Macro-scale Landslide Susceptibility Mapping in Kurseong – Mangpu area of Darjeeling Himalaya

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Abstract

Macro scale Landslide susceptibility map (LSM) of 316 Sq km in parts of Kurseong –Mangpu area of Darjeeling District was prepared by facet-wise integration of six causative factors (lithology, structure, slope morphometry, relative relief, landuse & land cover and hydrogeology) using GIS techniques (ARC/INFO 9.1 software) following the guidelines of Bureau of Indian Standards (BIS). The prepared LSM shows spatial distribution of five zones of increasing landslide susceptibility. The thematic maps with landslide incidences, prepared through detailed field studies and augmentation of available database, indicate the spatial distribution of thematic parameters vis-à-vis *landslide incidence of the area. Analysis of the LSM database reveals that about 38.51% of the studied area comes under high (HSZ) and very high susceptibility (VHSZ) zone. The moderately susceptibility zone (MSZ) covers 36.17% and low & very low susceptibility zones (LSZ&VLSZ) together constitute 25.32% of the study area. The prepared LSM when validated with the landslide incidence map of the area indicates a) no landslide incidence in VLSZ, b) a progressive increase in the relative abundance values of landslide for successive higher categories of susceptibility zones and c) a very high value (72.03%) for HSZ & VHSZ together. It is recommended that a) VLSZ&LSZ areas, which covers about 25.32% of the total area can be taken up for large scale future developmental work, b) Identification of suitable areas for developmental work within MSZ by Meso scale (1:10,000 /1:5,000) LSM and c) HSZ&VHSZ areas should be avoided for any large-scale development. Identification of suitable sites, if essential, within HSZ&VHSZ, has to be done by meso scale (1:10,000 /1:5,000) and micro scale (<1:5,000) landslide susceptibility and risk mapping. Re-evaluation of the prepared macro scale susceptibility maps at regular intervals is recommended after major earthquake (> 5.0 on Richter scale), cloud-burst and large scale anthropogenic changes.*

Introduction

Darjeeling Himalaya has experienced recurring landslides and slope instability events causing distressing & closure of important communication corridors, destruction of limitedly-available agricultural land, house and loss of human life. Macro scale Landslide susceptibility map of a part of this landslide prone region, therefore, will be useful to the planners for i) perspective planning for future developmental work ii) to frame up protection measures of the already fragile slope mass. With this background macro scale Landslide Susceptibility Map in parts of Kurseong-Mungpu area has been prepared following the *Bureau of Indian Standard* guidelines *(IS: 14496, part-2: 1998)*. The vector GIS techniques (ARC/INFO 9.1 software) were used to handle the large volume of thematic database for multiple retrieval, operation and production of LSM.

Status of Landslide Susceptibility Studies

A number of conceptual models have been used in India and elsewhere for preparation of Landslide susceptibility maps by various authors. {Brabb (1984), Carara (1989, 1993), Mazumder (1980), Seshagiri et al (1982). Saha et al (2002); Gupta et al (1993), Mehrotra et al(1996); Pachouri and Pant (1992)}. Despite the conflicting views, most of the methods proposed are founded on following considerations

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i) Identification, mapping and weightage of a set of geological – geomorphologic factors causing slope instability
ii) Mapping of the Landslide incidences and estimating their degree of instability.
iii) And finally Zonation of the hill slope into different susceptibility domains

In Darjeeling-Sikkim Himalayas, landslide susceptibility zonation on 1:63,360 scales have been attempted by Chatterjee (1983), Chatterjee& Chaudhuri (1988), and Sengupta (1995). Sarkar et al (2005) for the first time prepared macro-scale (1:50,000) landslide susceptibility maps covering major parts of Darjeeling hill using GIS techniques following BIS guidelines.

Methodologies

BIS Guidelines: The guidelines *(IS: 14496, part-2: 1998)* consider that the stability of a mountainous terrain depend on the combined effect of the causative factors like lithology, slope, relative relief, structure, landuse & land cover and hydro geology. *Macro scale(1:50,000)* landslide hazard zonation as per the guidelines suggest division of the target area into zones of varying degrees of hazard based on estimated significance of the said causative factors in inducing instability. The unit of study recommended for preparation of LHZ map is slope facet having similar inclination and aspect. Facets are generally delineated by ridges, spurs, gullies and rivers. The LHZ maps have been prepared by superimposing the above thematic maps in a particular seismic zone using Landslide Hazard Evaluation Factor (LHEF) rating scheme. The LHEF rating scheme is a numerical system based on the identified causative factors discussed earlier. The maximum LHEF ratings for the causative factors like Lithology, Structure, Slope morphometry, Relative Relief, Landuse and Land cover and Hydrological condition are 2,2,2,1,2and 1 respectively in a 10 point knowledge based rating system. LHEF values of each slope facet (along with extra rating for regional thrusts, where applicable) have been integrated to get the Total estimated hazard (TEHD) values of the said facet. Depending on the THED values the studied area has been categorised in to Very Low Hazard (< 3.5), Low Hazard (3.5 – 5.0), Moderate Hazard (5.0 – 6.0), High Hazard (6.0 – 7.5) and Very High Hazard (> 7.5) zones.

It is pertinent to add that the prepared map of the studied area as per the BIS guidelines should be "Landslide Hazard Zonation Map". However, as per the modern and accepted definition of Hazard for calculating risk by Varnes (1984), Fell (1994) and Leroi (1996) - "It is the probability of occurrence of an event within a reference period and is a function of both spatial probability (related to static environmental factors) and temporal probability". Since the prepared map shows spatial probability of landslide events only and does not include temporal probability of landslide events, hence, it is more appropriate to designate the prepared map as "Landslide Susceptibility map" instead of "Landslide Hazard Zonation Map".

