"First, have a definite, clear practical ideal; a goal, an objective. Second, have the necessary means to achieve your ends; wisdom, money, materials, and methods. Third, adjust all your means to that end."

Aristotle

INTRODUCTION 1

BACKGROUND INFORMATION

Uttarakhand state bounded between 77° 34' 27" East to 81° 02' 22" E longitude and 28° 53' 24" North to 31° 27' 50" N latitude is located in the northern part of India. It was known as *Uttaranchal* between 2000 and 2006. In January 2007, the name of the state was officially changed from Uttaranchal, its interim name, to Uttarakhand, according to the wishes of a large section of its people. Uttarakhand became the 27th state of the Republic of India on November 9, 2000 with 13 districts namely – Chamoli, Dehradun, Haridwar, Pauri Garhwal, Tehri Garhwal and the Uttarkashi together forming Garhwal division while, Almora, Bageshwar, Champawat, Nainital, Pithoragarh, Rudraprayag and Udham Singh Nagar forming the Kumaun Division. Uttarakhand borders Tibet to the north, Nepal to the east, and the states of Himachal Pradesh and Uttar Pradesh (of which it formed a part before 2000) in the west and south respectively. The provisional capital of Uttarakhand is Dehradun which is also a rail-head and the largest city in the region. The small hamlet of

Gairsen has been mooted as the future capital owing to its geographic centrality but controversies and lack of resources have led Dehradun to remain provisional capital. The total population of the state stands at 84, 79, 562 (2001 Census). The state covers an area of 51, 125 km^2 and comprises of 92.57 % of hilly area, 7.43% plains and about 63% of the area is covered by forests.

The Kali River Corridor between Tanakpur on Himalayan foothills and Jipti in Higher Himalayan domain, in the eastern most extremity of the Kumaun Himalayas, Uttarakhand State forms the Indo-Nepal border zone. This particular stretch is under the maintenance of Border Roads Development Organization (BRDO). The entire corridor from Tanakpur to Jipti is divided into two road segments – (i) Tanakpur – Pithoragarh – Tawaghat Road and (ii) Tawaghat – Jipti Road by BRDO and it has been designated with the National Highway status. The entire length of road is divided into number of small divisions and their maintenance and development is carried out by various Road Maintenance Platoon (RMPL), which are directly controlled from their headquarter, i.e., 65 RCC (Road Construction Company) at Pithoragarh. In 1993 with a view to further expand the road network till Tibet-China border the construction of Tawaghat – Jipti road segment was initiated and till date a total of 33km stretch of this road upto Jipti village has been completed. The Tawaghat – Jipti Route Corridor (TJRC) is witnessing stupendous growth in infrastructure development activities. Dhauliganga Hydroelectric Project at Chirkila-6km from Tawaghat has been commissioned in 2006, Sobla Stage – II is under construction and Stage – III is in investigation stage, also the route for famous Kailash-Mansarovar pilgrimage passes through this route corridor. This area being so much economically important and strategically vital is witnessing indiscriminate cutting of slopes for road network expansion and has resulted into large scale development of landslides. The Himalayas being tectonically active, various endogenetic coupled with exogenetic processes have further intensified widespread recurring incidences of landslides particularly during monsoon season and force these routes to close down thereby, disrupting normal lives of the people and causing interruption in the movement of defence supplies to high altitude regions. These landslides have also caused excessive damage to private and public property. Some recent noteworthy

landslide incidences (Plate I.1) took place in this corridor are at Jauljibi (1984), Bangapani (1984), Khela (1988), Malpa (1998), Charma (2000), Teentola (2000), Khet (2001), Mangti (2001), Shyamkhola (2001), Elagad (2004-05), Lakhanpur-Jipti (2005), and in Nepal Side Margaon – Sunsera (2000), etc.

AIMS AND OBJECTIVES

In this presented study the author has endeavoured to carryout engineering geological characterization of the Mangti landslide and slopes of Tawaghat – Jipti Route Corridor; an in-depth geotechnical study of the Mangti landslide and to attempt predictive mathematical model; prepare micro-level landslide hazards zonation map of entire route corridor and suggest landslide mitigation plan.

