intergranular bonding afforded by cohesion and internal friction by sudden shoak, irrespective of the degree of the solutions, lowers strength of the material toward its residual value, which could be caused by intensive slope movements.

3.3.6 TYPES OF LITHOLOGY

In the analysis of geomorphic process, geomorphologist strictly deals with the upper layers of the earth crust. The upper part of the earth surface is directly exposed to the exogenetic forces. These forces cause different geomorphic processes, which vary

[6] Veder, C. (1982), Landslide and Their Stabilization. Springer-Verlag New York Inc., U.S.A., pp.13

over space with environmental conditions. But the surface materials also play critical role to control these processes. Different types of rocks have varying mineralogical and chemical composition, structure, and texture having different properties. Hard rocks may have greater shear strength even on steep slope, rather than the softer one.

3.3.7 ROCK STRUCTURE, FAULTS, LINEAMENTS, CRACKS AND JOINTS

These are those geological factors, which are trigger mass movements, Sarkar and Kanungo (2000) found a strong association, between lineament density and landslide events. They noted that maximum density of these geological structures cause the maximum landslide failures. Such structure triggers the slope failures due to weakening the slope strength. Although these factor open the pore water pressure, which could initiate pressure on the bedrock and cause slope failures.

3.4 METEOROLOGICAL FACTORS

Rainfall is the other most important triggering factors of landslides. Due to increased water content in the soil it could quickly disturb the stability of the slopes, accelerating the mass movements. In the Himalayan region, due to heavy rainfall in the monsoon season the landslide failures are more pronounced.

Infiltration of the rainwater depends on various factors such as intensity and duration of rainfall, angle of slope, compaction and types of soils. After the water infiltrates in to the subsurface, developing seepage pressure, contributing to shear stress for slope movements. Although in the hard rocks, when water percolates through cracks and joints acting as lubricating agents, provide slip of surface. Also, when it soaks in the soil increasing the weight of the slope, these loading on the slopes could cause the massive slope failures.

3.5 ANTHROPOLOGICAL FACTORS

Due to the increasing human population and advancement of technology, one can reach anywhere and adjust even in the worse climatic conditions. These human led developmental activities, such as transportation routs, construction of dams, bridges, buildings and changes in landuse practices have disturb the environmental setup.

3.5.1 CONSTRUCTIONAL WORKS

On the hilly terrain, the developmental activities such as construction of road networks, has been increased for the various sets of purposes. These are national defense to protect our borders from neighbors. In the Himalayas, the government of India has been responsible for constructing, the road networks. Every year these roads witness large and worst mass movements, although these roads connect people of remote areas and tourist places on the hill slopes.

These excavations on the steep slopes for the transport, weaken the slope strength, and overload the slopes on the other hand. Another, important factor is construction of buildings on the hilly areas also increase the load on slopes. These loosen the regolith of the slopes. The dam construction also causes the major environmental hazard, damaging vegetation cover and creating hydrostatic imbalances, which could induce seismic events.

3.5.2 LANDUSE AND LANDCOVER

Land use refers to the agricultural and other human activities for different purpose on the earth's surface. These include, agriculture land, forestland, roads, village, town etc. All these activities have different relationships with terrain parameters. Landcover denotes the natural coverage of the surface by vegetation. A plant protects slope against erosion and contributes to the stability, because their roots system binds soil and regolith together. Where plant covers lack on rock surfaces, it gets directly exposed to the slope processes. Mass movement is enhanced specially if slope is steep and availability of water is sufficient.

3.5.3 CLOSING OF NATURAL DRAINAGE

This process evolves disturbing the natural drainage systems of the slopes. These could also be caused by the irrigation activity by the people. During monsoon season, runoff of water ceased if the small rivulet courses are blocked cause excess infiltration. It is overload slopes and induce slope failure.

3.6 HYDROLOGICAL PROPERTIES

This is one of the most important components of the terrain parameters. On the hill slopes, even a small change in the water content could result into worst mass movement. Many landslides occur in presence of water. Some times it acts as an agent of cohesive forces and at others provide slip of surface due to lubrication on the bedrock.

If water content increases in the surface, it increases the weight of slopes that could some times cause mass movements. The permeability of rocks and local groundwater fluctuations could bring different types of physio-chemical activity causing the massive landslides.

SLOPE SAFETY ANALYSIS

Slope is an open system always seeking towards stability forces. Slope instability is the condition, which gives rise to slope movements. The stability can be expressed in terms of the relationship between those stresses tending to disturb the slope materials and force it to moved downslope. Another forces those tending to resist the slope

Not [illegible]

movements[7]. As Taylor et al. (1997) observed that there is no such thing as a "100% safe" slope, whether natural or man made. Probabilities of failure form the only rational basis of assessment[8].

The stability of slope could be expressed in the term that if the slope at the point of movement, shear stress is greater than that of shear strength. Thus instability is determined by both inherent margin of stability, on the existing slope and magnitude of transient forces. Hence, stable slope are those where the margin of stability is sufficiently high to withstand all transient factors.

Transient forces that cause instability, such as climate and earthquakes vary greatly with time and space. Thus a large historical record is required to predict instability of slopes. In addition to the geological deterioration of the margin of the stability with time a long-term survey of slope instability is also taken in to consideration. Probability of regime changes within the transient factors, climate change, shift of tectonic activity and human modification of slope.

A quantitative comparison could be done of the stress, which tend to disturb the slope materials and those, which offer resistance. The influences of these forces conventionally are expressed by the ratio between shear strength and shear stress. This ratio provides factors of safety, which is assumed to be helpful in the instability analysis of the slopes.

Nonetheless, Terzaghi and Peck (1967) and Eigenberger (1972) have given some basic calculations for the slope safety analysis. This method of assessing stability is

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[7] Summerfield, M.A. (1991): Global Geomorphology. John Wiley and Sons Inc. New York, USA., pp.167 - 68

[8] Crozier, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp.36

refereed to as limiting 'equilibrium analysis'. In this methods shear strength can be measured by the formula given by Coulomb-Terzaghi[9]:

$$\text{Shear strength (s)} = c + \sigma .\ \tan \phi \qquad \ldots 3.2$$

Where, c = cohesion with respect to effective normal stress

σ = total normal stress

ϕ = is coefficient of plane sliding friction, which characterizes the packing surface roughness and hardened of constituent particles.

The ratio between shear strength and shear stress is termed as factor of safety. Its can be calculated by using formula:

Factor of safety (F) = resistance/ shear stress = s/τ

$$F = \frac{c + (\sigma - u) \tan \phi'}{\tau} \quad \text{or} \quad \frac{c + (W/A \cos \beta - u) \tan \phi'}{W/A \sin\beta}$$

Where, s = shear strength

τ = shear stress

u= pore water pressure

W = weight of materials; that is γ v

A = area of shear plane

γ = bulk density of slope materials

v = volume of slope materials involved

β= angle of the surface on which movements occur (shear plane)

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[9] Summerfield, M.A. (1991): Global Geomorphology. John Wiley and Sons Inc. New York, USA. pp.167 - 68

Resistance is represented in a simplest form by coulomb-Terzaghi "shear strength equation" but others give a more accurate expression of resistance. This equation provides two identifiable strength parameters; cohesion and internal friction. Cohesion (c) is the amount of the strength offered against shear stress, which is independent of normal stress. In other words cohesion represents the inherent strength of a materials that exist irrespective of any weight imposed directly on (normal to) the surface along which movements tends to take place. The angle of internal friction on the other hand, is the value that indicates the extent to which 'friction', induced by the weight by materials acting directly at right angle to the shear plane as a normal stress, contributes to shear strength. Thus the amount of strength derived from internal friction is a product of the angle of internal friction and the normal stress[10].

The effect of the gravity expressed by the weight of the material is a fundamental determinant of stability conditions, as it not only provides resistance through internal friction but it also supplies the major disturbing force by producing shear stress. The magnitude of these opposing stresses is determined by the resolving the vertically acting weight express as stress and the other acting parallel to shear plane. How much of the weight is manifest as normal stress and how much is shear stress depends on the angle of shear plane (Fig. 3.3). Crozier has been taken three different example of shear plane, and noted that when the angle of shear plane increases, the weight provides proportionally less normal stress and correspondingly greater shear stress.

[10] Crozier, M.J. (1986): Landslide-Cause Consequences and Environment. Croom Helm, London, pp. 39-40

Table: 3.3 Shear stress at different angle (adopted from Crozier, 1986)

Example	shear plane angle	sin	cos	σ(pa)	τ (pa)
A	30	0.50	0.87	75	131
B	45	0.71	0.71	106	106
C	60	0.87	0.87	131	75

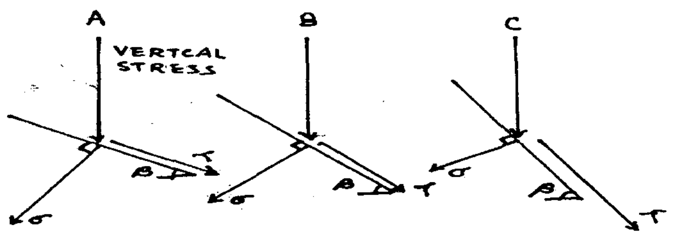

Fig. 3.3 Distribution of shear stress at different slope angles (Adopted from Crozier, 1986).

Another term, which has been covered in equation, is overloading of slope by porewater pressure (u). It is a positive causative factor and may build a ground water level above shear plane; in this case it will reduce the normal stress calculated from the total weight. Positive porewater pressure at any time of particular point in well-drained slopes could be determined by the height of water table vertical above the point and the unit weight of water.

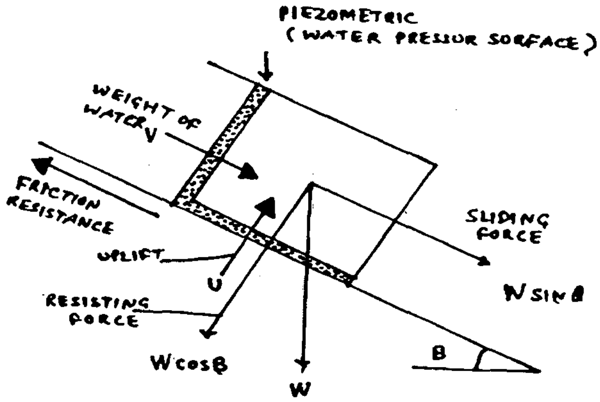

Fig. 3.4 Role of water in the slope instability.

Variation in weight of slopes also causes failure. Changes in the weight imposed on a slope (loading) result from both natural and human agencies. These are precipitation, mass movement depositions, overthrust faulting, vegetation growth, seepage drag from percolating water are natural proceeding, and storage and conveyance of water and other fluids, excavation etc. are man made. From these proceedings of slope loading, shear strength of slope is reduced. The effect of these variations in weight and their effect could be calculated from these equations[11]:

$S = \sigma \tan \phi$ ...3.4

Or $s = W/A \cos\beta \tan \phi$ ...3.5

And shear stress by $T = W/A \sin \beta$ ...3.6

The slope safety analysis could not meet the challenge of controlling landslides event, due to natural phenomenon vary over space and time. The large numbers of data

[11] Crozier, M.J. (1986): Landslide- Cause Consequences and Environment. Croom Helm, London, pp. 33.

can collect from field and taken for laboratory analysis even a small irregularity in data gathering could overruled the whole data module.

Calculating of slope safety will meet the objective only if exact data on marginal conditions and accurate soil-mechanical analysis are available. Of course, one must also remain aware of the fact that small irregularities and inhomogeneous in the soil, which were not discussed during soil explorations, may render the result 's of the calculation completely invalid[12].

Out of context of present study.

[12] Veder, C. (1981) Landslide and Their Stabilization. Springer-Verlag New York Inc., U.S.A., pp. 29

Chapter four

METHOD OF LANDSLIDE ANALYSIS: PHYSICAL SETTING OF THE BHILANGANA RIVER BASIN

METHODS OF LANDSLIDE ANALYSIS

In the present study landslide analysis has been taken in the Bhilangana river basin. This chapter deals with geo-environmental setting of the basin. An attempt has been made to find out the causes of slope failures.

Physical setting of a particular region is defined by the natural environment vis-à-vis cultural preposition. It is still an issue of great debate whether man is product of nature or master of the nature. Topography of any area has a greater role to define the climatic condition, land use pattern and way of life of people. If human activities change these patterns, a class of natural hazards, is resulted in which mass movement is one of them.

It is proved by researchers that problem of slope instability tremendously increase with increase altitude. Comparison of the Himalayas Mountains and other areas of India have been made by Rao (1997):

Table: 4.1 Macro- Zonation of Landslides in India (Rao, 1997)

Hill range	Landslides incident potential	proximate cause
Himalayas	Very high to high	Predominantly natural, Increasing due to human Intervention.
Northeastern hill range	High	Mainly natural
Western Ghats &. Nilgiris	High to moderate	Human intervention dominate natural causes are secondary
Eastern Ghats	Low	Predominantly due to human
Vindhyas	Low	Predominantly due to human

The Himalayas have the highest mountain peaks of the world. These mountain systems are of younger geological formation, weak lithology and tectonically active, prone to several types of natural hazards. Some disastrous landslides of the Uttaranchal Himalaya are as follows:

Table: 4.2 Disastrous Landslides Events in Uttranchal Himalayas (Sources: Natural Resource and Data Management system, DST, Govt. of India)

Events Date	**Events**
July, 1968	Active Kaleswar slides damages the roads
July, 1970	Alaknanda River caused massive damage to road and entire village washed away and 233 persons died, Caused by heavy rains
August, 1971	Alaknanda tragedy, village Beakuchi was completely washed away
July, 1976	Slide on Chamba- Massoorie road causing extensive damage to road
August, 1991	Utarkashi landslide killed more than 2000persons, extensive damage to road, dam and village
September, 1993	Ratighat landslides, blocked the Nainital hill road and damage to forest; induced by heavy rain
August 14, 1998	Okhimandal landslides killed 69 persons
August 18, 1998	Malpa landslides, Kali river; killed more than 205 persons and extensive damage to Kailash-Massrovar road

4.1 PHYSIOGRAPHY

Physiography is a description of features and phenomenon of the earth surface. It includes the study of the formation and development of surface features of landscape such as mountain, plain etc.

The Bhilangana River Basin occupies the area of both lesser and Great Himalayan ranges. Physically this area rises at the confluence in the Bhagirathi River (700 meters altitude) near Tehri town to Phanting Pithwara (6904 meters), Kirti Stambh (6548 meter) and highest peak of the area is Kedarnath (6940 meter). Apart from these higher peaks and deep valleys the whole area consists of highly dissected anticlinarium. Topography of the basin is highly rugged with precipitous slopes; horned peaks, torrential rapids and gigantic escarpments forming gorgeous topography. There is a flat summits surface along the river Bal Ganga (tributary of River Bhilangana) made from the constant erosion of the mountain range[1].

The mountain ranges of the Bhiangana River Basin can be divided into following divisions:

a. Great Himalayan ranges cover northern most part of the study area in an arc shape from Shastru (4846 meter) to Kedarnath (6940 meter), i.e. North-West to South-East.

b. Lesser Himalayan ranges,

What is the scale of map used for preparing DEM?

The Digital Elevation Model (DEM), prepared in GIS environment, represents physiography of the Bhilangana River Basin. A DEM represents an array of elevated points. The variation of surface elevation over an area can be modeled in many ways. DEMs can be represented either by mathematically defined surface or by points on line images. Line data can be used to represent contours and profiles, and critical features such as streams, ridge, slope etc. In GIS, regular grids (altitude metrics) and Triangular Irregular Networks (TIN) model DEMs.

The DEM of Bhilangana river basin is shown in Fig. 4.1. gets clear synoptic view of the physical variations of in the area.

4.1.1 ASPECT

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[1] Asthana, A.K.L. and M.S. Anantharaman (1987) A geomorphological study of Balganga Basin: Garhwal Himalaya, in Pangtey, Y.P.S. and S.C. Joshi (Edt): Western Himalaya, Vol. I. Gyanodaya Prakashan, Nainital, U.P., pp.51

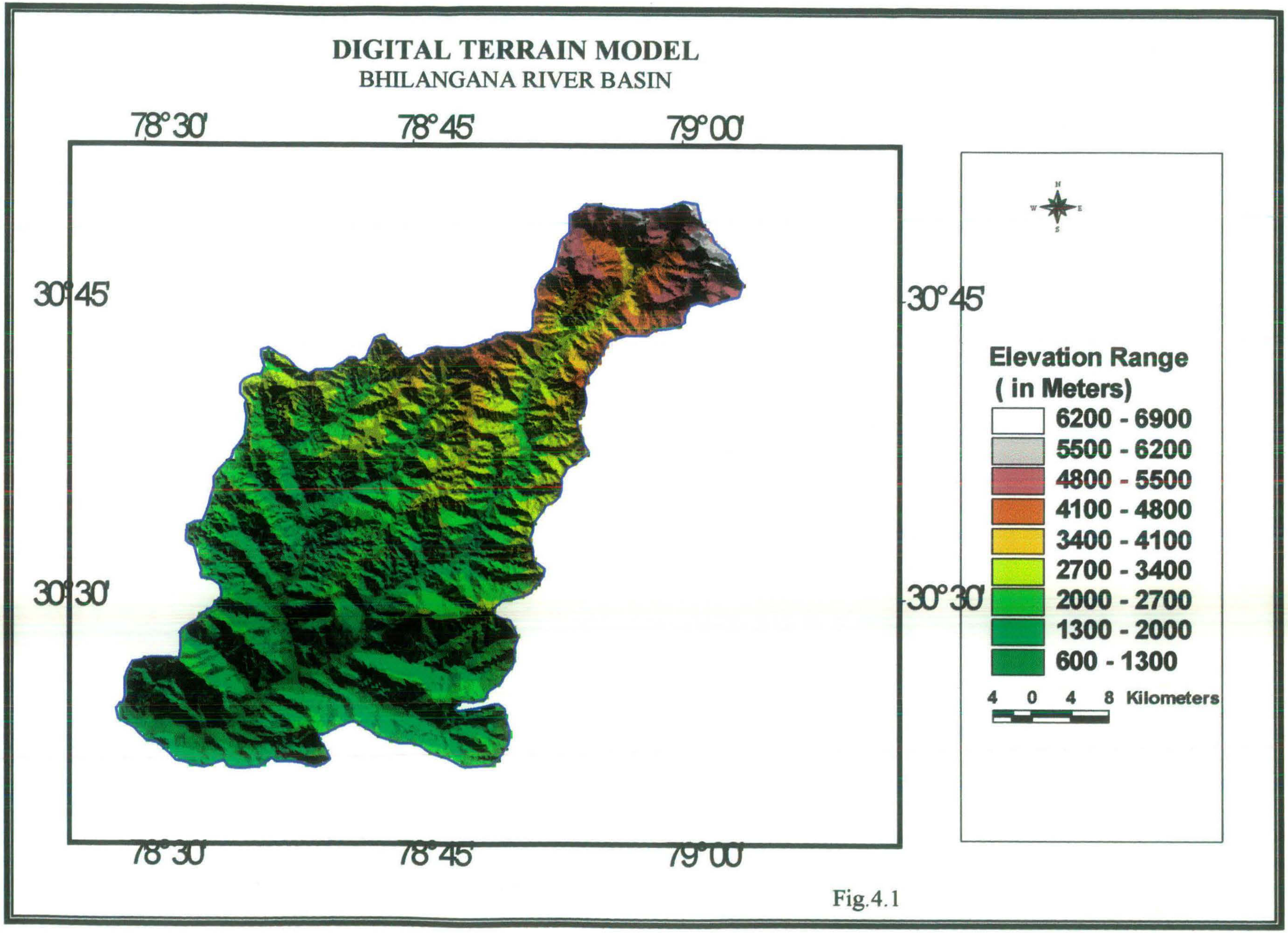
DIGITAL TERRAIN MODEL
BHILANGANA RIVER BASIN
78°30'
78°45'
79°00'
30°45'
30°30'
N
W
E
S
Elevation Range
(in Meters)
6200 - 6900
5500 - 6200
4800 - 5500
4100 - 4800
3400 - 4100
2700 - 3400
2000 - 2700
1300 - 2000
600 - 1300
4 0 4 8 Kilometers

Fig.4.1

An aspect is a very important geomorphic phenomenon. It refers to the slope inclination facing the sun. It is important to assess different types of physical and chemical weathering process that are active over surface facing sun which need certain amount of heat. The different slope surface and their inclination angle towards the sun have been shown in the Fig. 4.2. Aspect is not directly related to slope instability phenomena but its play important role in weathering process that finally results into mass movements.