Procedures followed: Macro scale (1:50,000) landslide susceptibility map of the studied area was prepared following BIS guidelines with a few modifications. Vector GIS techniques (ARC/INFO 9.1 software) were used to handle the large volume of thematic database for multiple retrieval, operation and production of LSM. The various stages of activities in preparation of LSM of the studied can be summarised in the following paragraph and flowchart (Figure-1).

i) Preparation of facet map, slope map (Fig-2) and relative relief map (Fig. 3) of the area from Digital Elevation Model (DEM). The DEM of the area has been extracted from derivation of terrain parameters using processed SRTM (Shuttle Radar Topography Mission) data

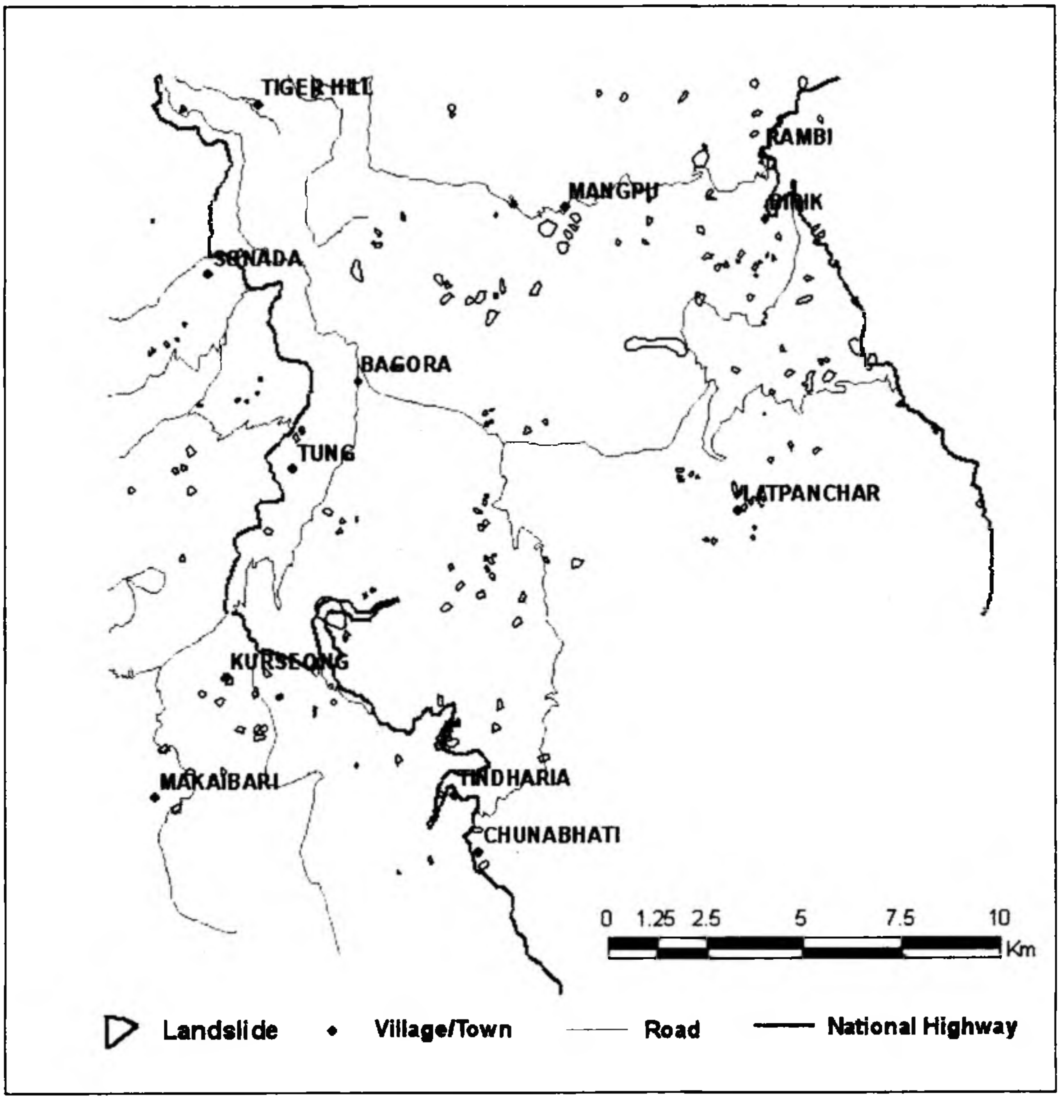


Fig. 1: Location map of the studied area showing major road networks, town/villages and landslides

ii) Preparation of Lithology, Structure; Landuse & Land cover, Hydrogeology; and Landslide *incidence map (Fig.-1)* of the area through detailed field studies and augmentation of available data base.

iii) Preparation of primary coverages and derived coverages for each theme and assignment of LHEF rating.

iv) Facet-wise calculation of Susceptibility values by integrating all the LHEF ratings and categorisation of the susceptibility values into five susceptibility classes.