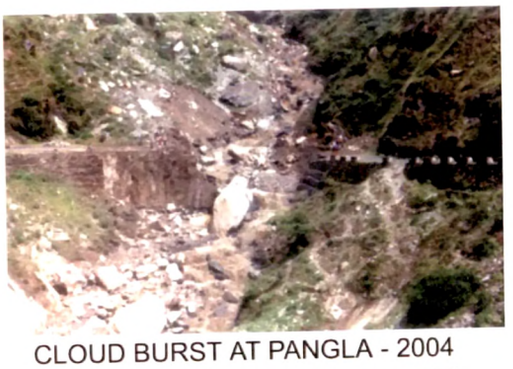
The study aimed at fulfilling following objectives –

- Carry out detailed Geological Investigation of the TJRC,
- Inventory of landslides and their historical accounts,
- Engineering Geological assessment of landslide environ along TJRC,
- Critical study of Mangti Landslide from the point of view of carrying out detailed geo-technical investigation, measurement and monitoring of its rate of movement and pore water pressure,
- Generation of various thematic layers such as landslide inventory, landuse, lithology, lineament, slope and slope aspect and preparation of database in Geographic Information System on various thematic maps and collateral data viz. geology, geotechnical properties, seismicity, etc.
- Preparation of micro-level Probabilistic Landslide Hazard Zonation **EIA** map using remote sensing and GIS techniques,
- Slope stability analysis and suggesting landslide specific mitigatory measures.

MALPA DEBRIS AVALANCHE - 1998

MANGTI LANDSLIDE - 2002

MARGAON-SUNSERA - 2000



CLOUD BURST AT PANGLA - 2004

SHYAMKHOLA - 2001

KHET DEBRIS AVALANCHE - 2001

ELAGAD - 2005

Plate I.1 - Major Landslide Incidences in the Study Area

METHODOLOGY

A multi-disciplinary approach has been adopted to investigate the study area. Although major study has been restricted in India side, a buffer zone of two kilometers on either side of Kali River sharing Indo - Nepal region was considered for hazard assessment. The envisaged methodology includes a three tier approach encompassing different domains of engineering geological investigations viz.

1. Collection of secondary data on geology, landslide hazards, meteorology and seismicity from various organization and their critical review; generate database in Geographic Information System on various thematic maps and collateral data;
2. Carry out detailed Engineering Geological Investigation of entire TJRC encompassing geological mapping, inventory of various discontinuities and their characterization using Rock Mass Rating (RMR) norms. Study of various geomorphic attributes using Survey of India Toposheets and Satellite Data. Detailed inventory of active landslides; their geometrical parameters, surface lithological profiles and geological attributes (i.e., spatial distribution of material types, discontinuity surfaces, etc.).
3. In-depth geotechnical study of the Mangti Landslide and its environ through-
    a. Development of 1m contour plan using Electronic Total Station & DGPS.
    b. Installation of movement Rods and Open Stand Pipe Type Piezometers for periodic monitoring of slope mass movement and pore water pressure respectively.
    c. Installation of rain gauge station for rainfall measurement.
    d. Collection of undisturbed and disturbed samples (regolith and rock) for determining various engineering properties in laboratory.
4. Integration of field and laboratory data to perform kinematic analysis to ascertain the factor of safety of slopes at critical places in the study area; carry out stability analysis and establish predictive model of landslide occurrence for Mangti landslide.

5. Empirical modeling using Information Theory to prepare Micro-Level Probabilistic Landslide Hazard Zonation (EIA) Map in GIS environment of the TJRC.
6. Field validation, accuracy estimation and suggestion of landslide specific mitigatory measures.

A sequential account on the adopted methodology is depicted as an exemplary flow chart (Figure 1.1).