4.1.2 SLOPE

A landscape is open system with highly variable inputs of energy and materials where slope is an important agent to perform these operations. An attempt has been made to analyze the distribution of average slope of the Bhilangana river basin and correlated with the morphometric attributes on the one hand and landslides susceptibility in other.

Slope is important measures to assess surface variations. It is mathematical calculation of degree of inclination of surface 0° to 90°. The 0° represents flat surface and 90° steep cliffs. If the slope angle is high the probability of slope failure should also be higher. For calculation of slope of the Bhilangana river basin Wentworth's (1930) methods has been used. The method is as follows:

$$\text{Tan}\ \theta = \frac{\text{no. of contour crossing/ km}^2\ \text{area} \times \text{contour interval}}{636.60}$$

To calculate the slope angle, the entire map was divided in to 1 km^2 grids. Slope angle for each grid was calculated separately (Fig. 4.3). The slope values, thus obtained for each grid, has been arrange into five categories. Taking into consideration of the landslide hazard zonation these slope angles have been grouped in the following classes.

ASPECTS
BHILANGANA RIVER BASIN

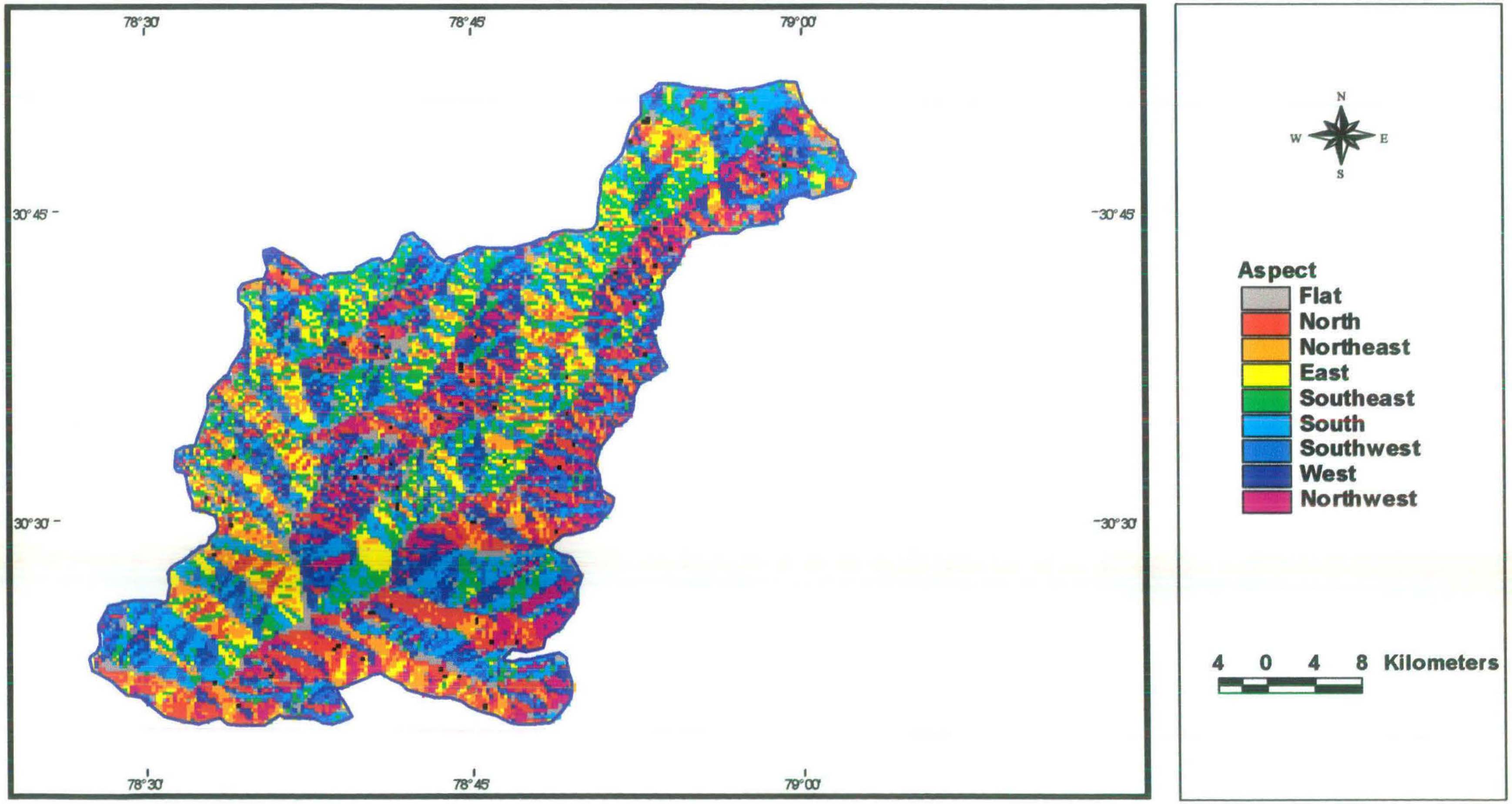

Fig. 4.2

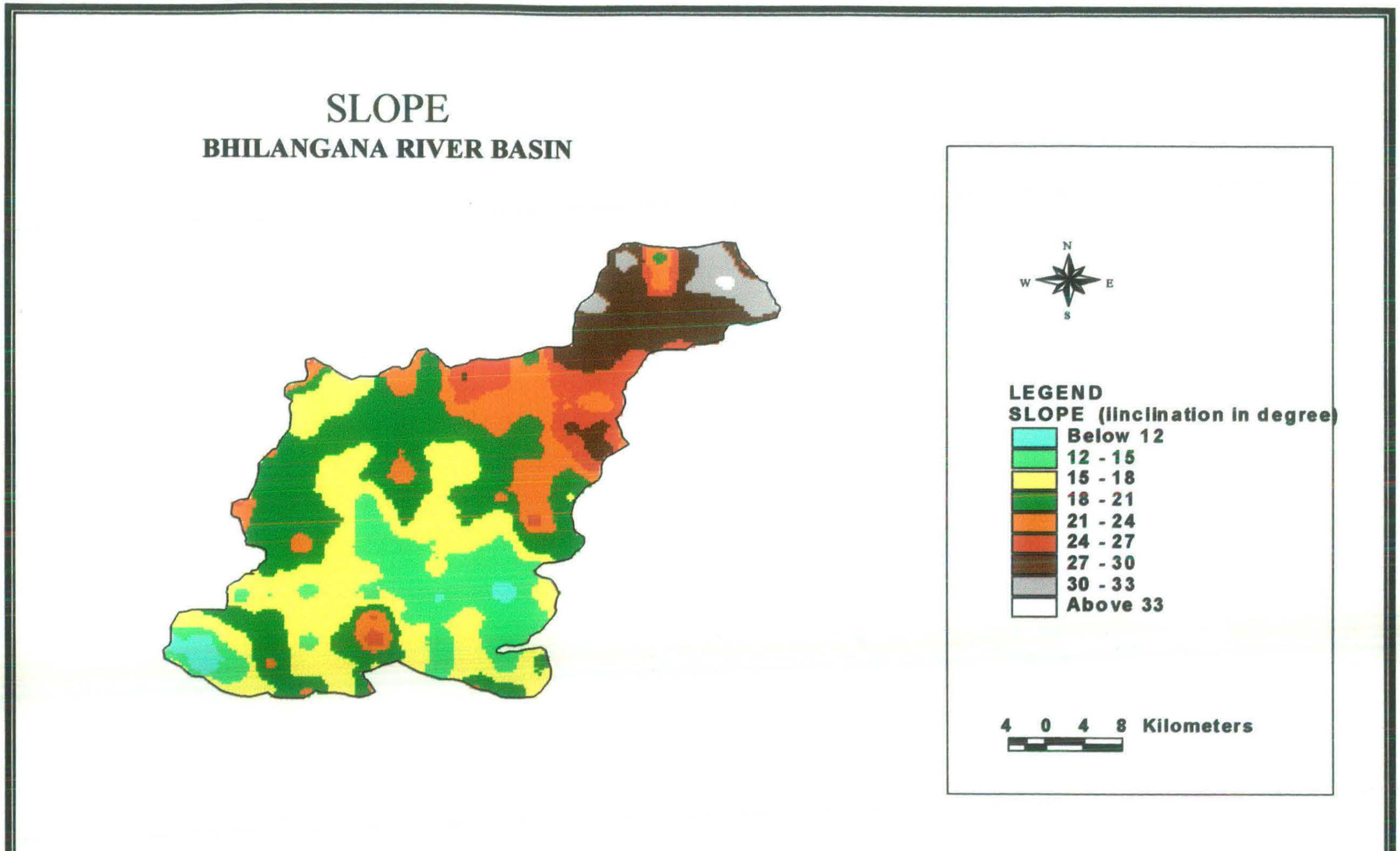
SLOPE
BHILANGANA RIVER BASIN
N
W
E
S
LEGEND
SLOPE (iinclination in degree)
Below 12
12 - 15
15 - 18
18 - 21
21 - 24
24 - 27
27 - 30
30 - 33
Above 33
4 0 4 8 Kilometers

Fig. 4.3

Table 4.3 Different slopes classes

Slope classes (angle in degree)	Description	Area (in km^2)	% Area
Below 12	Low slope	63	2.97
12 to 15	Gentle slope	312	14.71
15- 18	Moderate slope	585	28.12
18 - 21		369	18.03
21 - 24	Steep slope	269	12.68
24 - 27		186	8.77
27 - 30		203	9.57
30 - 33		109	5.14
Above 33	Very steep slope	24	0.01
Total		2120	100.00

4.2 GEOLOGY

Geology deals with different rock types that constitute the earth crust, their origin, compositions, chronology and tectonic settings. The study of geological structure of rocks further determines the hardness of rocks, chemicals and mineralogical compositions, susceptible to different exogenic processes leading to the slope instability phenomena.

The Himalayas are one of the complex mountain systems of the world. They represent great variety of rocks system, dating back from Cambrian to Pleistocene deposits and granite and gneisses to sandstone, limestone, boulder conglomerates and shale. At several places these rocks are highly metamorphosed. Intense folding has led to the formation of recumbent, overturned folds and even Nappes.

The evolution process of Himalayan ranges began during the Mid-Miocene periods (40 – 25 M.a.) to late Pliocene periods[2]. These mountain belts are one of the youngest and highest folded systems (Tertiary formations) which comprise both hard and soft lithologies. These lithologies and tectonic set-up play an important role in the stability of hill slopes[3]. The Himalayas are still in the process of uplift and some of the thrusts and faults are active which makes the slopes and the ranges fairly unstable or at least make them prone to slides and slips.

The Indian plate is still moving northeast at a rate of 5 centimeter per year. The northern boundary of Indian plate coincides with the southern margins of Tan Shan-Nan Shan 'mobile fold belt'[4], and more fracture have appeared on the outer fringe of the Siwalik Hills, which demarcate these hills from Gangatic plain. Geologists postulate that newer mountain ranges would form in the Gangatic plain, forcing the rivers to migrate further south.

Many scholars have discussed geology of the Bhilangana River Basin along with Garhwal Himalaya [Auden (1937), Saklani (1970), Jain (1971) and Valdiya (1980)]. The study area could be divided clearly in to two distinct geological and tectonic zones; the lesser Himalayan range and the Great Himalayan range. These ranges are demarcated by 'Main Central Thrust'.

Saklani (1989)[5] has discussed the geology of Main Central Thrust (MCT) and Lesser Himalayan Nappes. MCT has come up as intercontinental subduction zone along with Indus zone. Along with this thrust, northern parts of the Himalayas, comprising the central crystalline and the Tibet zone overriding the Lesser Himalaya units[6]. The

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[2] Wadia, D.N. (1975), Geology of India. Tata McGraw-Hill Publishing Co. New Delhi, pp. 86

[3] Valdiya, K.S. (1985). Accelerated erosion and landslides prone zones in the Central Himalayan region, in Singh, J.S. (Edt.) Environmental regeneration in Himalaya, Ganodaya Prakshan, Nainital, pp. 12 –38.

[4] Farooq, S. et al. (1981), Evolution of the Himalayas. Science Reporter, pp. 456-465

[5] Sakalini, P.S. (1989), Himalayan Mountain Building. Today and Tomorrow Printer and Publisher, New Delhi, pp.41

[6] Valdiya, K.S. (1980). Geology of Kumaun Lesser Himalaya. WIGH, Dehradun; pp. 2-12

crystalline were at that time in the state of active regional metamorphism. It can be demarcated that how the mineral isogards of the hot metamorphic complex become deformed. Thrusting of the hot amphobolite grade metamorphics in to the cool underground led to the rapid cooling of the crystalline, documented by the Miocene cooling age, and produced the inverse metamorphism of the lesser Himalaya. Intensity of alteration is highest in the upper units and decreases downwards and southward, away from the root zone. In northern part of the Lesser Himalayas several thrust were formed and dragged toward the south at the base of the crystalline Nappes.

Some of these units (Chail Nappes) show normal upright stratigraphic sequences. The Chail Nappes generally exhibits green schist metamorphic grade, which folds away downward in the parautocthonous units of the inner carbonate zone. The transition from amphobolite to green schist facies occurs at little below the MCT. Thus thrusting took place under the condition of the recrystallization, which prevented the formation of major maylonite zones.

There is a debate in views of various scholars, who's studied on the MCT, whether there exist a single or more thrust plane, which one should termed the 'MCT', or is a Schuppen Zone represents the MCT. A schuppen zone mostly, implies a tectonic mixture, which certainly did not take place[7].

Table: 4.4 Tectonic Succession of the Bhilangana river Basin (Adopted from Valdiya, 1980)

Group	Outer Lesser Himalaya	Inner Lesser Himalaya
		Vaikrita group (early pre-Cambrian)
		— Vaikrita (main central) Thrust —
Almora	Gumalikhet Formation	Munisiari Formation
	— Almora Thrust —	— Munisiari Thrust —
Ramgarh	Nathukhon Formation	Bhatwari Formation
	— Ramgarh Thrust—	—Bhatwari Thrust—
Mussoorie	Karol Formation	
Jaunsar		Berinag Formation
		— Berinag Thrust —

Valdiya (1980)[8] postulated that there is existence of a thrust plane. The lower on is represents the typical chail formation from a grade association of mica-schist to phyalites, augen and paragneisses, amphobolites, quartazites, and carbonate, which are termed as lower crystalline nappes by Saklani (1989). He suggest that relatively thin basal thrust sheet of the crystalline is overthrust by the high-grade gneisses, migmatite and thich orthogneisses of the upper crystalline nappes that could be called as MCT. The Miocene cooling ages of the crystallines very well dates the Lesser Himalayan nappe tectonics. Oligo-lower Miocene outcropping as the youngest series in the windows, and

[7] Sakalini, P.S. (1989), Himalayan Mountain Building. Today and Tomorrow Printer and Publisher, New Delhi, pp. 41

[8] Valdiya, K.S. (1980), Geology of the Kumaun Lessser Himalaya. WIGH, Dehradun, pp. 8-12

the Siwalik sedimentation commencing in the Miocene[9]. Geological units of the Bhilangana river basin are given in Fig. 4.4.

LITHOLOGY

The lithologial map of the study area has been adopted from the NATMO (Fig. 4.5). The important litho-stratigraphic units are as follows:

GRANITE

The northern most part of the study area is covered by granite and gneiss. These rocks formed during the period of Archaean rocks and have a very complex geological structure. These rocks are lightly metamorphosed and some place lost their original characteristics. These are crystalline and extremely controlled, folded and foliated, largely intruded by plutonic intrusions. Gneiss is very common with more or less have foliated or banded structure[10]. These are covered by snow throughout year in the study area, and exposed to physical weathering processes by freeze and thaw, also dominated by the glaico-fluvial erosion.

SLATE

These rocks have complex geological formation but lack of fossilferous deposits. These are highly metamorphosed with folding and faulting. Schist- quataz-mica schist, feldspar are the some important rock groups.