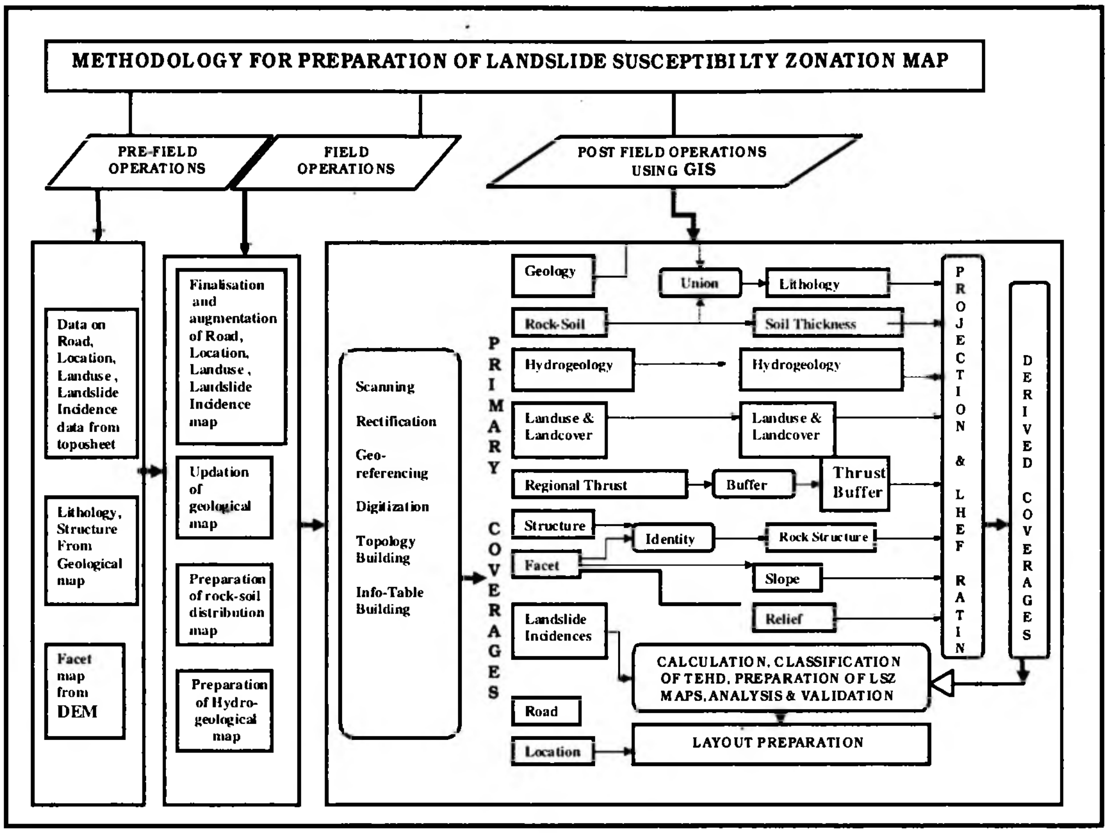


Fig. 1A : Methodology for preparation of Landslide Susceptibility Zonation Map

Discussions

The studied area is part of the Himalayan fold-thrust belt (FTB) in which a spectrum of litho-assemblages from Precambrian to Quaternary ages having varying composition, competency, structure and metamorphism have been encountered. The rocks are juxtaposed along certain E-W trending regional thrusts. The litho assemblage includes coarse to very coarse-grained clastics (conglomerate-sandstone-siltstone) of Siwalik Group separated from the adjoining Quaternary sediments of the fore deep region in the further south by a frontal thrust (Himalayan Foothill Thrust or Himalayan Frontal Thrust HFT). The coarser clastics of Siwalik Group towards the north are thrusted over by Sandstone-shale ± Coal sequence of the Gondwana along the Main Boundary Thrust (MBT). To the further north, low grade meta-psammo-peletic sequence of Precambrian Daling Group is thrusted over the Younger Gondwana / Siwalik rocks. In the Higher Himalaya, granite gneisses and high-grade meta-sediments belonging to the Central Crystalline Gneissic Complex (CCGC) are thrusted over the low-grade metamorphics of Daling Group along the Main Central Thrust (MCT). Along MCT, a strongly lineated, coarse to medium grained granite gneiss and granite mylonites (Lingtse gneiss) in the form of sheets are conspicuously disposed as thrust wedges. The rocks in the area are covered by different soil types of variable thickness and are separately mapped (Fig-4&5). The estimated aerial coverages of rock and overburden in the area are 43% and 57 % respectively. The rocky portion includes areas of bare rock in