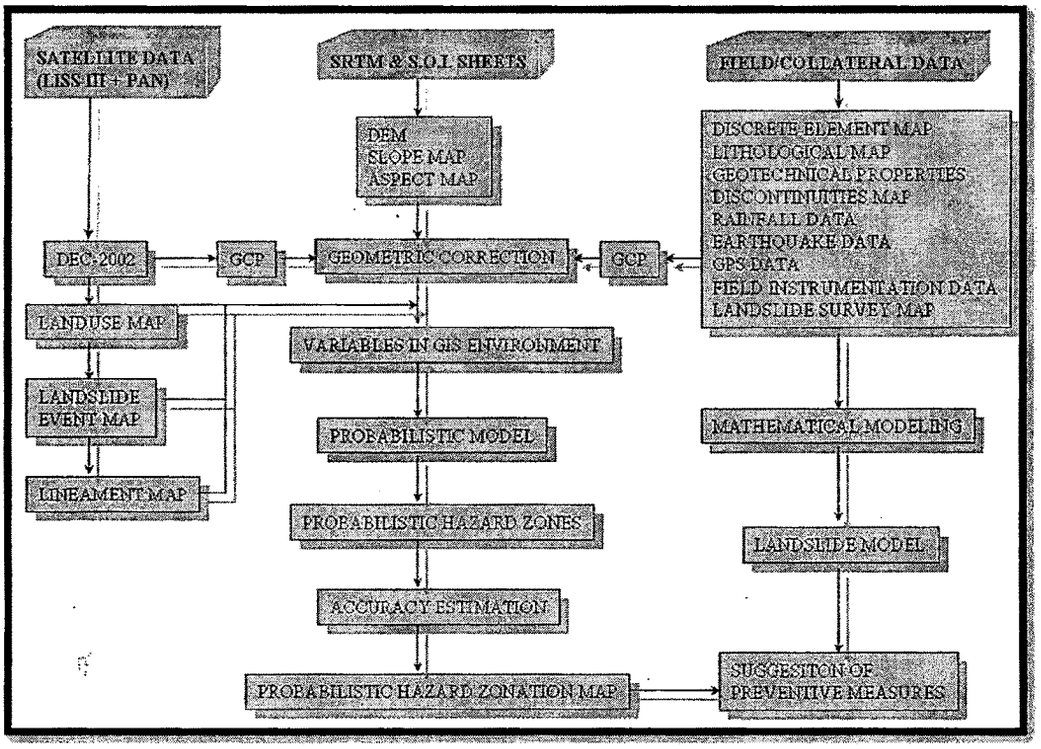


Figure 1.1 - Schematic Representation of the Adopted Methodology

STUDY AREA

The investigated area forms a part of Dharchula block on the northeastern part of Pithoragarh district of Uttarakhand State bordering Nepal (Figure 1.2). The Tawaghat-Jipti Route Corridor sprawling over an area of 158.22 km^2 is geographically bounded between longitudes E 80°34'46'' to 80°45'00'' and latitudes N 29°53'37'' to 30°02'37'', dominantly embracing the Lesser Himalayan domain and partly the Higher Himalayan region of the Kumaun Himalayas. The entire road stretch from Tawaghat to Jipti runs along Kali River for about 33 kilometer distance till the last