[9] Fuchs, G. (1989), Different kinds of Thrusting in the Himalayas, In P.S. Sakalini (ed.) Himalayan Mountain Building, Current Trends in Geology –XI, Today and Tomorrow Printer and Publisher, New Delhi, pp. 44

[10] Mehdiratta, R.C. (1962), Geology of India, Pakistan and Burma. Atma Ram & Sons, Delhi,pp. 48

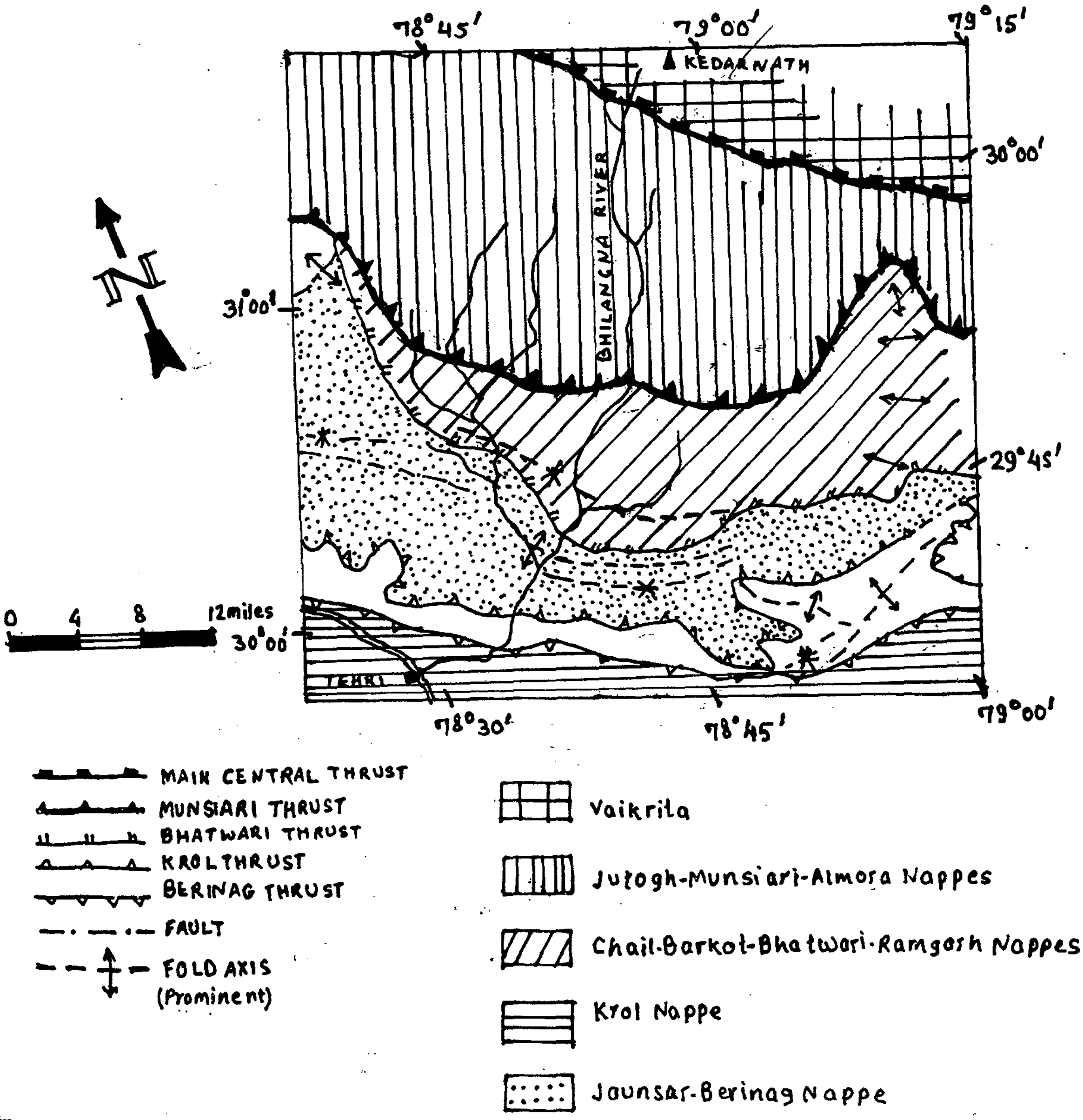

Fig. 4.4 STRUCTURAL MAP OF BHILANGANA RIVER BASIN (MODIFIED AFTER K.S. VALDIYA, 1980).

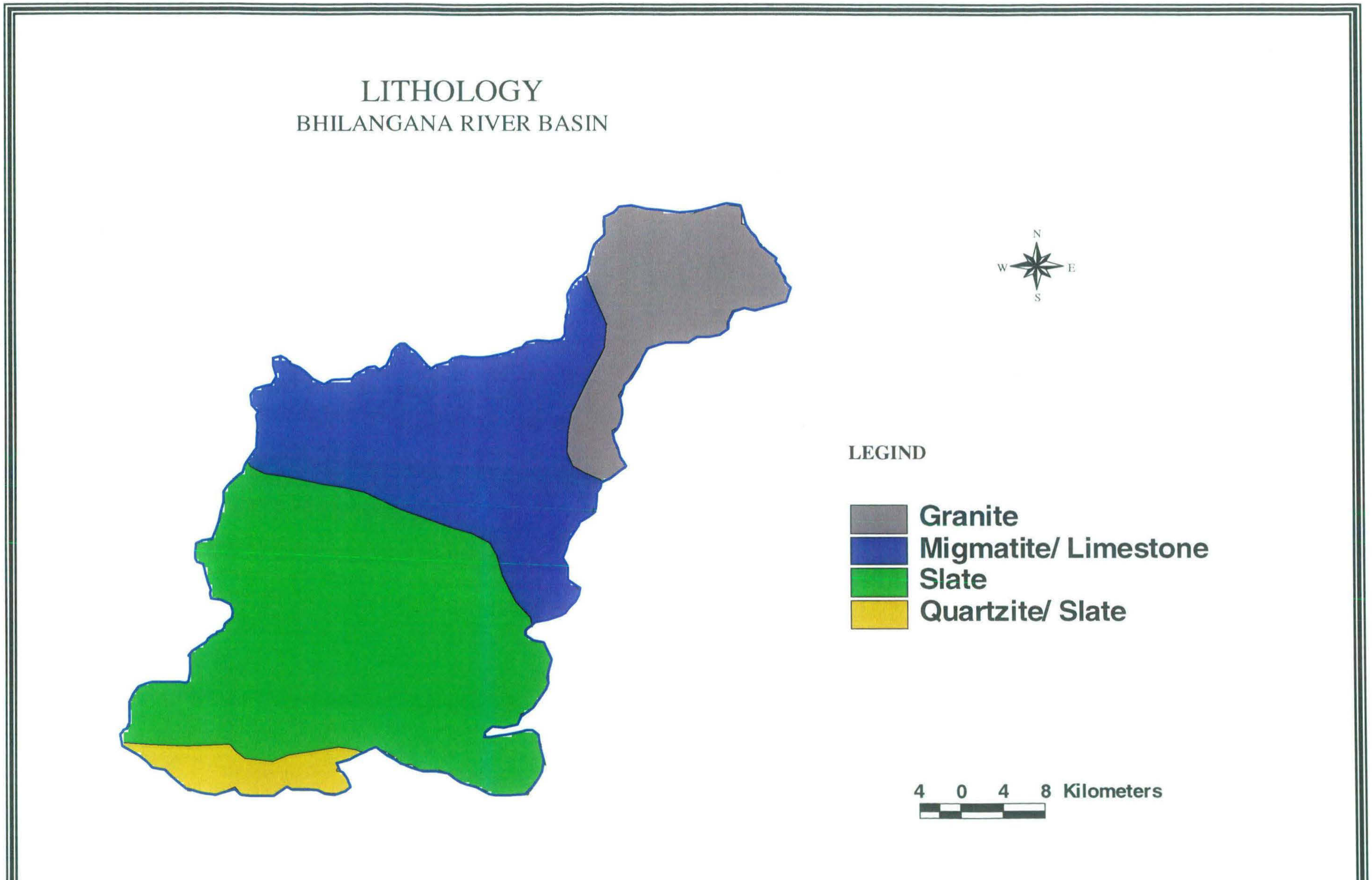

Fig. 4.5 Modified after District Planning Map Tehri Garhwal (Source: NATMO)

MIGMATITE/ LIMESTONE

This is a sedimentary rock having micro grains to coarse textures, with calcite and dolomite mineral composition. At some place it has mixed exposure with migmatite, and igneous rocks.

QUARTAZITE/ SLATE

Quartzite is formed by the metamorphism of the quartz rich sandstone. It is non-foliated fine grained rock where the grains are deformed and defused in to a hard rock. It is quit resistant to weathering processes but stable to mass movement. It exists with slate.

4.3 SOIL

Earth's landscape is generally covered with loosened regolith, termed as soil. Soil is dynamic natural materials composed of fine particles in which plants grow, and contains both mineral fragments and organic matter. The formation of soils depends upon the several factors, such as parent rock, climate, vegetation cover, anthropogenic factors, time etc.

Relief features influence the process of soil formation in several ways. For example, slope determines the flow of water and mass wasting. Hence, soil development takes place well in an area with gentle slope. Climate, especially precipitation plays predominant role in the formation of soils, it controls the type and effectiveness of weathering processes, water percolation, humas contents and nature of microorganism.

There is a very close relationship between soil and slope instability in the hilly terrain. The study of physical properties of soils is very important. These include soil texture, colour, effective depth, structure, permeability and moisture holding capacity, surface drainage etc.

The relative proportion of sand, silt and clay are studied under soil texture. Colour of the topsoil is determined by it drainage. Well drained soils are generally brown in colour while the poorly drained soils are gray. Black colour is an indication of the presence of rich organic matter in the soil. Soil structures refer to the way in which individual particles are present in the soil such as granular, blocky and peaty. Permeability of soils depend upon it structure. Sandy soils have higher permeability rather than clay and silt. Course soils have lower water holding capacity while fine soil have high moisture holding capacity.

All these soil information are very relevant and could be associated with mass movement process. For instance, effective depth of soil depends upon the degree of slope angle, higher the slope angle lesser will be soil depth or no soil.

The Bhilangana river basin has been classified, in to three principle soils category by NATMO (1995), Department of Science and Technology, India (Fig. 4.6). These are as follows:

4.3.1 HISTOSOLS

This is high mountainous snowfield soil, covered throughout year by snow. Histosols also forms in small, poorly drained depression. These soils have course texture. Weathering processes disintegrate the parent rock. This soil does not support growths of plants and is categorized as wasteland.

4.3.2 MOLLISOLS

These soils refer to mountain meadow soil, commonly found on the gentle slopes of the hilly areas. These soils are fine loamy to course loamy texture, with thick organic rich surface layers. Grasses and lichens cover these soils, some times due to snowmelt,

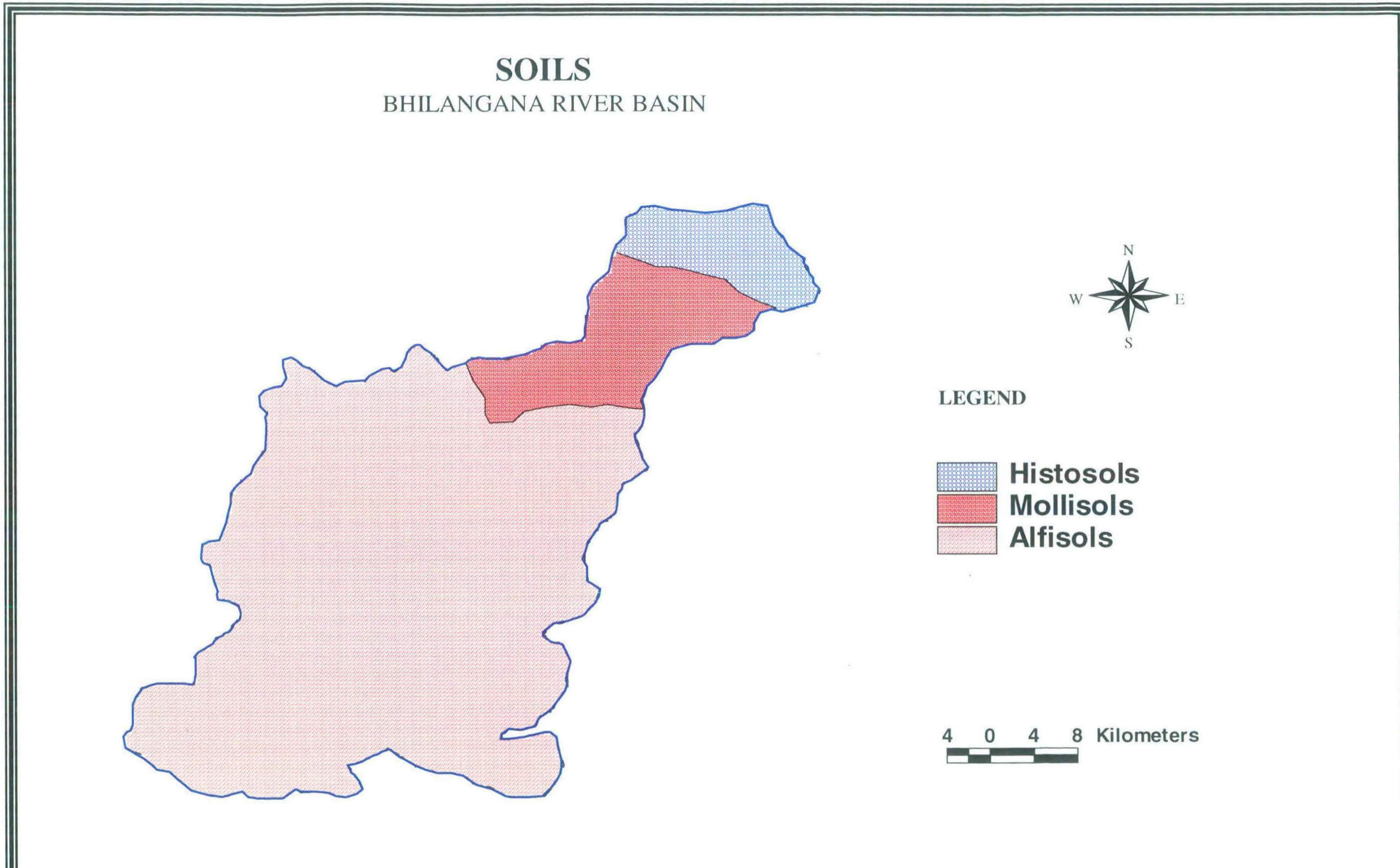

Fig. 4.6 Modified after District Planning Map Tehri Garhwal (Source: NATMO)

water accumulates in the depression to form peaty soil. Calcification process (accumulation of calcium or magnesium carbonates in the B or C horizons) is predominant due to humid to semi humid climatic conditions.

4.3.3 ALFISOLS

These soils are found in the lower elevation areas called 'sub-mountain soil'. These soils are moderately weathered soil, having fine to course texture and varies with slopes. These soils have high organic contents. Dense forest covers these soils in the Bhilangana river basin. Cultivation practices are prevalent in the lower areas.

4.4 RELIEF ASPECTS

Relief aspects of the Bhilangana River Basin are related to the study of three-dimensional features of the basin. These are area, volume and altitude of vertical dimensions of landforms, where different morphometric methods have been used to analyze terrain characteristics that are the results of geomorphic processes. Thus, this aspect includes the analysis of relationship between area and altitude, relative relief and slope angle, dissection index, profile of terrain and river etc.

4.4.1 ABSOLUTE RELIEF

Absolute relief provides the elevation of any area above the sea level in the absolute terms. It is useful in delineating the terrain morphology, including the existence of erosion surfaces. Absolute relief has been obtained by dividing the contour map of the study area into a 2.56 km^2 grid, and marking the maximum height of each squire grid with the help of contour and spot height (Fig. 4.7). These values range from a minimum of 700 meter at confluence of Bhagirathi-Bhilangana River at Old Tehri town of Uttaranchal to highest Peak of the Study area is Phating Pithwar (6904 Meter).

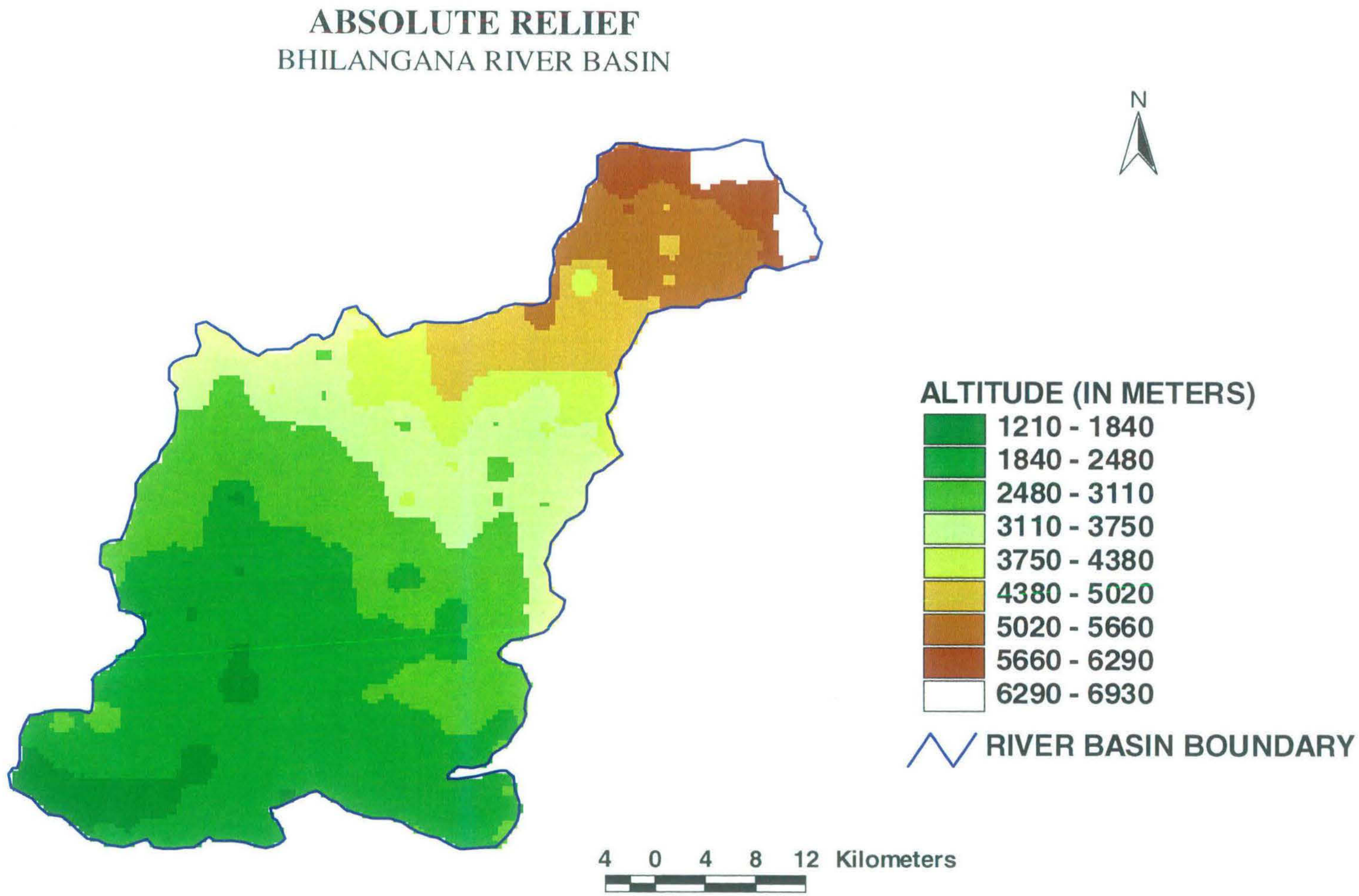
ABSOLUTE RELIEF
BHILANGANA RIVER BASIN
N
ALTITUDE (IN METERS)
1210 - 1840
1840 - 2480
2480 - 3110
3110 - 3750
3750 - 4380
4380 - 5020
5020 - 5660
5660 - 6290
6290 - 6930
RIVER BASIN BOUNDARY
4 0 4 8 12 Kilometers

Fig. 4.7

Table 4.5 Distribution of Absolute relief.