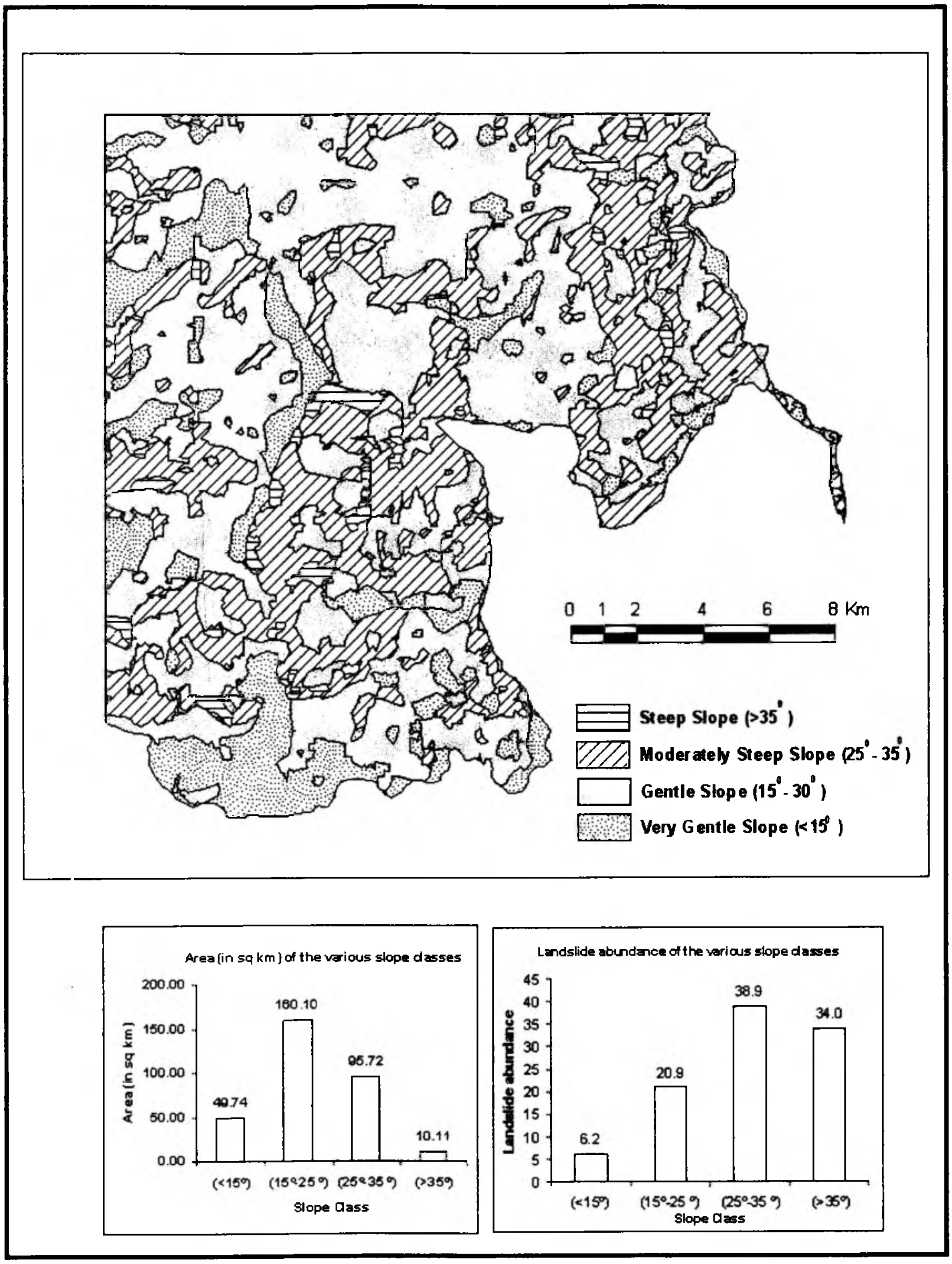


Fig. 2: Slope map of the studied area showing four categories of slope