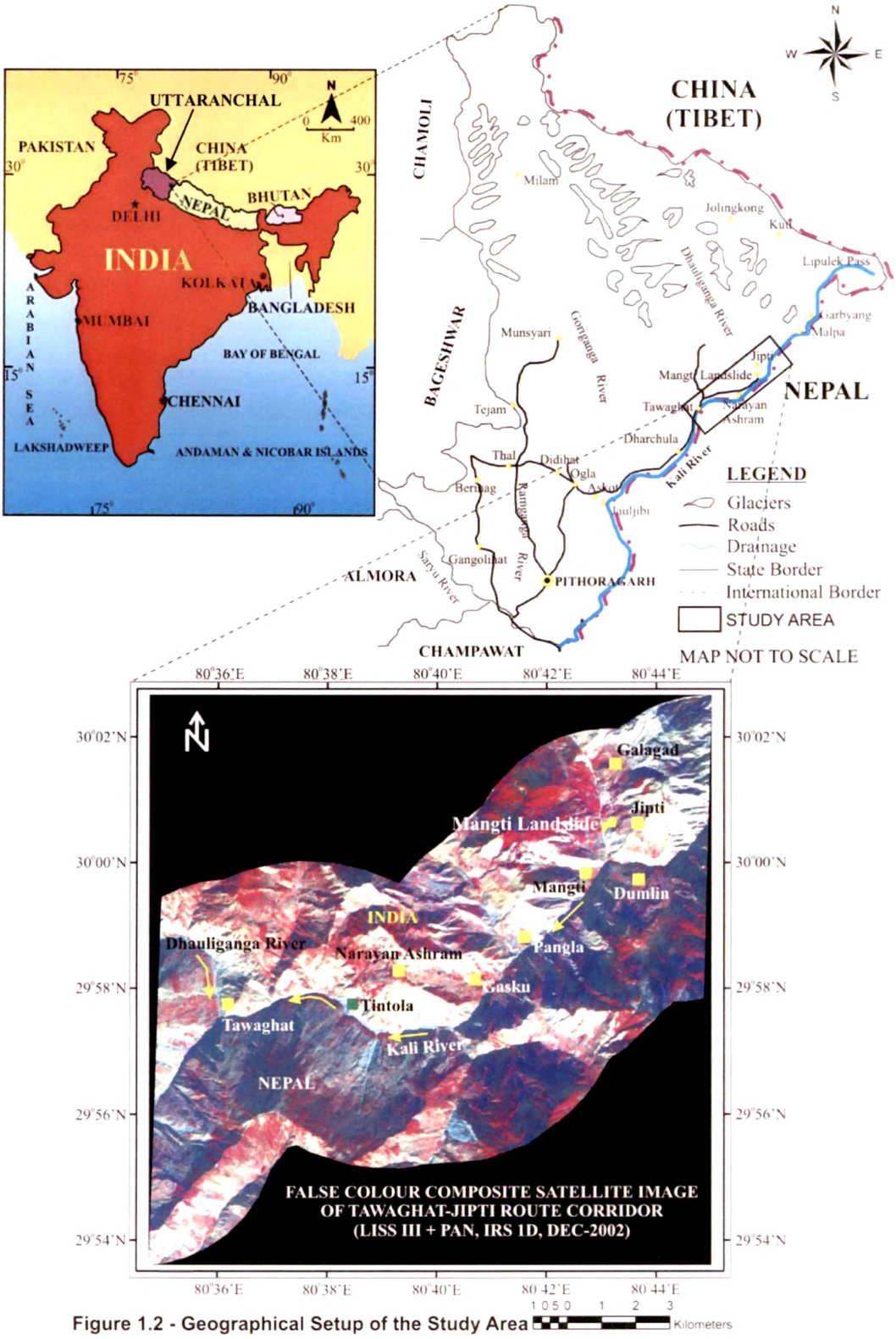


Figure 1.2 - Geographical Setup of the Study Area

motorable point and is covered in the Survey of India Topographic Sheets 62B/12 and 62C/9. Correspondingly, the IRS-1D satellite path 98 & 99 and row 50 envelopes this area. Kali River forms the international border between India and Nepal in this region. The present study is carried out for a buffer distance of 2 kilometers on either side of Kali River Valley axis.

The study area has been experiencing land degradation due to inadequate forest cover, denudation of forest, uncontrolled grazing and neglect of available pasture land. Area receives its maximum rainfall in the months of July, August and September. The average annual rainfall is nearly 2200mm while sudden cloud bursts resulting in very heavy rainfall to the tune of 150-200 mm in 24 hours is a very common phenomenon in this region. Landslides, sheet and rill erosion are common hazards found in the study area.

COMMUNICATION

The study area and its neighbourhoods have a picturesque landscape and is a trekker's paradise. The famous pilgrimage route to Great Mount Kailash-Manasarovar also passes along this river. Hence, it attracts a large number of tourists from every corner of the world. On account of large number of tourist places, the study area is well linked with the communication network. All the major towns viz. Berinag, Thal, Didihat, Dharchula, Pithoragarh, etc. are well connected with roads. The Uttarakhand State Roadways Transport and the buses owned by the Kumaun Motor Union (KMOU) ply regularly to these centres from Delhi as well as Kathgodam. The broad gauge railway link (North Eastern Railway) is available upto Kathgodam, which is located on foot-hills of Kumaun. The only air-link between the study area and the rest of the country is Pithoragarh, situated on the eastern fringe of the Kumaun Himalayas and is also the district head quarter. The interior areas are accessible through mule tracks and foot paths.