Absolute relief class (in meter)	Description	Area (in km^2)	% Area
Below 1840	Very low relief	153	7.21
1840 -2470	Low relief	828	39.05
2470 - 3110	Moderate relief	246	11.65
3110 - 3750		225	10.61
3750 - 4380	High relief	162	7.64
4380 - 5020		117	5.51
5020 - 5660		189	8.91
5660 - 6290		72	3.39
Above 6290	Very high relief	128	6.03
Total		2120	100.00

4.4.2 RELATIVE RELIEF

Relative relief also termed as 'amplitude of available relief' or local relief, is defined as the difference in height between the highest and the lowest points in falling in particular unit area (Fig. 4.8). Smith (1935) presented the first scientific study of relative

Table 4.6 Distribution of Relative reliefs

Relative relief class (in meter)	Description	Area (in km^2)	% Area
Below 340	Very low relief	27	1.27
340 - 660	Low relief	243	11.47
660 - 980	Moderate relief	801	37.78
980 - 1310		662	31.22
1310 - 1630	High relief	243	11.46
1630 - 1950		81	3.82
1950 - 2280		54	2.54
2280 - 2600		0	0.00
Above 2600	Very high relief	9	0.44
Total		2120	100.00

relief. Relative relief is very important morphometric variables, which is used for the overall assessment of morphological characteristics of terrain and degree of dissection of surfaces. The values of relative relief could be calculated using following formula:

Relative relief = Highest contour - Lowest contour (of that particular grid). – What is the grid area

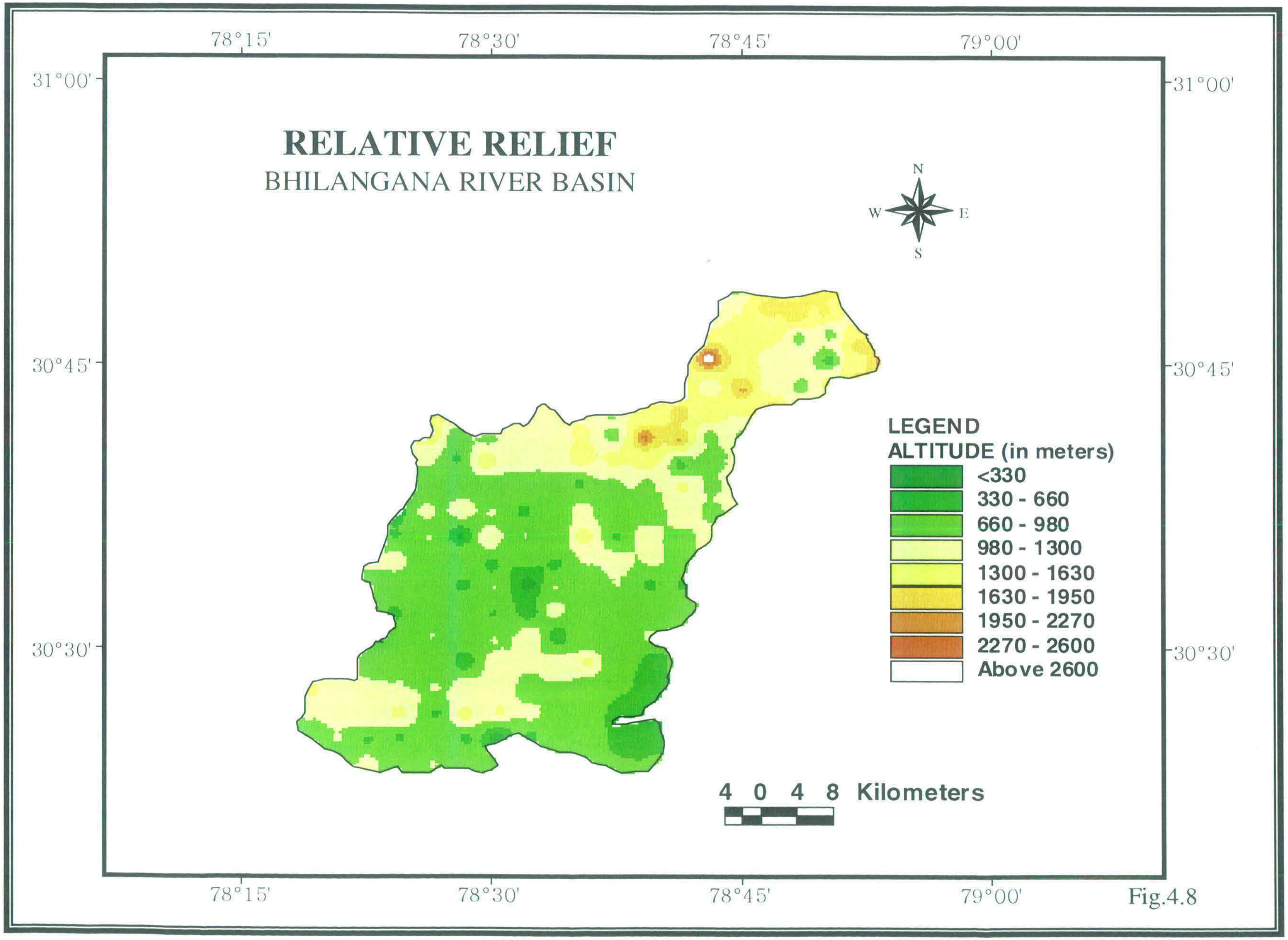
78°15'
78°30'
78°45'
79°00'
31°00'
30°45'
30°30'
RELATIVE RELIEF
BHILANGANA RIVER BASIN
N
W
E
S
LEGEND
ALTITUDE (in meters)
<330
330 - 660
660 - 980
980 - 1300
1300 - 1630
1630 - 1950
1950 - 2270
2270 - 2600
Above 2600
4 0 4 8 Kilometers

Fig.4.8

4.4.3 PROFILE ANALYSIS

Profiles indicate of the nature of surface configuration as well as the degree of dissection of terrain. The contour map, sometimes, does not reveal a total picture of the landscape, but profiles drawn along different directions, gives a better virtual representation of the morphology of the terrain (Fig. 4.9). The latter, in fact gives a panoramic view of the landscape, indicating both the sharpness of absolute relief and the flatness of the valley bottoms[11].

4.4.4 DISSECTION INDEX

Dissection index, expressed as ratio of the maximum relative relief to the maximum absolute relief, is an important morphometric indicator of the nature and magnitude of dissection of terrain. Dov Nir (1957)[12] states, "as a criterion of relief energy, the concept of relative altitudes are not entirely satisfactory. Equal relative altitudes are not always of equal importance since their absolute altitude may differ. The picture gained from relative altitudes only is static, for it fails to take into account the vertical distance from the erosion base, i.e., the dynamic potential of the area studied". On this basis, he suggested the necessity of describing the relief in terms of the ratio between the two variables, absolute and relative relief. It can be obtained by the following methodology:

Dissection index = Relative relief/ Absolute relief

In the present study grid method has been used for the computation of dissection index of the Bhilangana River Basin. The value of dissection, derived so varies between

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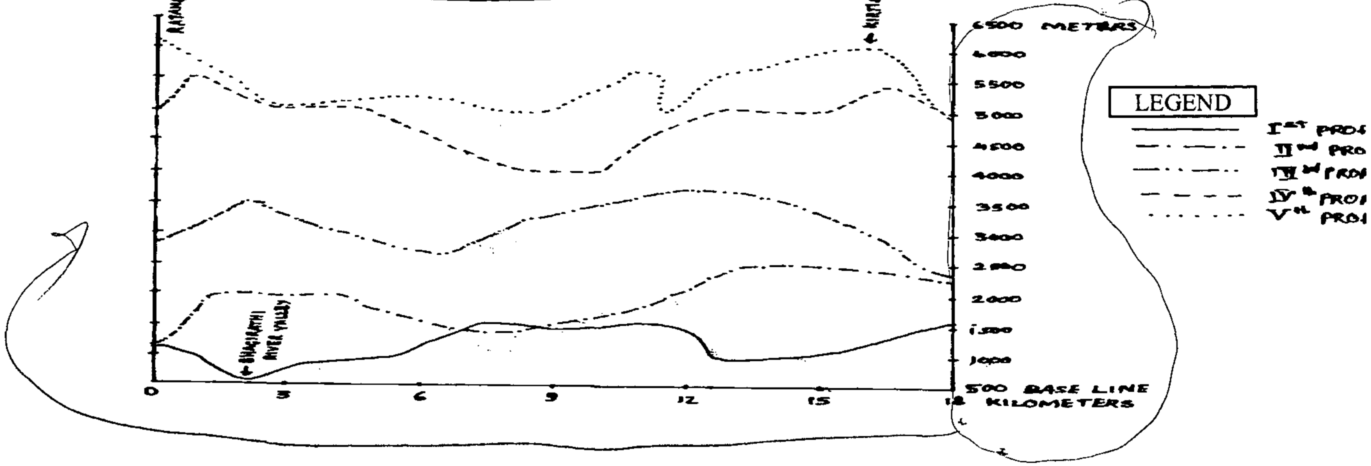
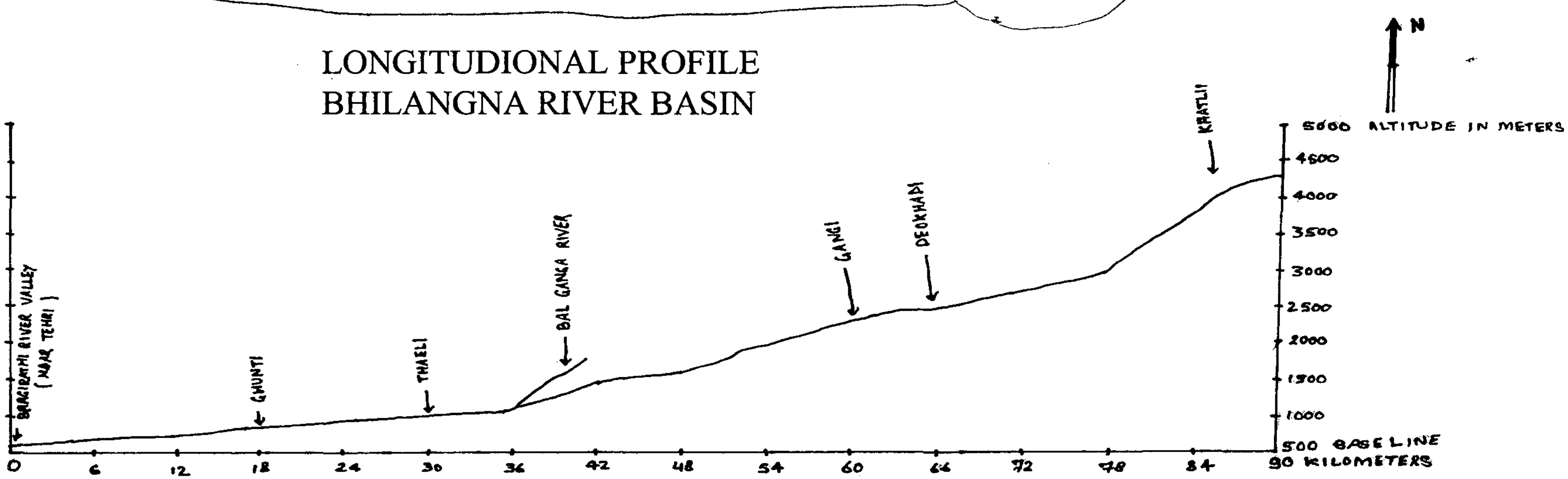
[11] Jha, V.C. (1996): Himalayan Geomorphology. Rawat Publication Jaipur, India, pp. 154

SUPERIMPOSED PROFILE
BHILANGANA RIVER BASIN



LONGITUDIONAL PROFILE
BHILANGNA RIVER BASIN



SOUTH WEST TO NORTH EAST

Fig. 4.9

0 (complete absence of dissection) to 1 (vertical cliff). Dissection index is also used as morphometric determinant of the stage of cycle of erosion wherein old, mature and young stages are related to dissection indices of less than 0.1, 0.1 – 0.3 and more than 0.3 respectively (Fig. 4.10).

Table 4.7 Distribution of Dissection index.

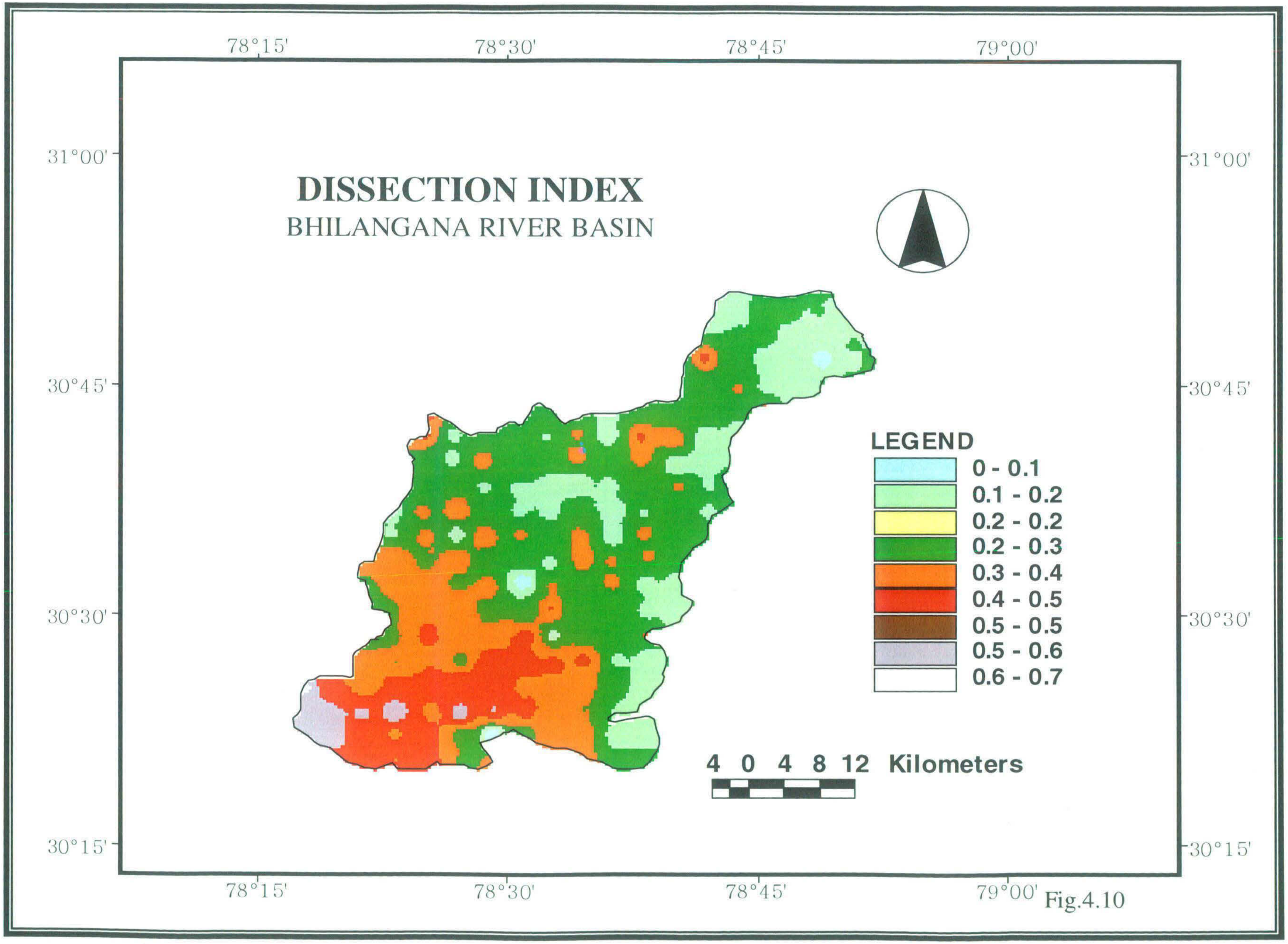
Dissection Index	Description	Area (in km^2)	% Area
Below 0.1	Low dissection	234	11.03
0.1 - 0.3	Moderate dissection	724	34.17
0.3 - 0.4	High dissection	603	28.44
0.4 - 0.5		405	19.10
Above 0.5	Very high dissected	154	7.26
Total		2120	100.00

4.5 BASIN MORPHOMETRY

Morphometry may be defined as the measurement and mathematical analysis of the configuration of the earth's surface and of the shape and dimensions of its forms[13]. Basin morphometry includes the analysis of the linear and areal aspects of the fluvially originated drainage basin.

The present study is an attempt to find out the stage in the geomorphic development of the Bhilangana River Basin with the help of different morphometric attributes, and correlated with slope instability. These drainage attributes are directly related to relief, slope, surficial geology, climatic condition, vegetal cover and the stage of basin development.

[12] Nir, D. ((1957): The ratio of relative and absolute altitude of Mt. Carmel-A contribution to the problem of relief analysis and relief classification. Geographical review, vol. 47, pp.564-69.


78°15'
78°30'
78°45'
79°00'
31°00'
30°45'
30°30'
30°15'
DISSECTION INDEX
BHILANGANA RIVER BASIN
LEGEND
0 - 0.1
0.1 - 0.2
0.2 - 0.2
0.2 - 0.3
0.3 - 0.4
0.4 - 0.5
0.5 - 0.5
0.5 - 0.6
0.6 - 0.7
4 0 4 8 12 Kilometers
Fig.4.10

4.5.1 LINEAR ASPECTS OF THE BASIN

Linear aspects of the basins are related to the channel patterns of the drainage network wherein topological characteristics of the stream segments form open links of the open system are analyzed. The linear aspect of the basin includes stream order (μ), stream frequency (Nμ), bifurcation ratio (Rb), sinuosity indices etc.

4.5.1.1 STREAM ORDER

Stream ordering refers to the determination of the hierarchical position of a stream within a drainage basin. A river basin consists of its several segments having different positions in the basin area. Horton (1945) presented the first scientific method of stream ordering, which Strahler (1952) modified latter. According to Strahler (1964), the first-order of streams are those, which has no tributaries. The second orders of streams are those, which have tributaries as first-order channel. When two second-order channels join a channel of third-order of segment is formed (Fig. 4.11). Similarly when third-order channels join, they give rise to fourth-order channel and so on. Thus, the trunk stream, through which all discharges of water and sediment pass, is the stream segment of the highest order.