and distribution of landslides.

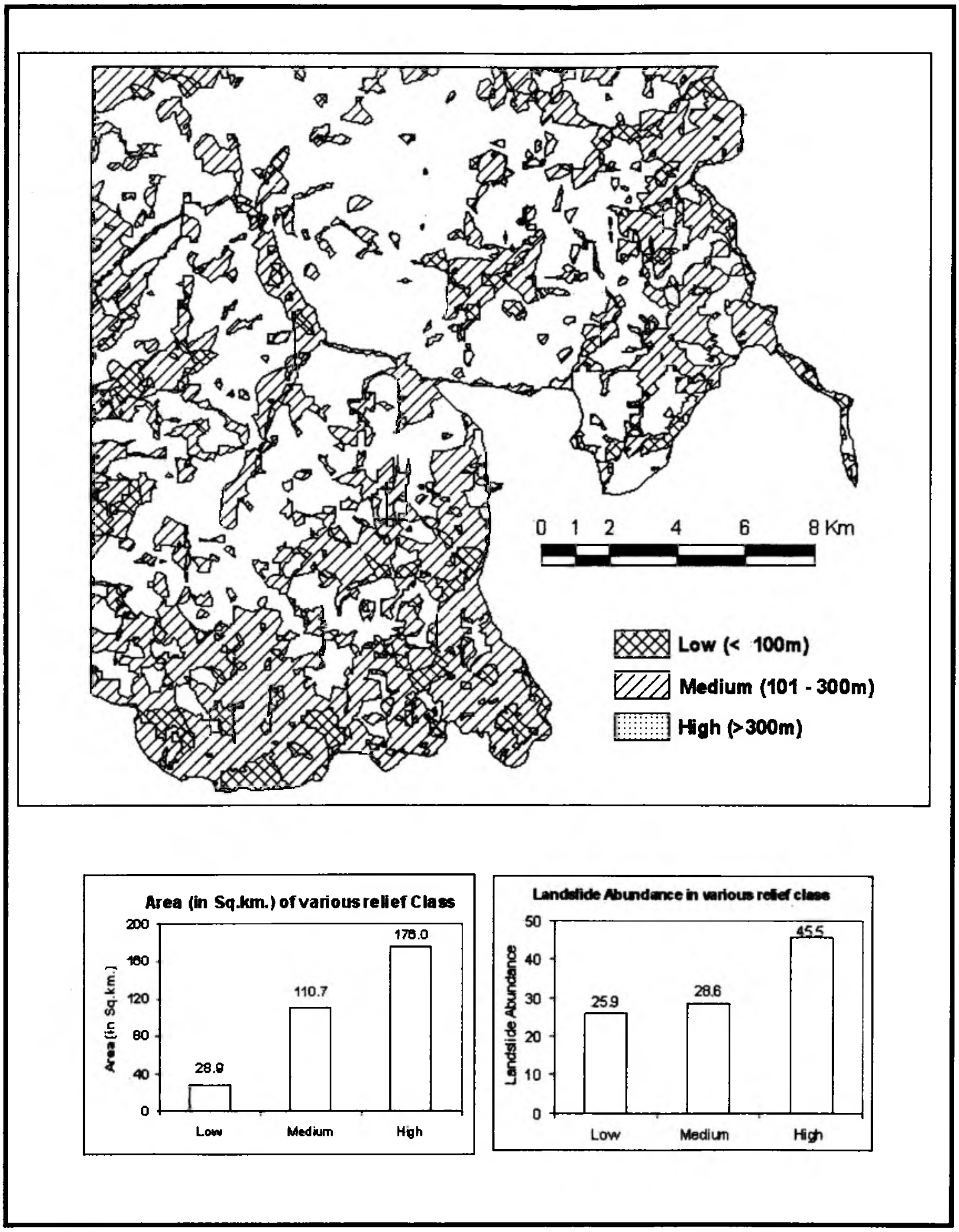
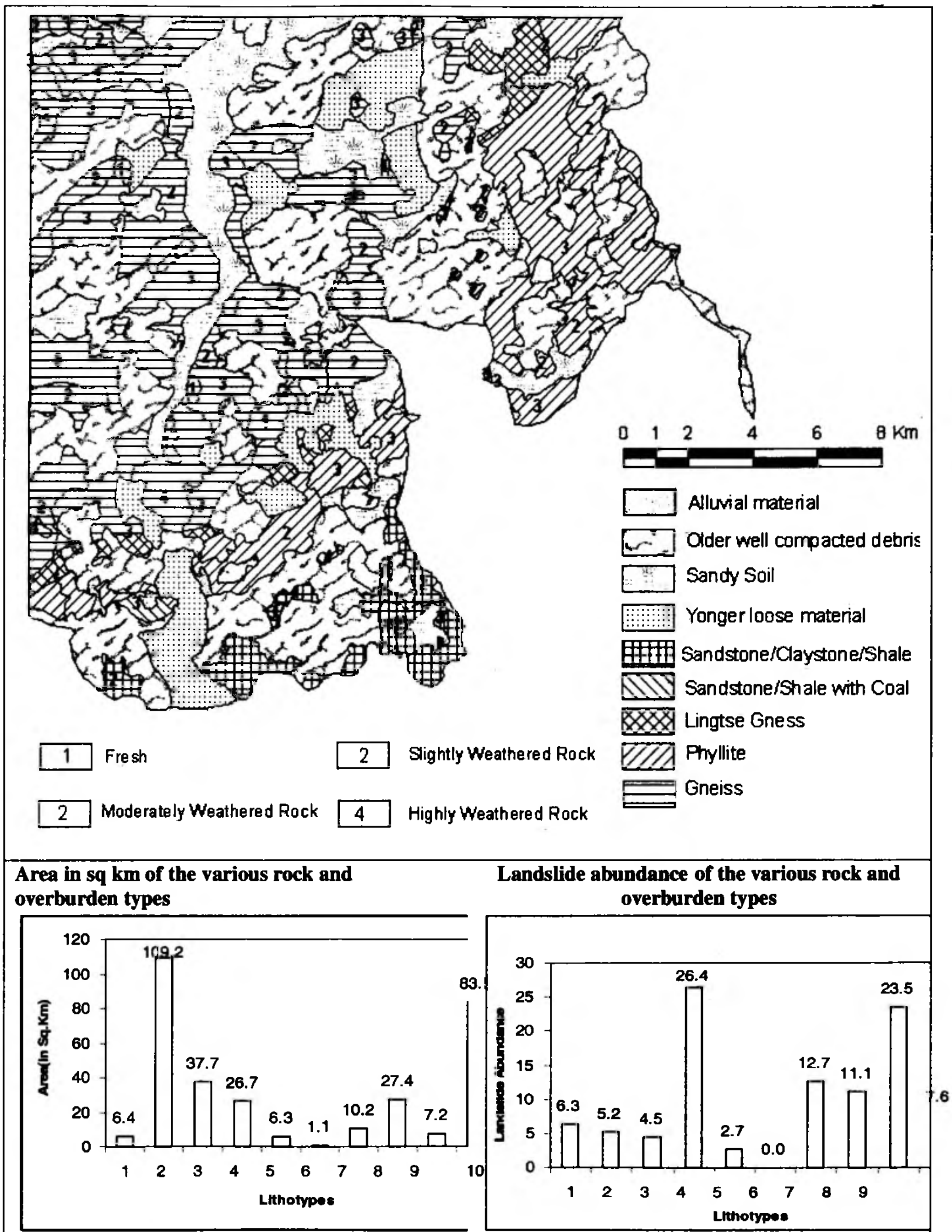