PHYSIOGRAPHY

Physiographically the study area forms a small part of Kali Watershed embracing the realms of Lesser and Higher Himalayas. The Main Central Thrust (MCT) demarcates the boundary between the Lesser Himalayan domain to the south and Higher

Himalayan domain in the north. The Lesser Himalayan terrain attains heights between 1,200 and 3,000m above mean sea level (a.m.s.l.) and represents a blend of young and mature landscapes with gentle to steep slopes and deeply dissected valleys. However, being tectonically active the Higher Himalayan segment is characterized by youthful topography and a rejuvenated drainage system rising to the altitude of 4800 – 6000m a.m.s.l. The Kali River originates from Kalapani in the Tethys Himalaya and flows through the study area. The general slope of the basin is towards South-West. The study area is characterized by a highly rugged terrain comprising lofty ridges, escarpments and a variety of landform features attributed to glacial, fluvial and tectonic processes. The Dhauliganga River is the major tributary system that drains into Kali River in the study area and meets the main channel at Tawaghat. A number of small streams viz., Shymkhola Gad, Jiunti Gad, Ritha Gad (Nepal), etc. also drain their waters into Kali River in the study area.

CLIMATE

The climate though sub-tropical varies from region to region. In general, there are three well – marked seasons, i.e., summer, monsoon and winter. Summer starts with gradual rise in temperature from March onwards and continues till mid June when easterly winds, often accompanied by pre – monsoon showers make the climate humid. During summer the temperature rises above 30°C in the regions below 1200m a.m.s.l. and at times there are thunder storms accompanied by rains. The areas above 1400m elevation a.m.s.l. remain pleasant for most of the time during summers. Monsoon season commences from end of June and continues till the end of September. The area south of the Higher Himalayan Zone experiences heavy rainfall (37-50cms), while to its north the area comes under 'Shadow Zone' where rainfall is less than 15cm. There is occasionally unpredictable snowfall. The relative humidity remains above 70%. Winters start with gradual cooling in October and lasts till February. December and January months are the coldest months when the temperature may drop to 2-3°C. Higher and Tethyan Zones remain snow-bounded and in-accessible. There are winter rains accompanied by snowfall.

TERRAIN RESOURCES

The Himalayan mountain range is characterized by illustrious tropical Alpine deciduous forests, harbouring large number of valuable and fragile floral and faunal assemblages.

FLORA

Flora includes many unique sub-tropical, temperate and alpine plants. The flora includes many Bryophytes, Pteridophytes, Gymnosperms and Angiosperms. Rare varieties of orchids are also present in the high altitude valleys of Darma, and Kuthi. Among them *Myrica esculenta* (Kafal), *Saussurea obvallata* (Brahm Kamal), *Zanthoxylum armatum* (Timur), *Berberis aristata* (Kirmod), *Saussurea simpsonia, Rhododendron campanulatum, Rubus rotundifolius* (Hisalu) *Rhododendron barbatum* (Burans), *Cypripedium cordigerum, Dendrobium normale, Vanda cristata, Prunus puddum, Prunus cornuta, Pedicularis punctata, Quercus incana, Quercus leucotricophora* (Banjh), *Quercus semicarpifolia, Quercus dilatata, Pinus roxburghii* (Salla or Chir), *Pinus wallichiana* (Blue Pine or Raisalla), *Cedrus deodara* (Deodar Cedar), *Taxus wallichiana* (Himalayan yew), *Abies pindrow, Aconitum heterophyllum, Betula utilis* (Himalayan birch or Bhoj Patra), *Nardostachys grandiflora* (Jatmasi), *Picrorhiza kurroa* (Kutki) are abundantly found.

FAUNA

In the Himalayan region there are musk deer (*Moschus moschiferus*), barking deer (*Cervulus muntajae*), Himalayan black bear (*Urus toruatus*), tigers, panthers, leopards. Goat families include Thar (*Hemitragus jemlaicus*), Gorhal (*Neoorhoedus gorhal*) and the sheep bharal (*Ovis nahura*). Sometimes, wild horse kyang (*Equus hemionus Pallas*) and yak (locally called Jhaboo) cross over from the Tibetan zone to the Tethyan part and are seen grazing in the meadows.