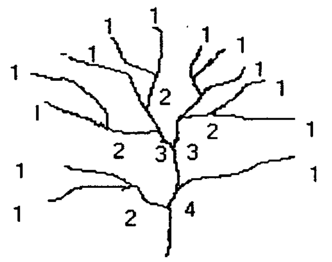


Fig. 4.11 Stream Order Method of Strahler (1964).

[13] Clarke, J.I (1966): Morphometry from maps, in G.H. Dury (ed.), Essay in Geomorphology, Heinemann, London, pp. 235

In the present study Strahler's scheme of stream ordering has been used to rank the position of streams of the Bhilangana River Basin (Fig. 4.12). Thus, the Bhilangana River, which is the trunk stream of the study area, is the 5^{th} order stream. The size and shape of streams were done in the Arc View 3.2 software by on screen digitization.

4.5.1.2 BIFURCATION RATIO

The ratio between total numbers of streams of one order to that of next higher order in a drainage basin is known as bifurcation ratio (Rb). It is very important because it controls the flow discharges of the streams during severe storms event.

The bifurcation ratio can be calculated by the method presented by Horton's (1945) law of stream numbers, which states that the number of streams of different orders in a given drainage basin tend closely related to approximate an inverse geometric series in which the first term is unity and the ratio is bifurcation ratio[14]. The following formula has been used:

$Rb = N\mu / N\mu+1$ 4.1

Table 4.8 Bifurcation ratio in the Bhilangana River.

Stream Order	Number of Streams	Bifurcation Ratio	Stream Length (in Km.)
I	135	3.75	491.21
II	36	7.20	149.89
III	5	2.50	111.96
IV	2	2.00	34.06
V	1		26.06

[14] Horton, R.E. (1945): Erosional development of streams and their drainage basin- hydrophysical approach to quantitative morphology, Geol. Soc. Amer. Bull., vol. 56, pp.291

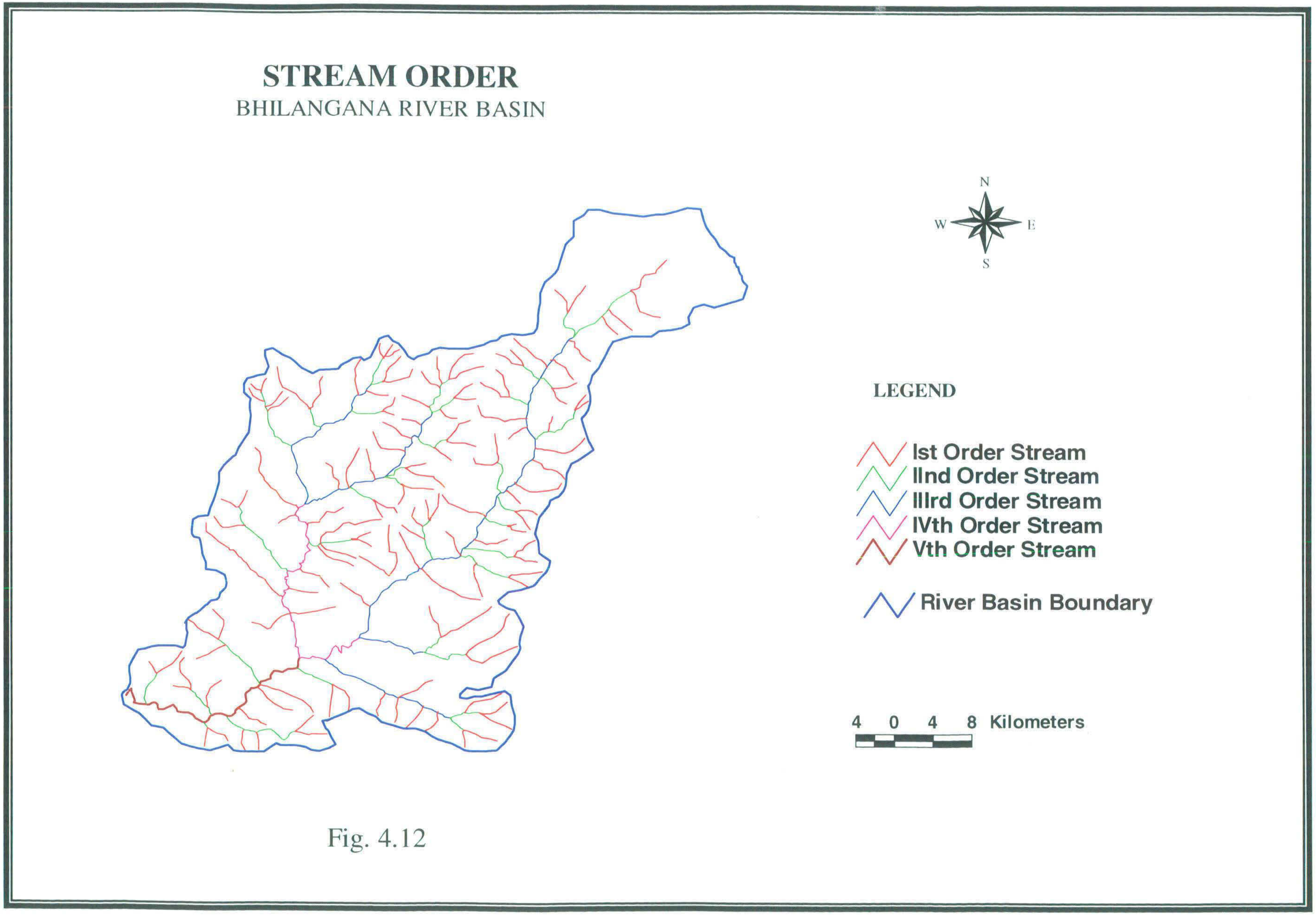

STREAM ORDER
BHILANGANA RIVER BASIN
N
W
E
S
LEGEND
Ist Order Stream
IInd Order Stream
IIIrd Order Stream
IVth Order Stream
Vth Order Stream
River Basin Boundary
4 0 4 8 Kilometers

Fig. 4.12

Where, $N\mu$ is the number of segments of given order and $N\mu+1$ is the number of segments of next higher order in the drainage basin.

High value of bifurcation ratio indicates lower degree of drainage integration and vice-versa. The bifurcation ratio is generally influenced by the variations in the physiography, geology and climatic condition prevailing over the drainage basins. Thus, basins with uniform lithology and tectonic history, similar climatic conditions and in similar stages of development are characterized by more or less similar values of bifurcation ratio. Bifurcation ratio of the Bhilangana river basin is varying between 2 to 7.2 of the various order streams (Table 4.8).

Bifurcation ratio is very important because it is one of the factors, which controls the rate of discharge in the drainage basin after sudden storms[15].

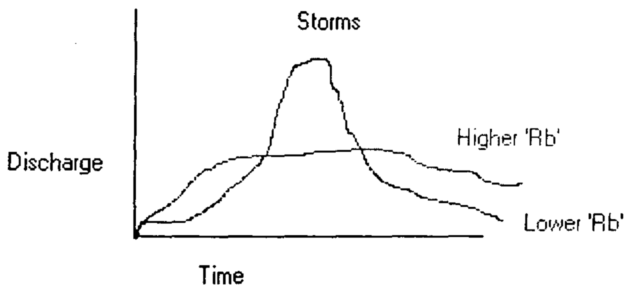


Fig. 4.13 Rate of Drainage Basin discharge and bifurcation ratio.

4.5.1.3 SINUOSITY INDEX

Channel sinuosity is an index, which measures the deviation of drainage lines from their geometric path. Streams are generally originated in sinuous form. This sinuosity is depends upon the underlying rock structures, climate, vegetation and time involved in development of the drainage system. Mueller (1968) suggested that the

[15] Mc Gullagh, P. (1978): Modern Concept in Geomorphology. Oxford University Press, London, pp. 84

sinuosity index is the ratio between channel length (CL) and the river valley length (VL). The values of sinuosity indices is generally varies between 1 to 4 and more; river having sinuosity index below 1.5 are called sinuous and those having indices of more than 1.5 are called meandering[16].

Sinuosity index value calculated of the Bhilangana river basin is 0.77.

4.5.2 AREAL ASPECTS OF THE BASIN

The drainage basin area is very important morphometric attributes as it is related to the spatial distribution of a number of significance attributes such as drainage density, stream frequency, drainage texture, basin geometry, elongation ratio etc.

4.5.2.1 GEOMETRY OF BASIN SHAPE

The geometry of basin shape is of paramount significance as it helps in the description and comparison of different forms of the drainage basin. The shape of the basin depends on the size and length of the master stream of the basin and basin parameters, which themselves depend on other variables such as absolute relief, slopes, geological structures, and lithological characteristics etc. And hence a wide range of variation in basin shape is bound to happen.

Horton (1932) presented a method known as 'form factor' of basin shape:

$$F = A / L^2 \qquad \ldots 4.2$$

Where 'F' is form factor of basin shape, A is area of the basin and L^2 is square of length of the basin perimeter. The value of 'F' varies from 0 to 1, highly elongated to perfect circular. Higher the values of 'F', shape of the basins are more circular and vice-versa. Value calculated for the Bhilangan river basin is 0.261 indicating elongated shape.

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[16] Jha, V.C. (1996): Himalayan Geomorphology. Rawat Publication, Jaipur, India; pp130-133

4.5.2.2 ELONGATION RATIO

This refers to shape of form of a drainage basin, which is the ratio of diameter of a circle of same area as basin to the maximum basin length[17]. This ratio varies 0.6 to 1.0 over a wide variety of climatic and geologic types. Values close to 1.0 are typical of regions of very low relief, whereas values in the range of 0.6 to 0.8 are generally associated with higher relief and steep ground slopes[18]. This ratio is very important for classifying drainage basin into varying shape, such as circular (above 0.9), oval (0.8-0.9), less elongated (0.7-0.8) and elongated (below 0.7). A circular basin has a maximum efficiency in the movement of the run-off, whereas an elongated basin has the least efficiency. This information is very significant in forecasting of drainage discharge, particularly in times of floods. It can be derived as:

$$Re = d/Lb \qquad \text{........4.3}$$

Where 'Re' is the elongation ratio, 'd' is the diameter of a circle of the same area as the basin and 'Lb' is the basin length. The 'Re' value of the Bhilangana river basin is 0.621, indicating elongated basin.

4.5.2.3 STREAM FREQUENCY

Stream frequency is the measure of number of streams per unit area. Computation of the stream frequency of the Bhilangana river basin has been done by grid method (Fig.4.14). The unit of a grid is 2.55 km^2.

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[17] Schumm, S.A. (1956): The evolution of drainage systems and slopes in badland at Perth Ambey, New Jersey, Geol. Soc. Amer. Bull. Vol. –67, pp.612

[18] Strahler, A.N. (1964): Quantitative morphology of drainage basins and channel networks, in V.T. Chow (ed.), Handbook of Applied Hydrology, pp. 4 - 51

STREAM FREEQUENCY
BHILANGAGNA RIVER BASIN

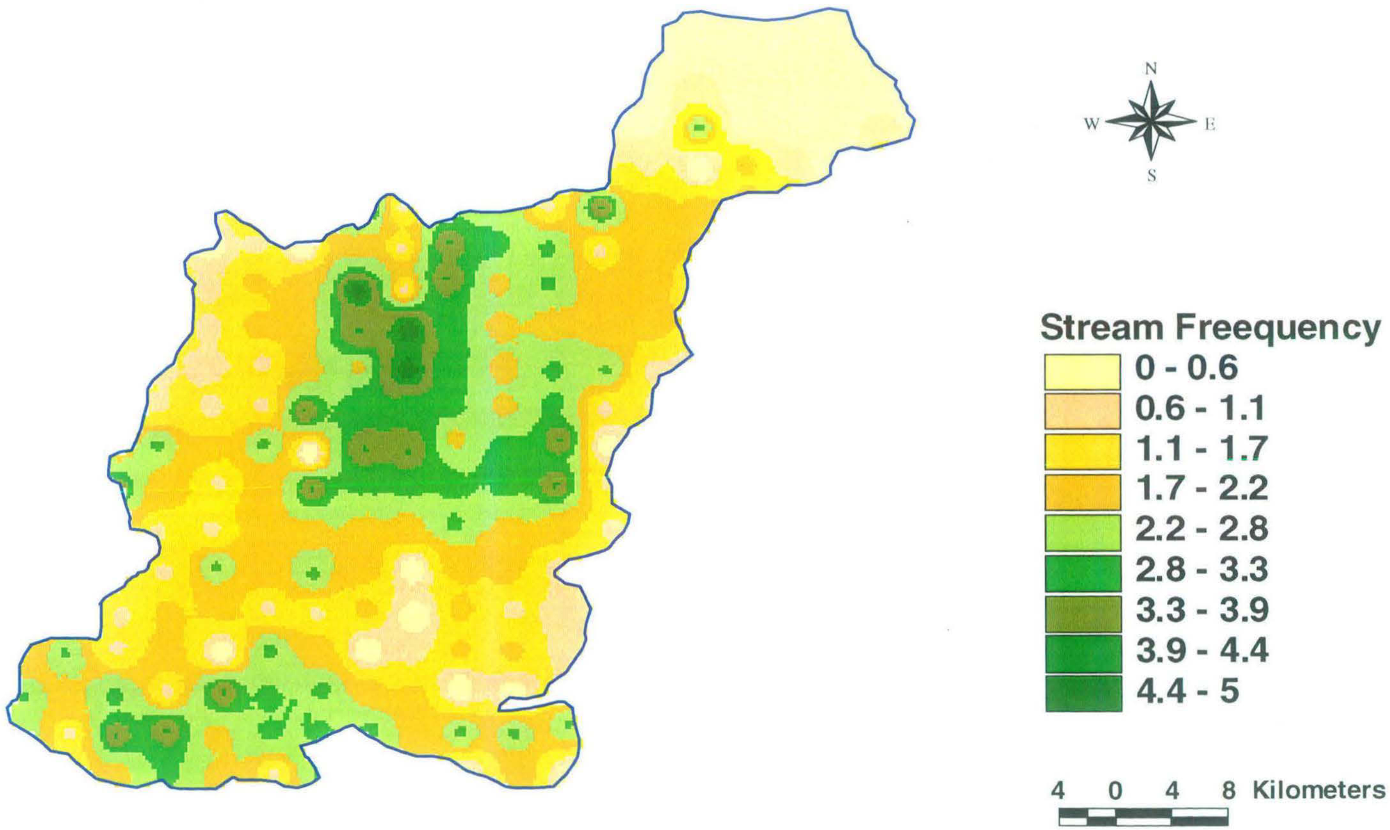


Fig. 4.14

Generally occurrence of stream segment depends upon the nature and structures of rock, vegetation cover, intensity and amount of rainfall and infiltration capacity of soils. It indicates various stages in landscape evolution and related geomorphic processes. The drainage frequency has been obtained by the following formula:

$$Df = \sum N / A \qquad ......4.4$$

Where ' Df' is drainage frequency, $\sum N$ is total number of streams and A is the unit area.

Table 4.9 Distribution of Stream frequency.

Stream Frequency	Description	Area (in km^2)	% Area
Below 1	Low	842	39.71
1 - 2	Moderate	702	33.11
2 - 3	High	414	19.52
3 - 4		126	5.97
Above 4	Very high	36	1.69
Total		2120	100.00

4.5.2.3 DRAINAGE DENSITY

Drainage density is refers to the total length of streams falling in per unit area. It is function of intensity and amount of rainfall, surface run-off, erosion proportionality factor, relative and absolute relief, and viscosity of the fluids and its acceleration due to gravity. Horton (1932), was first time introduced the methods of analysis of drainage density. It is calculated by using following formula:

$$Dd = \sum L / A \qquad ......4.5$$

Where $\sum L$ is the total length of streams and 'A' is unit area. According to the river courses per unit area drainage density are classified in four classes. The rating system for drainage density based on the number of water courses per unit area[19]. The distribution of drainage density presented in Table 4.10 and Fig. 4.15.

Table 4.10 Distribution of Drainage density.

Drainage Density/ km2	Description	Area (in km^2)	% Area
Below 2	Low density	612	28.86
2 to 4	Moderate density	743	35.04
4 to 6	High density	576	27.16
6 to 8		126	5.97
Above 8	Very high density	63	2.97
Total		2120	100.00

4.5.2.4 DRAINAGE PATTERN

Drainage pattern is refers to the spatial arrangement of streams in the networks of tributaries, which collectively form a drainage basin. Spatial arrangements of streams generally depend upon the underlying lithology, geological structures, faults/ lineament appearance, tectonic history and geomorphic processes of the drainage basin. According to the Thornbury (1969) drainage pattern 'provides a more practical approach to an understanding of structural and lithological controls in landform evolution and other geomorphic phenomenon.'

The drainage pattern of Bhilangana river basin is well adjusted to geologic and tectonic history as well as geomorphic processes. The drainage pattern is dendritic, which indicates the uniform lithology and younger geological formation of the Bhilangana river basin.

[19] El-Ashry, M.T. (1971): Quantitative methods of grading drainage density. Geol. Soc. Amer. Bull. Vol. No. 82, pp. 1703-1706

DRAINAGE DENSITY
BHILANGANA RIVER BASIN

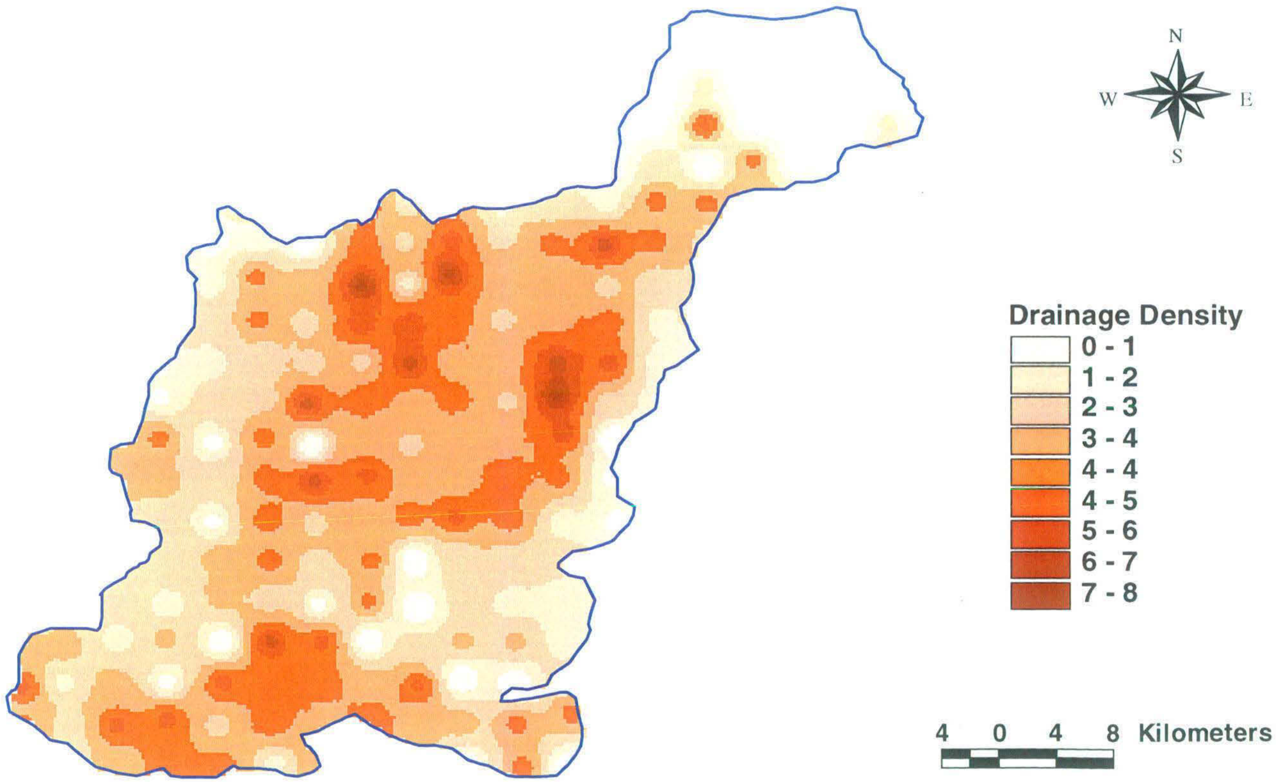


Fig. 4.15

4.6 CLIMATE

The climatic conditions in the Himalayan region is vary according to the change in altitude and aspect. So far, there has been no systematic survey of the Himalayan region, owing to its complicated relief, microclimates are considerably important.