Fig. 3 : Relative relief map of the studied area showing distribution of three categories of relative relief and landslides



1. Alluvial Material 2. Older well compacted Debris 3. Sandy Soil 4. Younger Loose Debris 5.Sandstone/ Claystone/Shale 6. Sandstone/Shale with coal 7. Lingtse Gneiss 8. Phyllite 9. Gneiss

Fig. 4 : Lithological map of the studied area showing distribution of various lithotypes, rock weathering intensity and landslides

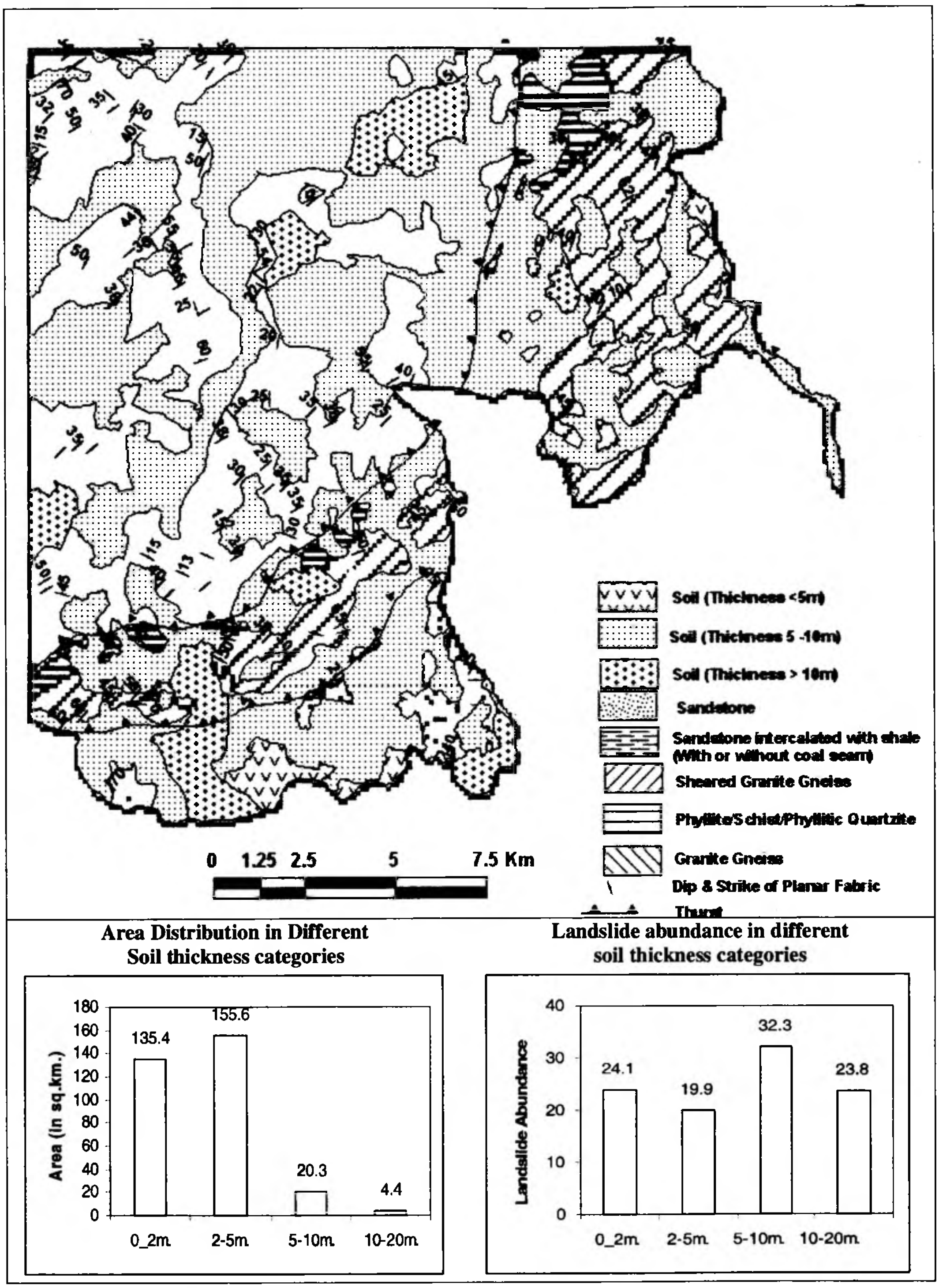


Fig. 5 : Rock-Overburden map of the studied area showing disposition of planar fabrics in the rock and soil thickness of the overburden

the slope as well as bed rock overlain by weathered encrustation and thin overburden material maximum up to 2 m (0-2 m thickness category). The rocky portions are further mapped as fresh, slightly, moderately and highly weathered categories depending on their weathering intensity. Granite gneiss (61.47%) and Older Well Compacted Debris (60.64%) has occupied maximum area within the rock and overburden covered area respectively (Fig-4). The landslide abundance value (landslide area/ total area *100 normalised) within the rock is maximum and minimum in the sheared gneiss (23.75) and sandstone (2.7) respectively. In the overburden covered area Younger loose material has the highest landslide abundance (26.43), the same is least in insitu sandy soil.

A number of prominent regional thrusts *viz.* MBT and MCT have traversed the studied area (Fig-5). It is observed that the areas proximal to the above thrust zones largely come under "High Susceptibility Zone (HSZ, Zone- 4)" and "Very High Susceptibility Zone (VHSZ, Zone-5)". Poly-phase deformation and thrusting in the area is responsible for development of various generations of structural elements (Fig-5). LHEF of a particular slope facet in the rocky part (0-2 m thickness category) has been estimated from the relationship of planar structure and slope. Structure rating in case of soil-covered areas has been calculated on the basis of thickness of overburden. In the studied area average landslide abundance in the rock covered part is 24.1. In the over burden part, thickness category (5-10 m) found to have highest landslide abundance (32.3).

The slope and relative relief maps of the area shows prevalence of "Gentle" (50.7%) and "moderately steep" (30.31%) zones. "Very Gentle slope" and "steep slope" including escarpment have relatively lower aerial extent (15.75 and 8.90 % respectively) (Fig-2). The landslide abundance is found maximum in "moderately steep" and minimum in the "Very gentle slope" areas. The spatial distribution of relief categories (Fig-3) indicates that high relief (55.7%) and moderate relief (35.8%) zones occupy 91.5% of the total area. The landslide abundance is found maximum in high relief (45.51) and minimum in low relief (25.9) areas.

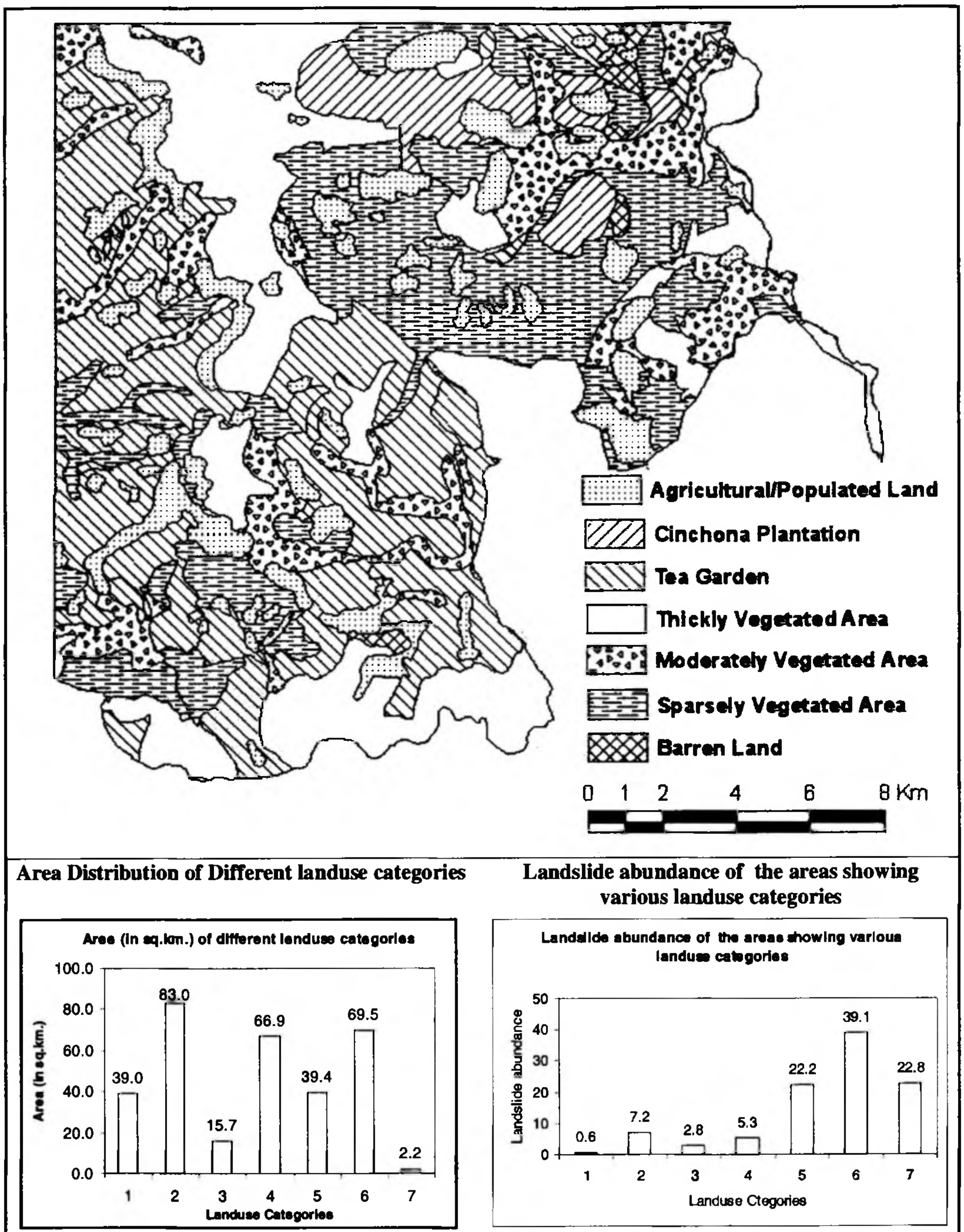
The distribution of "landuse & land cover" categories over the studied area (Fig-6) indicates that about 43.60% of the total area comes under "agriculture/ populated land/ tea garden" and "cinchona plantation". The forest ("thickly vegetated" and "moderately vegetated" areas) covers about 33.66% of the area and 22.64% of the area comes under "sparsely vegetated and barren" categories. It has been observed that the agricultural land and sparsely vegetated category has the least and maximum landslide abundance values respectively (0.58 and 39.18).