The micro-climatic conditions usually differ from valley to valley and locality to locality according to the (i) direction of ridge (ii) degree of slope (iii) density of forest cover, and (iv) nearness to the glacier. The region has been divided into seven climatic zones, primarily based on altitude[20] (Table 4.11).

Table 4.11 Climatic Zones in the U.P. Himalayas (Adopted form Singh, 1980)

Climatic Zones	**Altitude in Meters**	**Temperature in °C**					
		January	Mean	June	Mean	Annual	Mean
Tropical Zone	300-900	13.3	11.1	29.4	27.2	21.1	18.9
Warm temperate	900-1800	11.1	6.1	27.2	21.1	18.9	13.9
Cold temperate	1800-2400	6.1	2.8	21.1	17.2	13.9	10.3
Cold zone	2400-3000	2.8	1.7	17.2	13.3	10.3	4.5
Alpine zone	3000-4000	Below 0 for 6 months snow melt in July, Aug.		13.3	5.6	4.5	3.0
Glacial zone	4000-4800			Ten Months below 0 , two months between 2.2 and 3.9			
Perpetually Frozen	Above 4800	Cold desert no vegetation					

- **RAINFALL**

The Bhilangana river basin receives more than 75% rainfall in the monsoon season. The monsoon commences towards the end of June or early July and ceases by the mid-September. July being the rainiest month, which alone receives 25 to 35 percent of the total precipitation. There are two-rainfall minima, one in April and another one in November. The winter precipitation is generally caused by the passage of western disturbances and is often in the form of snowfall particularly at higher altitudes[21]. Severe thunderstorms cause rainfall in the pre monsoon months (May -June).

- **TEMPERATURE**

The Bhilangana river basin being hilly with deep valleys, temperature varies considerably with altitude. As the insolation at the higher altitudes is intense, temperature is much higher in the open rather shade in summer, while in the valleys stagnant pool of cold air causes large diurnal variations of temperature. After the January, temperature begins to rise. June is the warmest months with mean maximum temperature recorded at the Tehri 29.1°c in valleys with elevation 762 meters above m.s.l. With the onset of the monsoon

Table: 4.12 Mean Monthly Temperature and Precipitation of selected stations.

Months	Stations							
	Tehri		Deoprayag		Narendra Nagar		Uttarkashi	
	Temp.	Precp.	Temp.	Precp.	Temp.	Precp.	Temp.	Precp.
January	11.6	5.4	-	5.0	-	7.0	12.3	3.3
February	14.4	4.5	-	4.0	-	8.0	15.8	1.0
March	19.4	5.7	-	4.0	-	3.0	20.0	3.8
April	24.0	3.7	-	6.0	-	1.0	22.6	6.7
May	26.9	4.8	-	2.0	-	2.0	22.6	7.3
June	26.4	8.8	-	6.0	-	14.0	25.6	2.6
July	29.1	17.9	-	35.0	-	81.0	25.3	30.1
August	27.7	23.5	-	16.0	-	76.0	24.9	51.7
September	25.5	14.8	-	18.0	-	42.0	25.8	10.5
October	22.6	2.2	-	8.0	-	5.0	18.3	0.2
November	18.0	3.2	-	1.0	-	2.0	16.8	0.2
December	13.4	3.6	-	4.0	-	4.0	12.0	0.8
Annual	-	98.1	-	109	-	178	-	118.2

towards the end of June and early July day temperature suddenly fall approximately 3 to 5 °c. But in post monsoon season day and night temperature both decrease rapidly till January. January is the coldest month. During the winter season, cold waves in the wakes

[20] Singh, R.L. edt. (1980), India: A Regional Geography. BHU, pp.453
[21] District Gazetteers, Tehri Garhwal District, U.P. 1990, pp. 4.

of western disturbances cause the temperature to fall. There may be also considerable accumulation of snow in the valleys.

- **HUMIDITY**

The lowest humidity in the Bhilangana river basin, recorded in the months of April and May, when the relative humidity towards the afternoon in less than 25 percent in the valleys and 35-40 percent over highlands. Humidity increases rapidly with onset of monsoon (relative humidity recorded in the month of July in 92.3 percent.).

- **CLOUDS**

During monsoon season (July to September) and winter months (December-February) when the region is affected by passing western disturbances skies are heavily clouded. Cloudiness is least in the months, May and November.

- **WINDS**

Winds are mostly light and calm in the area. In the wake of the western disturbances and also in association with thunderstorms, winds are quite strong. Strong katabatic winds is also experienced during night as a local effect produced by the nature of terrain.

- **SPECIAL WEATHER PHENOMENA**

Thunderstorms are the typical weather systems in the basin, which frequently occur in the pre-monsoon season (May-June). They are mostly absent in the months of November and December. Thunderstorms are accompanied by hail. Dust storms are rare but some times they occur in valley in the summer season. Fog occurs in the winter season due to passage of western disturbances. In the valleys, morning fog is frequent in the winter season.

4.7 SEISMICITY

The Garhwal Himalayas have a well-known and recorded history of large magnitude earthquake. The entire area is under Zone IV and V seismic zone map of India (Fig. 4.16). The Bhilangana river basin completely lies in the zone V, which has a very high seismic vulnerability. The Garhwal Himalayas has already faced 36 major earthquakes (Magnitude >5.0 on Richter scale) in last one and half century. In last one century, the region has faced 12 events of magnitude greater than 6.0 on the Richter scale.

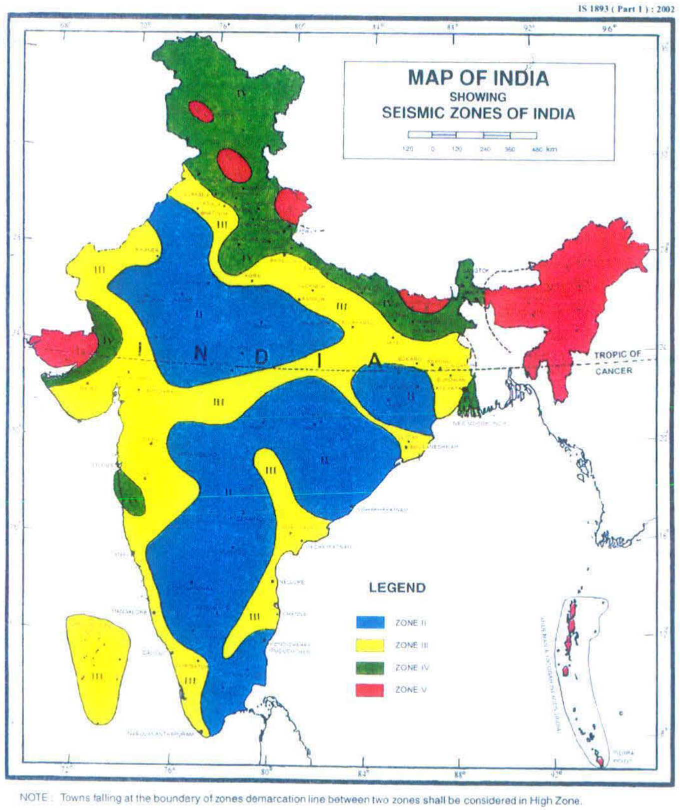
It is found that massive landslide events occur in the wake of high intensity earthquakes in the Himalayas. A 6.6 magnitude earthquake rocked the Garhwal Himalayas of October 20th, 1991 and caused massive landslide events. The Epicenter of the earthquake was near Uttarkashi town. This event caused massive damages in three districts of Uttarkashi, Tehri Garhwal and Chamoli. As a direct consequence, many Villages were completely disrupted, massive damages to transports, communication networks, cultivated lands as well as unvaluable human lives. As per official records about 723 people lost their lives with thousands left injured. More than 70,000 houses were fully or partly damaged[22].

4.8 LAND USE/ LAND COVER

Land use refers to "man's activities and various use which carried on land". Land cover refers to natural vegetation; water bodies, rock, soil, artificial cover and the other resulted due to land transformation. In the present study, land use / land cover map of the Bhilangana river basin (Fig. 4.17) has been prepared from the landuse map published by

[22] India: INDNR and Beyond, 2000. National Center for Disaster management, IIPA, New Delhi, pp. 19

SEISMICITY MAP
INDIA



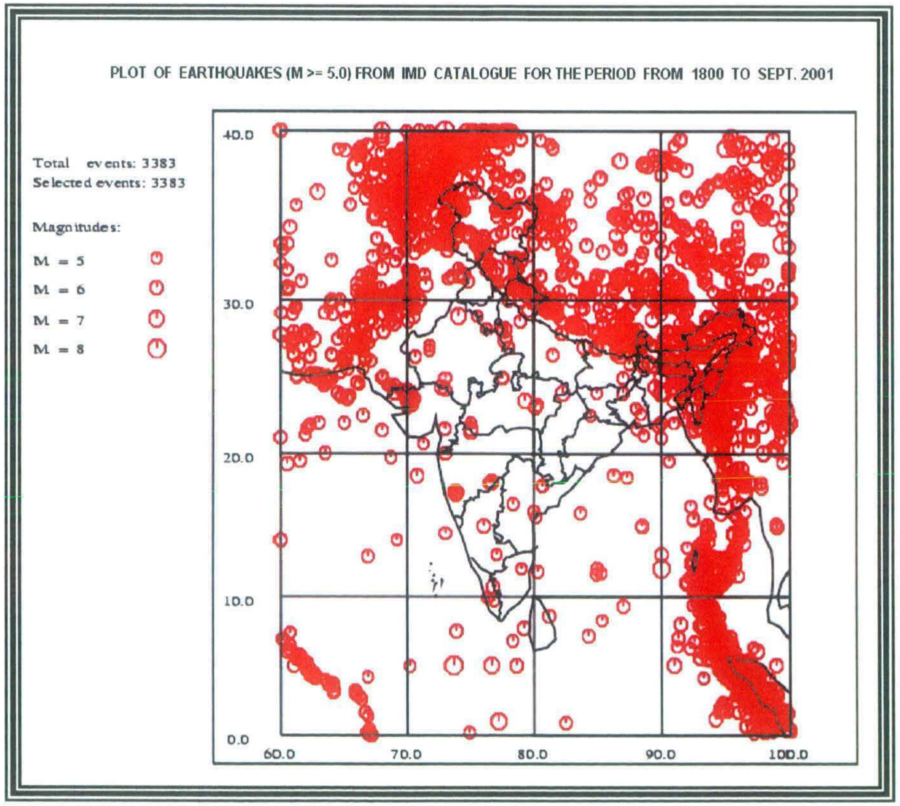


Fig. 4.16

Source: IMD

National Atlas and Thematic Mapping Organization, Government of India. Also landuse/ landcover classification has been made from IRS-1C (digital satellite image dated April, 20th 2000), in Erdas Imagine 8.4 software supervised classification is used (Fig. 4.18).

The general landuse pattern of Bhilangana river basin is presented in the Table 4.13.

Table 4.13 Distribution of Land use/ Land cover in the Bhilangana river basin.

Landuse Types	Area (in km^2)	Percentage of Total Area
Forest	1546.621	72.957
Cultivated Land	332.542	15.687
Settlements	12.431	0.586
Culterable waste	162.354	7.659
Wasteland	65.95	3.111
Total	2119.898	100.000

with exposed rocky surface, classified as wasteland. Due to intensive cultivation in the valley some cultivated land loose fertility and become barren.

Landuse data is a qualitative attribute, so it is necessary to assign them some quantitative weightages according to properties to increasing or reducing slope instability. Weightages are given of respective landuse cover; higher the probability of slope failure higher weightage has been assign.

4.9 NATURAL VEGETATION

The vegetation cover of the Bhilangana river basin is includes the vast range of species, which vary from the subtropical species that grow in outer ranges of low hills to the rich Alpine flowers in the north. The important tree species are as follows Chir, Oake, Conifers, Sal, Deader, Haldu, Yew, Cypress, Shododendron, Birch, Horse-chestnut, Cycamore, Willow and Alder, with variety of herbal plants, bushes, Serbs and grasses.

GENERAL LANDUSE PATTERN

BHILANGANA RIVER BASIN

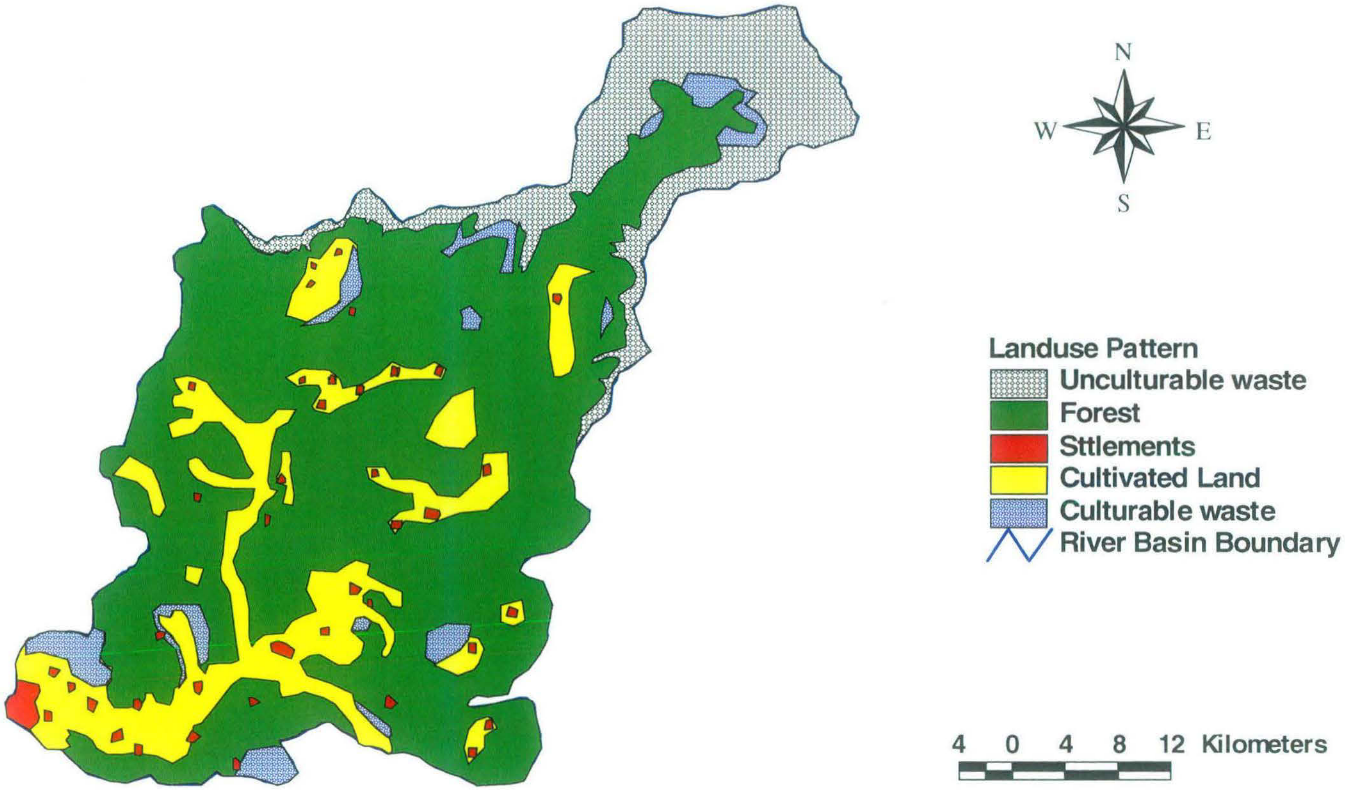


Fig. 4.17 Modified after District Planning Map Tehri Garhwal (Source: NATMO)

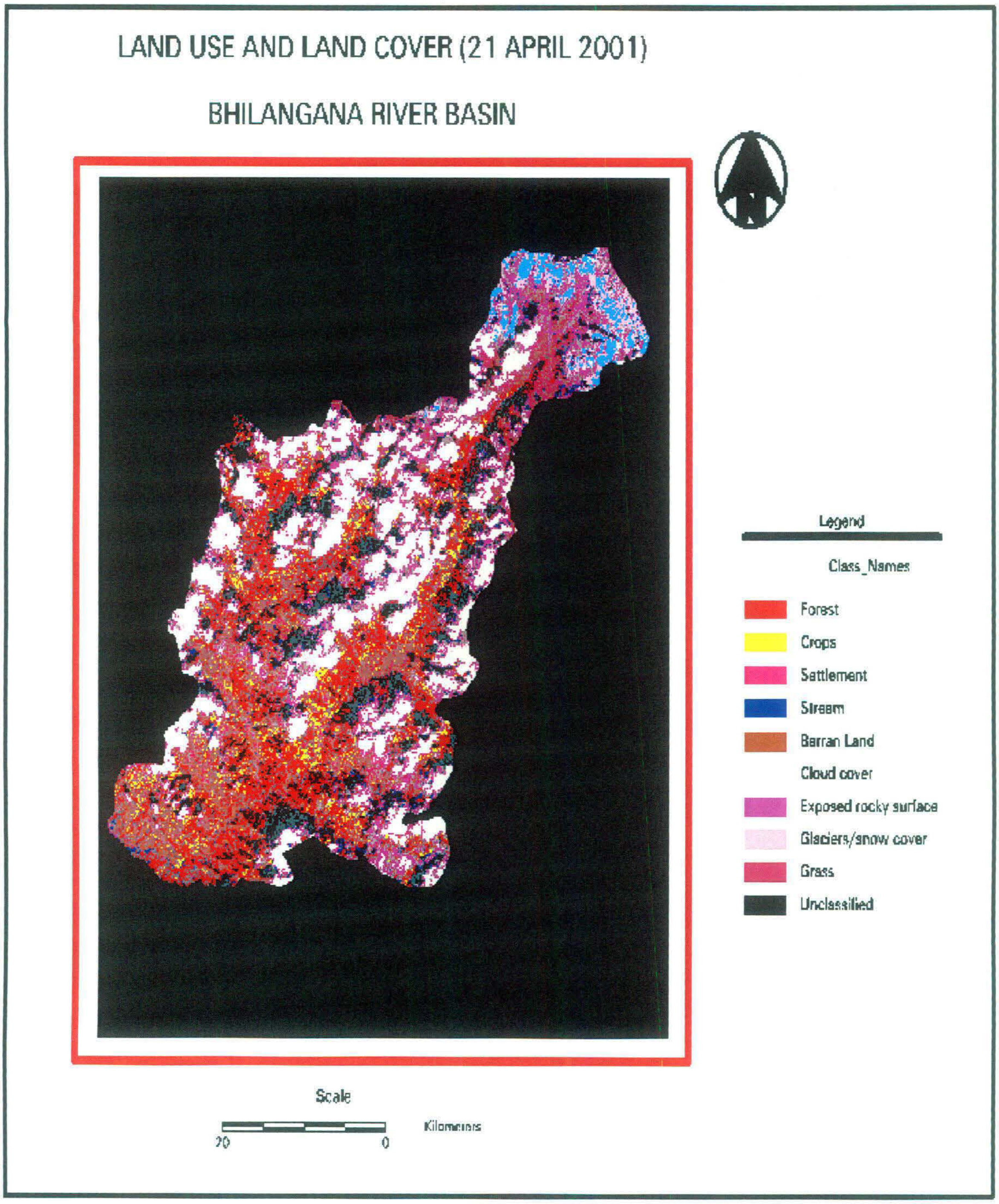


Fig. 4.18 (Source: IRS-1C LISS- III)

The vegetation cover of the study area has been divided into three parts by administrative authority. These are as follows:

a. Bhilangana Forest Division

b. Pratapnagar Forest Division, and

c. Tehri Forest Division

The vegetation cover of the Bhilangana river basin has been grouped in six classes on the basis of plant species[23]. These are as follows:

- **Tropical Dry Deciduous Forest-** these types of forests are found up to altitudes of 1200 meters. The predominant species are kurni, kemela, jhinjan and mander. should be given botanical name

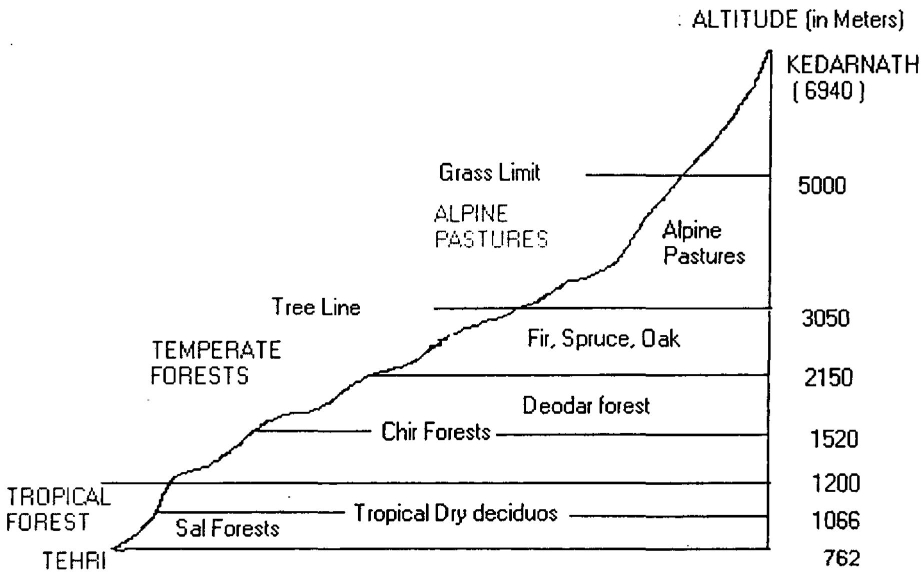


Fig.4.19 Growth of natural vegetation with altitudes in the Bhilangana river basin.

[23] District Gazetteers, Tehri Garhwal District, U.P. 1990, pp. 7-8.

- **Sal Forest-**.It exists up to altitudes of 1066 meters. It is found in the valley of Chandan Rao, of Deoprayag tahsil. It rarely grows on the southern slopes where the altitude is more than 762 meters and northern slope with altitude of 1066 meters. The other tree species are Sain, Bakli, Kanju, Sandan, Rohini and Amaltas.
- **Chir Forest-** This types of forests generally grows in the southern slope (900 to 2000 meters), and also in the valley of the Bhilangana river basin
- **Deodar Forest-** These forests are grows in the northern parts of the area, where altitude vary form 1520 to 2150 meters. It is mainly an open forest.
- **Fir and Spruce Forest-** This type of forests is found on the higher altitude (2150 to 3050 meters). Silver fir is the dominant species except when it occurs mixed with spruce.
- **Alpine Pastures-** Land cover with pastures and grasses are found in the higher altitudes (3050 meters to 5000 meters). During the winter season the snow covers these areas.

4.10 HYDROLOGY

Hydrology, play an important role in the slope instability process. It is depends on geological structure, relief, slope, depth and texture of soils. Hydrological map of the study are prepared by NATMO. According to the map the Bhilangana river basin has very low potential of ground water, yield below 1 liters/sec. This region exhibits limited ground water potential due to compact formation with the less inter-granular porosity and fracture.

What about surface water?

4.11 ROAD NETWORKS

The road networks of the Bhilangana river basin are traced from the NATMO (Fig. 4.20). According to the nature of road, i.e. metteled, pack track, foot track weighteges are assign to them. It is important to note that excavation of slopes for roads construction, stability of slopes disturbed and cause slope failures.

ROAD NETWORKS

BHILANGANA RIVER BASIN

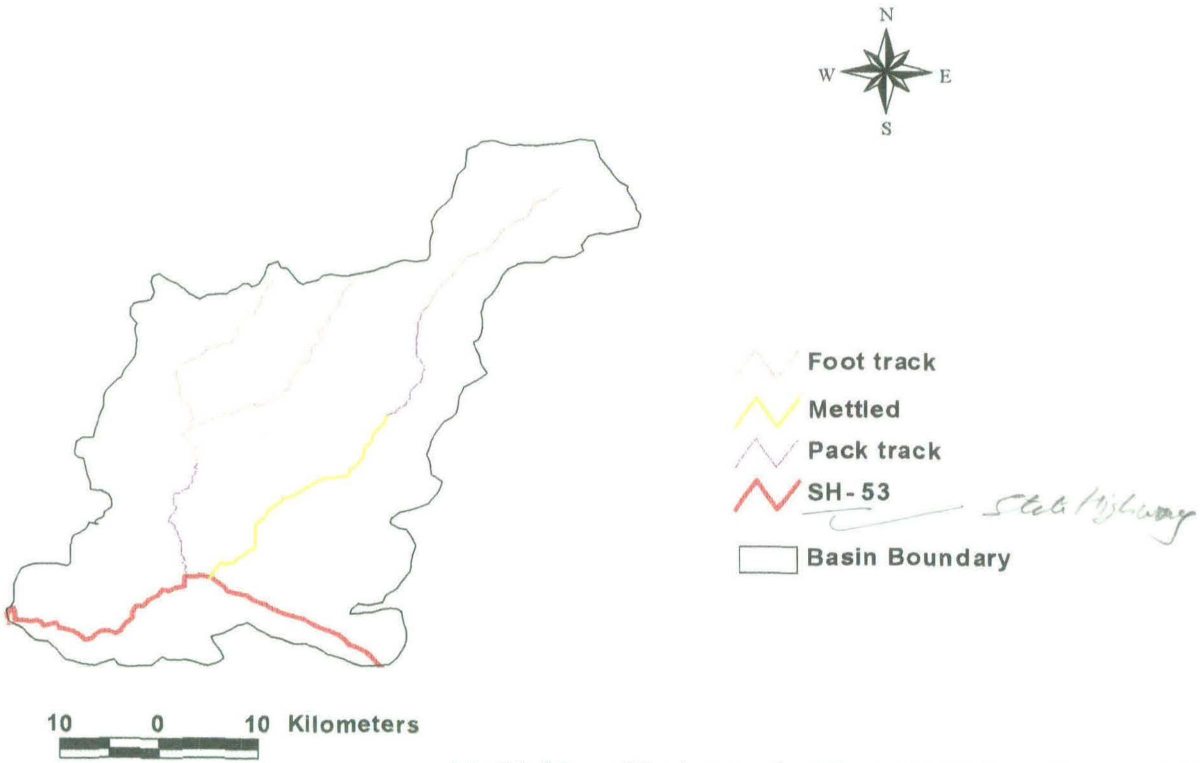


Fig.4.20

Modified From District Planning Map, Tehri Garhwal (Sources: NATMO)

Chapter five

LANDSLIDE SUSCEPTIBILITY MAP

APPROACHES TO LANDSLIDE SUCSEPTIBILITY MAPPING

The study of hillslope process is essential not only for understanding the landscape, but also a practical means for controlling erosion and sedimentation. Men modify the landscape through agricultural practices, engineering excavation and construction on slopes. Cultivation and grazing accelerate the natural rate of surface wash and also lead to the initiation of gullies. Engineering construction often produces un-natural steep slopes as a result regolith falls suddenly.

Landslide hazard zonation (LHZ) refers to 'the division of land surface into homogeneous areas and their ranking according to degree of potential hazard caused by mass movement'. In order to prepare hazard map, the total area is divided into grid cells of 2.25 Km^2.

Integrating factor maps with landslide hazard map, the highest value is needed to assign scores and weighted scores or numerical rating[1]. In the recent past various methods and techniques had been proposed to analyze landslide causative factors and also to prepare maps, which portray the probability of failures. Broadly these methods are classified into three categories. These are direct methods or 'sighted weighting approach', indirect method or 'weighting approach', and overlap approach. The direct methods consist of a geomorphological mapping in which past and present landslides are identified and assumption are made on the factors leading to instability, after which a zonation is made of those sites where failures are most likely to occurs. The 'weighted approach' includes two different methods, namely the heuristic approach and statistical

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[1] Bhandari, R.K. (2004): Landslide Hazard Zonation: Some thoughts, in Valdiya, K.S. (Edt.) Coping with Natural Hazard: Indian context, Orient Longman Pvt. Ltd. Hyderabad; pp. 134-152.

techniques. In the heuristic approach, landslide-influencing factors such as slope, rock type, landforms and land use are ranked and weighted according to their assumed or expected importance, in causing mass movements. This is normally based on priority of knowledge available to experts on various causes of landslides.

In the statistical approach, the importance of each factor is determined based on the relationship with the past/present landslide distributions. With the advancement of computing technology, it has become feasible to apply various statistical methods to analyses slope instability process and produce hazard zonation maps.

The 'overlay approach' requires mapping of each of the causative factors separately and then overlaying the entire factor maps in order to prepare landslide hazard zonation map. In this process of overlaying of factor maps involves highly interrelated factors, which induce or inhibit slope instability for interpreting the landslide hazard zones. Each category within each factor map is given a weightage according to how much it inhibits landslide susceptibility.

In the present study, weightage approach has been used. Weightage method includes the use of statistical techniques to get the composite index of all causative variables. Heuristic approach is used to assign quantitative data to qualitative variables such as, lithology, land use/ land cover, road networks and fault/lineament.

5.1 LANDSLIDE SUSCEPTIBILITY MAPPING

Two methods have been used to prepare landslide hazard zonation map of the Bhilangana river basin. These methods are as follows:

5.1.1 Principal Component Analysis (PCA)

The principal component analysis is a branch of factor analysis and is a technique to synthesize a large number of variables into a smaller number of general components, which retain the maximum amount of descriptive ability. It provides a better statistical analysis of the given set of structural variables and suggests some underlying dimension (components), accounting for the statistical relationship among them. PCA essentially requires an orthogonal transformation of a set of interrelated structural variables into a new set of independent variables. Hotelling (1933) presented formula of the PCA:

Let $X = (x_1, x_2 \ldots\ldots x_n)$ be a set of n vectors of standardized random variables having a good correlation among them with gives the maximum variance.

Thus, it is linear function of –

$$Y = a_1x_1 + a_2x_2 + \ldots\ldots\ldots\ldots + a_nx_n \quad \ldots\ldots 5.1$$

The coefficient vector $a' = (a_1, a_2 \ldots . a_n)$ must be such that:

i. $S^2y = a' Sa_1$ (i.e. the variance of y) is maximum for all value of a, and

ii. $a'a = 1$ (a normalization condition, only for the sake of mathematical covariance),

Where S is the variance –covariance matrix of X and S^2y is the variance of Y. A variance-covariance matrix of the variables $x_1, x_2 \ldots x_n$ is a matrix where diagonal elements show their variance and the off diagonal terms Sij show the covariance between the variables xi and xj. These covariance are given by[2]-

[2] Mahmood, A. (1977). Statistical method in geographical studies. Rajesh publication, New Delhi, pp. 153-156.

$$S_{ij} = \frac{\sum (x_i - \bar{x}_i)(x_j - \bar{x}_j)}{n} \quad \text{.............5.2}$$

In the present study, principal component analysis has been used to compute susceptibility of slope failure in the Bhilangana river basin. Relative relief, slope, dissection index, ruggedness index, lithology, road density, and fault/ thrust density / unit areas have been used for the computation of PCA.

The matrix of inter correlation of these variables, Eigen values and respective Eigen vectors have been worked out in using software SPSS 10.0. Considering the Eigen value 1 as unity there are seven Eigen value (Table 5.1) greater than unity. These Eigen values account 99.99 % of the total variation in the data matrix.

Values of the first principal component have been presented in the Fig. 5.1. On the basis of these values, landslide susceptibility map has been prepared of the Bhilangana river basin. Factor loading of the I[st] principal component shows that it has a significant positive correlation with relative relief, slope, dissection index, ruggedness number and negative correlation with lithology. It is alone explain 71.57 % of the total

Table: 5.1 Eigen Values and Total Variance Explained of the Bhilangana River Basin.

	Initial Eigen Values			Extraction Sums of Squared Loading		
Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	41.637	71.57	71.57	41.637	71.57	71.57
2	11.958	9.97	81.54	11.958	9.97	81.54
3	5.894	6.433	87.973			
4	3.204	4.584	92.557			
5	2.362	3.38	95.937			
6	1.478	2.115	98.052			
7	1.358	1.943	99.995			
8	3.31E-03	4.73E-03	100			

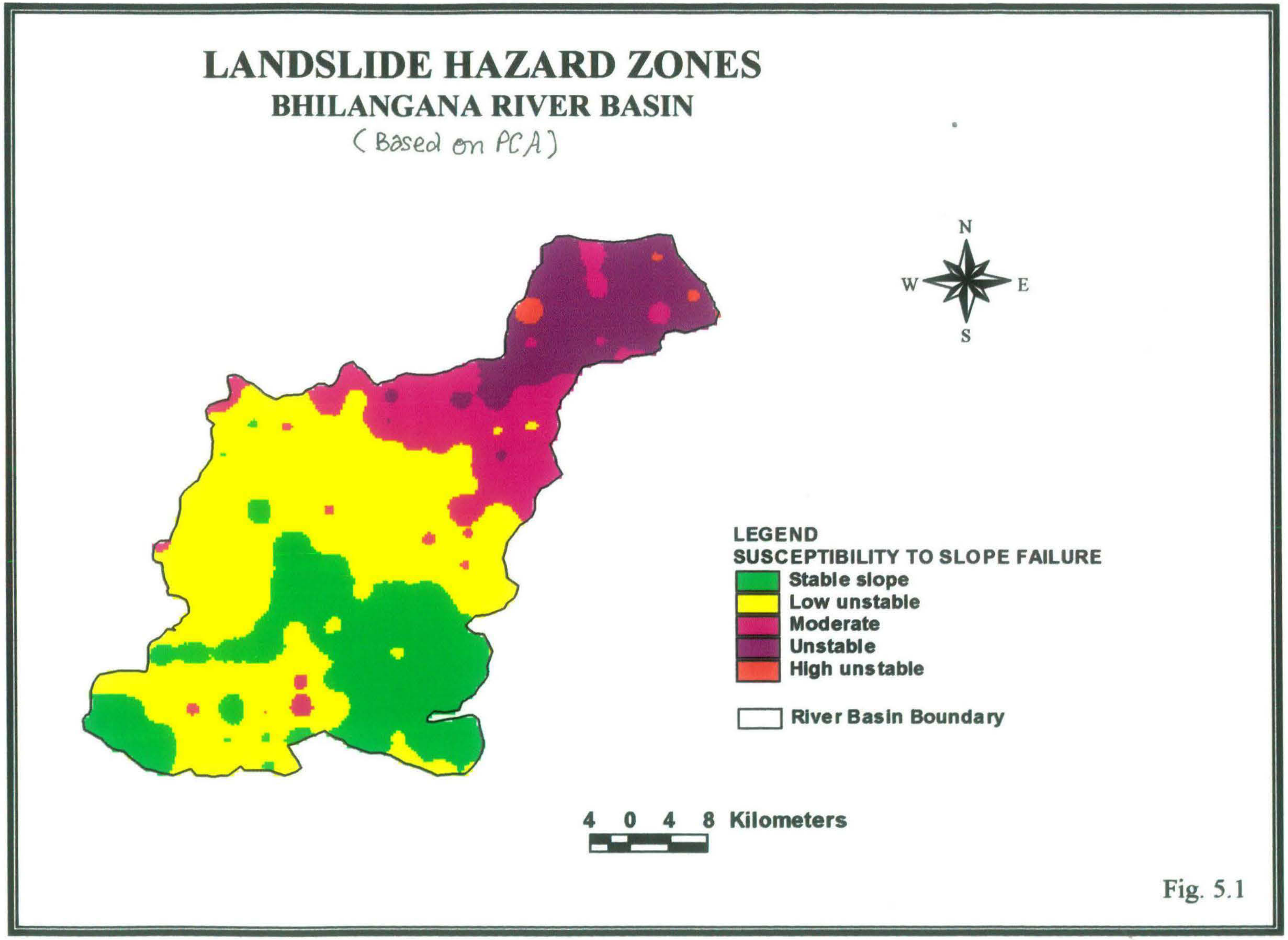
LANDSLIDE HAZARD ZONES
BHILANGANA RIVER BASIN
(Based on PCA)
N
W
E
S
LEGEND
SUSCEPTIBILITY TO SLOPE FAILURE
Stable slope
Low unstable
Moderate
Unstable
High unstable
River Basin Boundary
4 0 4 8 Kilometers

Fig. 5.1

variations in the data matrix. This shows that relative relief, slope, dissection index, lithology play an important role in slope instability processes.