Four categories of hydro geological situations namely, "damp', "wet", "dripping" and "flowing" were identified and mapped (Fig-7). It is found that a major part (64.09 %) of the studied area comes under "wet" category. The average spatial coverage for "damp", "dripping" and "flowing" categories are 15.59 %, 19.26 % and 1.06 % respectively. The landslide abundance of in "dripping" and "flowing" together found to have a high value (77.1).

The spatial distributions of various LSM zones as estimated from the prepared macro scale susceptibility map are — "very low susceptibility zone (VLSZ)" – 0.39%, "low susceptibility zone (LSZ)" – 24.90%, "moderately susceptibility zone (MSZ) – 36.18%, "high susceptibility Zone (HSZ)" – 36.82% and "very high susceptibility zone (VHSZ)" – 1.71%.

The prepared LSM has been validated with the landslide incidence maps of the study area. The summary of validation is as follow:

a) "Very low susceptibility zone (Zone – 1)" is devoid of any landslide incidences.



1. Agricultural/Populated Flat Land 2. Cinchona Plantation 3. Tea garden 4. Thickly Vegetated Area 5. Moderately Vegetated Area 6. Sparsely Vegetated Area 7. Barren Land

Fig. 6 : Landuse –Landcover map of the studied area showing distribution of various categories of landuse & landcover and landslides

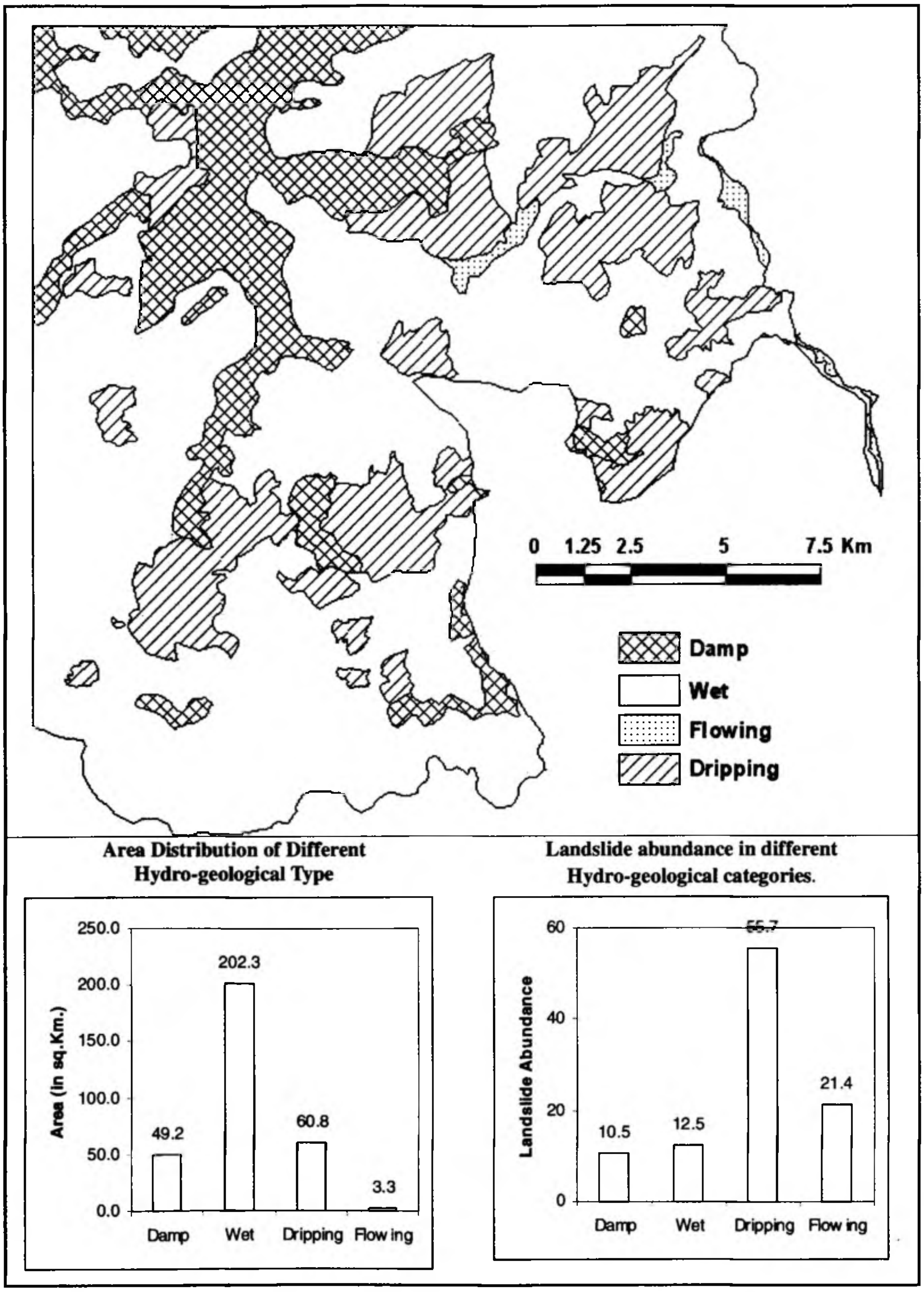


Fig. 7 : Hydro-geological map of the studied area showing distribution of four hydro-geological categories and landslides