Result obtained from the Principal Component Analysis shows that relative relief or slope inclination is one of the variables that cause slope failure but also it could not always explain the cause of slope failure. There are so many factors, which are incorporated in slope failure mechanism. Some places where relative relief is high but due to hardness of rock, the slopes are much stable rather than the slopes of relatively low relief having soft rock. Therefore, the soft rock areas are more prone to slope failures.

5.1.2 Information Value Method

Sridevi (1993)[3] applied this method while evaluating landslide hazard in Alaknanda valley, Garhwal Himalaya. Information Value Method is new branch of probability theory. This method has been used in the present study by dividing the study area into 2.25 km^2 grid. For each grid the respective information of causative factors of slope instability has been noted. A particular grid j (j = 1, 2, 3......... n) is defined stable or unstable on the basis of its information value. Higher the information value of particular grid, higher is the susceptibility of slope failures.

The total information value of particular grid, j can be given by:

$Ij = \sum^{m} XjiIi$..................................5.3

Where Xji is value of variables I (j = 1, 2, ...n), 1 if variables exist in the grid, 0 if variables does not exist in the grid and 'm' is number of variables associated in the landslides suspectibility analysis.

[3] Sridevi, J. (1993): Statistical model for slope instability classification. Engineering Geology, Vol. 36, pp.91-98

Result obtained from the information value method has been shown in the Figure 5.2. The figure reveals that those grids having steep slope inclination and high relative relief as is this case of parts of the Great Himalayan range are more stable than the low slope angle and moderate relative relief in the lesser Himalayan range. Steep slope angles and high relative relief are the variables, which often induce slope failures. The Great Himalayan range is more stable because of hard rocks and less human intervention. While the area near Tehri town has which is relatively high susceptibility of slope failure due to the unscientific land use practices, increased urbanization, deforestation on slopes, road construction, soft lithology and the presence of Karol and Berinag Thrusts.

It has been found that road construction along fault line cause very high susceptibility of slope failures. This can be seen in the case of State Highway – 41, constructed parallel to the Berinag Thrust. The other areas having the high probability of slope failures are found along streams. These areas are prominently affected by stream undercutting and loosening of cohesive force on slopes.

It is important to note that the high susceptibility of slope failure is noted along the metalled roads in the Bhilangana basin. Deep excavation of slopes for road construction disturbs the stability of slopes and cause massive slope failures. Unscientific land use practices, deforastation of slopes are also the important causes of slope failures.

These causative factors in association with heavy rainfall causes massive slope failures in the monsoon season. Climatic conditions have prominent role in causing slope failure in Bhilangana river basin.

LANDSLIDE HAZARD ZONES

BHILANGANA RIVER BASIN

(Based on Information Value Method)

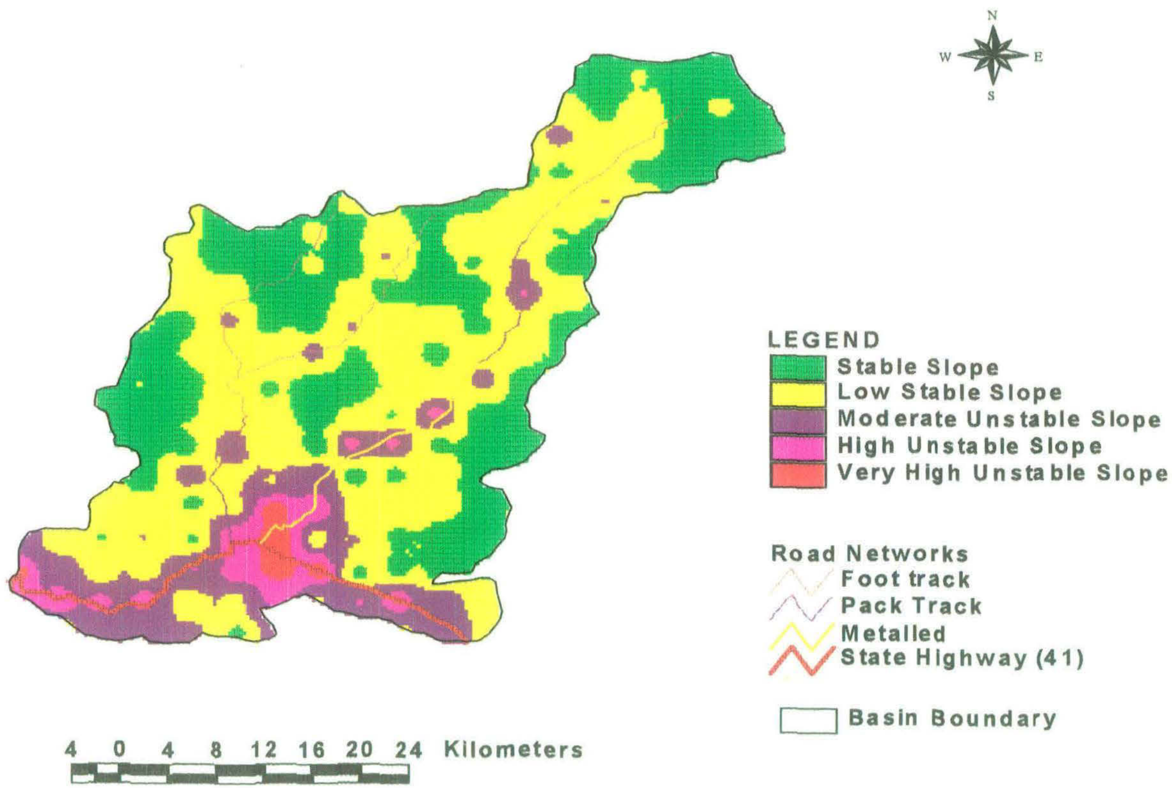

Fig. 5.2

5.2 PREVENTION OF SLOPE FAILURE

Slope instability is a natural hazard, which causes damage to public utilities, natural resources and pose threats to human life. These events are, up to a certain level, predictable in nature to avoid disaster. This has become possible with the advancement of technology to study environmental variables for a clear understanding of mass movements. Land surface can be categorized into different hazard classes according to their susceptibility of occurrence. In the present study, an attempt has been made to suggest the some preventive measures to minimize the frequency and magnitude of landslides in Bhilangana river basin.

Stabilization of landslides or slopes prone to sliding movements must be executed according to a well thought-out plan. This would require individual analysis of slope of a particular site and geological setting. These corrective measures are generally difficult and expensive. It is necessary to recognize the danger of slope movements with in a particular site. For instance, the level of threat along the road sites differs in many ways to the site of construction of buildings, dams etc.

The concerns of the corrective measures are necessary to prevent devastation of environment. It is required to understand as to what would be the consequences of slope failure such as- broken ground surface with slumps, bare hummocks, uprooted trees and disturbed vegetation or on a ground that has to remain fallow for a long time. Several measures can be adopted to minimize the risk of slope failure. These are as follows:

a. The effect of particular preventive measure can change under different geological conditions of the site,

b. The use of techniques to the prevention of slope failure is also influenced by several aspects, involving economic in character, and

c. Local conditions of the site play dominating role in the stability potential of slide area, i.e. it is not easy to provide a permeable rock layer for the construction of drainage on the slopes surface.

To stabilize the slope instability process, the important corrective measures should be followed. These measures are –

5.2.1 STABILIZATION OF SLOPE

Reducing the volume of materials on the head or expanding the volume at the slope toe could reduce the instability of a slope. The deep excavation of slopes for the road construction or by the down cutting of the river action i.e. toe erosion, steep angle of slopes are formed. These steep slopes are highly susceptible to slope failures. If the inclination of these slopes is minimized up to the "safe angle" depending upon the lithology, the probability of slope failure is reduced.

Strata/layers at the base

The presences of ~~a lower layer possessing~~ large shear strength make the slopes more stable. Because, a small extra load may be sufficient to make the slope unstable. If this is filled up on the slope toe it will reduce the slope instability. This method has been shown in figure 5.3.

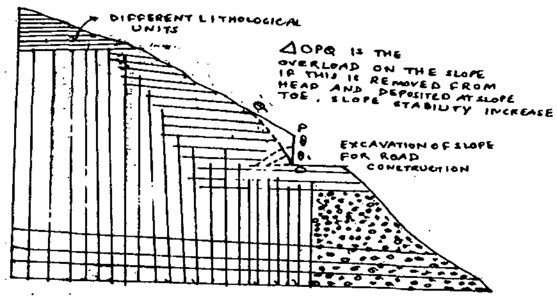

Fig. 5.3 Stabilization of Slope by reduces shear stress.

5.2.2 PROPER DRAINAGE OF SLOPE

The surface of any area affected by sliding is generally uneven and traverse by deep fissures. Water get accumulated in the depression and fissures, and percolate in the sub-soil increasing the shear stress on the slope. This extra loading on the slope increases slope instability. Therefore, construction of surface drainage on the slope may be required to carry away rainwater from the slopes to streams. Although surface drainage by itself is seldom sufficient to stabilize a slope, which is in motion, it can contribute substantially to the drying out, and thus also to control landslides. However, all streams and temporary surface watercourses cannot be made and diverted from the threatened area.

5.2.3 RETAINING WALLS

Retaining walls are sometimes erected to bring greater stability to dangerous slopes, or to stop existing landslides. These are stabilizing slopes in many cases of pile walls, which can be installed in advance of excavation work. Along the roads cut, concrete crib, retaining walls should also be constructed to stabilize slope.

5.2.4 ROCK BOLTS AND ANCHORS

These are very important methods to prevent slope failure around mines, tunnels, dam sites, roads and along railway lines, rocky slopes and for the stabilization of rock slides. It is also very useful to stabilize slopes in association with retaining structures.

Rock bolts are shallow – fitting elements, while anchors are fixed deep into the slopes. Thus rock bolts help to stabilize the slope face by exerting a force that is compressing joints and loosening by freeze and thaw. The bolts are mostly drilled in along their entire length with cement and other chemical agents. These are very useful in preventing rock dialatancy.

Rock anchors are longer than rock bolts. They are anchored into the rock along their root section in order to transmit a tension force to the rock face. The angle of inclination of rock bolts and anchors should be examined carefully to ensure that if deformation of the slope occurs there would not be an increase of tension in these.

5.2.5 HARDENING OF SOIL

This method is very important to reduce slope instability by compacting the loose soils of slope. Loose soils have properties to absorb rainwater, increase shear stress and would cause slope failures. This method has certain limitations in permeable soil.

5.2.6 FILLING OF JOINTS AND CRACKS

There are various types joints, faults, cracks and fissures in the mountainous rugged terrain, along these severe sliding events occur. If these slopes features are filled with sand and silt materials to stop penetration of water these would reduce slide movements.

5.2.7 PLANTATION ON THE SLOPE

Slope movement generally disturbs vegetation cover. Afforestation of slopes is an important method for stability of slopes. Plantation is preceded by drainage area, leveling of the surface and filling of the cracks.

It is generally accepted that forest growth helps to dry up slope surface therefore roots. Trees suck water from ground by their roots and loosing it by the process of transpiration. Hence, it is suggested that plantation of deciduous trees rather than conifer is more suitable to stabilize the slope.

However, tree planting is an effective method to control slope failure, only in the case of shallow sheet slides. Landslides with deep-lying slides surface cannot be stopped by vegetation growth, although this method does has the effect of reducing infiltration of water on slope surface.

Chapter six

Summary and Conclusion

SUMMARY AND CONCLUSION

The Bhilangana River is a left bank tributary of the Bhagirathi River running from the North East to South West and covers the area between the Great Himalaya range in the North East and the Lesser Himalaya range in the South West. The 'Main Central Thrust' (MCT) separates the Great Himalaya and the Lesser Himalaya ranges. The Bhilangana River originates in the glaciers i.e., Khatling and Dudhganga Bamak, which cover North East parts of the Tehri Garhwal district of Uttranchal. In the early stage, it flows to south before taking a turn near Ghuttu therefore it flows to the southwest direction, and joins the Bhagirathi River near old Tehri town. The region is characterized by high altitude. Some of the highest peaks in the region are Kirti Stambh (6548 m), Phanting Pithwara (6904 m) and Kedarnath (6940 m).

The study area comprises Tertiary to Archaean geological formation and is a part of the Himalayan mountain system. Evolution of the Himalayan mountain system began from the Mid-Miocene (40 – 25 M.a.) to late Pliocene periods. The Himalayas are still in the process of upliftment. Active thrusts and faults make the slopes fairly unstable or at least make them prone to slides and slips. Severe seismic events occur along these thrusts and faults plane. The Bhilangana basin comes under the high to very high intensity seismic zones.

Temperature varies considerably with altitude in the study area. As the insolation at higher altitudes is intense, temperature is much higher in the open rather than shade in summer season, while in the valleys stagnant pool of cold air causes large diurnal variation in temperature. The Bhilangana basin receives more than 75% rainfall in the monsoon season. The monsoon commences towards the end of June or early July and ceases by the mid-September.

Natural vegetation of the basin varies from subtropical to alpine species owing to the variation in the altitude and aspect. The important tree species are Chir, Oak, Sal, Deodar, Haldu, Yew, Cypress, Rhododendron, and Birch etc. The tree line is at 3050 m and beyond this altitude; alpine pastures grow up to the altitude of 5000 m. The forest covers 75 percent area of the basin while the cultivated area covers only 15 percent.

Slope instability is a common process in the Bhilangana basin. Slope failures are very frequent during monsoon season due to heavy rainfall. Rainwater infiltrates into regolith and increases the shear stress at steep slopes causing slope failure, which is very frequent along roads. Deep excavation of slopes in order to construct road adds to the gradient that makes it highly prone to slope failure. Earthquakes also make the slope unstable and are responsible for the major landslides in the basin.

Hazard zonation map of the basin shows that the high altitude areas in the Greater Himalayas having steep slope to be quite stable due to presence of hard rocks (granite and genesis). Therefore, the probability of slope failure is low in these lofty areas. The probability of slope failure is very high in the lesser Himalayas due to soft lithology, deep excavation of slopes for road construction, unscientific land use practices and channel incision.

The hazard zonation map shows the following facts:

i. Slope failures are the product of geological formation. The probability of slope failure is higher in soft rock (Limestone, Quartzite, Migmatite, etc.) than the hard rock area (Granite and Genesis).

ii. Unfavorable dipping discontinuity or shear zone along steep slope makes slope failures more common.

iii. Earthquakes are also responsible for the slope failures in both hard as well as soft lithology more so along the convex slopes. These trigger the sudden fall of loose regolith and bedrock.

iv. Very high instability of slope is observed along the Bhatwari thrust, which comprises soft lithology; land is under cultivation and State highway-41 constructed parallel to the fault plane.

v. Slope failures occur more frequently in the areas, which are rugged and dissected and are associated with earthquakes and heavy prolonged rainfall.

APPENDIX – 1

Landslide Factor Rating Scheme [Based on Thigale and Khandge (2004)]

Lithology-	Rock types	Score
	Vaikrita	1
	Munisiari	2
	Berinag	4
	Chail	6
	Krol	8
Landuse-	Landuse types	Scores
	Settlement	1
	Forest	2
	Wasteland	3
	Barren land	4
	Cultivated land	5
Road-	Road type	Scores
	Foot track	1
	Pack track	2
	Mettaled	4
Fault/ Thrust	Types	Scores
	Absence	0
	Present	4

These are formation not rock type

APPENDIX - 2

Factor Analysis:

Correlation Matrix

Correlation	STDRRE	SLOPE	DSIND	RUGG	LANDUSE	ROADS	LITHO	LINEA
STDRRE	1	0.483	0.356	0.369	0	-0.154	-0.451	-0.144
SLOPE	0.483	1	-0.354	0.03	-0.066	-0.243	-0.71	-0.214
DSIND	0.356	-0.354	1	0.446	0.183	0.293	0.511	0.182
RUGG	0.369	0.03	0.446	1	0.11	0.228	-0.029	0.021
LANDUSE	0	-0.066	0.183	0.11	1	0.196	0.087	-0.004
ROADS	-0.154	-0.243	0.293	0.228	0.196	1	0.347	0.168
LITHO	-0.451	-0.71	0.511	-0.029	0.087	0.347	1	0.297
LINEA	-0.144	-0.214	0.182	0.021	-0.004	0.168	0.297	1

Total Variance Explained

Component	Initial Eigen Values				Extraction sums of Squared Loadings		
	Component	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
Raw	1	41.637	71.57	71.57	41.637	71.57	71.57
	2	11.958	9.97	81.54	11.958	9.97	81.54
	3	5.894	6.433	87.973			
	4	3.204	4.584	92.557			
	5	2.362	3.38	95.937			
	6	1.478	2.115	98.052			
	7	1.358	1.943	99.995			
	8	3.31E-03	4.73E-03	100			
Rescaled	1	41.637	71.57	71.57	2.188	27.347	27.347
	2	11.958	9.97	81.54	1.563	19.543	46.89
	3	5.894	6.433	87.973			
	4	3.204	4.584	92.557			
	5	2.362	3.38	95.937			
	6	1.478	2.115	98.052			
	7	1.358	1.943	99.995			
	8	3.31E-03	4.73E-03	100			

Extraction Method: Principal Component Analysis.
a When analyzing a covariance matrix, the initial eigen values are the same across the raw and rescaled solution.

APPENDIX – III

Landslide probability classification (after Crozier, 1984)

Class VI	Slopes with active landslides. Material is continually moving, and landslide forms are fresh and well –drained. Movement may be continuous of seasonal.
Class V	Slopes frequently subject to new or renewed landslide activity. Movement is not a regular, seasonal phenomenon. Triggering of landslides results from events with reoccurrence intervals of up to five years.
Class IV	Slopes infrequently subject to new or renewed landslide activity. Triggering of landslides results from events with reoccurrence intervals of greater than five years.
Class III	Slopes with evidences of previous landslide activity but which have not undergoes movement in the preceding 100 years. Subclass IIIa- Erosional form still evident Subclass IIIb- Erosional forms no longer present activity indicated by landslide deposits.
Class II	Slopes which show no evidences of previous landslide activity but which are considered likely to develop landslides in the future. Landslides potential indicated by stress analysis, analogy with other slopes or by analysis of stability factors; several subclasses may be defined.
Class I	Slopes which shoe no evidence of previous landslides activity and which by stress analysis, analogy with other slopes or by analysis of stability factors are considered highly unlikely to develop landslides in the foreseeable future.

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