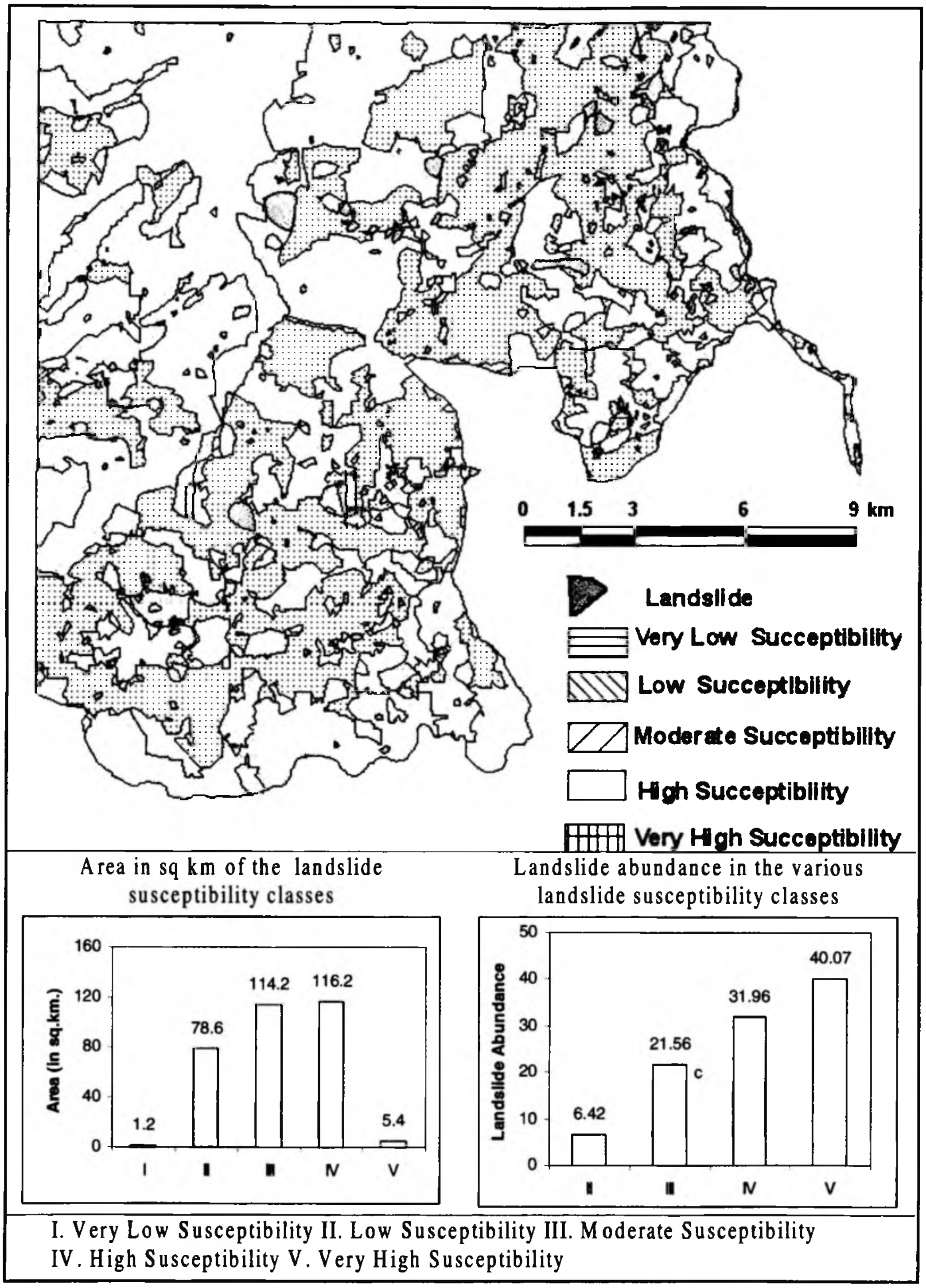


Fig. 8 : Landslide Susceptibility map of the Kurseong –Mangpu area showing distribution of landslide susceptibility classes and landslides

b) A progressive increase in the landslide abundance value for successive higher categories of susceptibility zones. The respective values are 6.42, 21.56, 31.96 and 40.06 for Zone-2, 3, 4 and 5 respectively.

c) Landslide abundance value for "High susceptibility zone (Zone-4)" and "Very high susceptibility zone (Zone-5)" together is found to be 72.02

Recommendations

The use of generated LSM of the area is enumerated below:

The "Very low susceptibility zone" and "Low susceptibility zone" can be utilised for major developmental work with necessary precautions after maintaining the natural slope condition as far as possible. The" moderately susceptibility zone" contains a number of active landslides and future development work within this zone can only be taken up after identification of suitable areas through meso scale (1:10000/5000) susceptibility mapping. No large-scale future developmental work as such is recommended in the "High susceptibility zone" and "Very high susceptibility zone". Identification of suitable sites for any developmental work, if needed, in this areas, has to be done through meso scale (1:10000/ 5000) and micro scale (larger than 1:5000) landslide susceptibility mapping considering in-situ slope characteristics. Detailed micro scale susceptibility and risk evaluation of this populated part within "High susceptibility zone" and "Very high susceptibility zone" are required to frame up mitigation measures.

It is felt that factors like antecedent rainfall, erodability of the drainages, large scale anthropogenic interferences are also equally important in inducing instability in this area. Therefore, locally, the present susceptibility status of the existing slope may undergo significant changes due to the effect of the above-mentioned factors. Therefore, re-evaluation of the prepared macro scale susceptibility maps at regular intervals are needed especially after major earthquake (> 5.0 on Richter scale), cloud-burst, natural calamities and large scale anthropogenic changes.

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