Zonation of landslide hazard for urban planning-case study of Nainital town, Kumaon Himalaya, India

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Abstract: The paper aims to classify the area around Nainital town in Kumaon Himalaya into zones of relative susceptibility to landslide hazard. The geological parameters used for the study include-slope forming material, structural details, tangent of slope angle, slope direction, spatial distribution of landslides and land use pattern. Thematic maps *viz*. slope morphometry, slope forming material and landslide occurrence are prepared and their interlayering derived various parametric inputs. The Micro-zoning of landslide hazard of the town has been attempted evolving a failure probability model that estimates the failure of slopes out of the total number of slopes in a specific domain of geo-factors. The critical zones, thus, derived were further subjected to slope mass rating depending upon the bedrock lithology, bedding-dip relation and condition of structural discontinuities etc. The slopes with more than 80% failure probability have been included in a very high landslide hazard prone category and that range 80% to 50%, 50% to 20% and less than 20% were classified into High, Moderate and Low category respectively on the map. The model of micro-zonation of the landslide hazard around the town demarcates the terrain with relative degree of severity of the hazard that has been used for urban planning of the town. Such Micro-zoning model may be of use for urban planning in mountainous environments.

Resume: Le papier vise à classifier le secteur autour de la ville de Nainital dedans Kumaon Himalaya dans des zones de susceptibilité relative au risque d'éboulement.. paramètres géologiques utilisés pour l'inclure-pente d'étude formant le matériel, détails structuraux, tangente d'angle de pente, direction de pente, spatiale distribution des éboulements et du modèle d'utilisation de la terre. Cartes thématiques *à savoir*. la pente morphometry, la pente formant le matériel et l'occurrence d'éboulement sont préparées et leur interlayering derieved de diverses entrées paramétriques. Le Micro-zonage de le risque d'éboulement de la ville a été essayé évoluant une probabilité d'échec modelez qui estiment l'échec des pentes hors de tout le nombre de pentes dedans un domaine spécifique des geo-facteurs. Les zones critiques, ainsi, dérivées étaient encore soumis à l'estimation de la masse de pente en dépendant de la lithologie de roche en place, literie-plongez la relation et la condition des discontinuités structurales etc.. des pentes avec la probabilité d'échec plus de de 80% ont été incluses dans très un haut catégorie encline de risque d'éboulement et cette gamme 80% à 50%, 50%to 20% et moins que 20% ont été classifiés dans la catégorie élevée, modérée et basse respectivement dessus la carte. Le modèle de la micro-zonation du risque d'éboulement autour de la ville délimite le terrain avec le degré relatif de sévérité du risque qui a utilisé pour la planification urbaine de la ville. Un tel modèle de Micro-zonage peut être utile pour la planification urbaine dans l'environnement montagneux.

Keywords: Geological hazard, landslide, slope stability, urban geoscience, model.

INTRODUCTION

Landslide hazard is frequently the cause of colossal damages to the urban infrastructure in complex geological environment of the Himalaya. Rapid urbanization may result in increased vulnerability of mountain slopes to mass wasting processes. Planning of developmental activities in such terrain, therefore, warrant demarcation of relative landslide susceptibility to mitigate the consequences of the hazard. The effect of geological hazard on the development of towns has been documented in several parts of the world (Zaruba 1946, Coelho 1979, Nasmith and Mercer 1979, Smith & Ellison 1999, Culshaw *et a*l.1990, Forster *et al*., 2004 etc.).

Nainital town, in Kumaon Himalaya is a picturesque hill resort spread around the periphery of a 1.4 Km long crescent shaped lake, flanked by high hill ranges. The lake basin is bounded by Sher-Ka –danda ridge to the east, Naina peak (2610m) to the north; Ayarpatha ridge (2352m) on the west has narrow stream outlet towards south. The urban sprawl of the town during last few decades has been phenomenal consequently exerting pressure on already vulnerable geological environment. The town has experienced disastrous landslide events several times in its short span of development (Oldham 1880, Auden1942, Nautiyal 1949, Hukku *et al*.1977, Pant and Kandpal 1990, Sharma 1996a, 1996b, 2005). In fact, the entire northwest portion of the town is developed over landslide debris that accumulated in past due to successive landslides. With this scenario in the background an assessment of the terrain around the vicinity of the town has been carried out to demarcate zones of varying degree of landslide proneness. The key geological factors like slope forming material, structure, slope bedding relation and scatter of the landslide relevant to evolve such zonation model were identified and summarized on thematic maps at 1:5000 scales encompassing the lake basin.

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GEOLOGICAL SETTING

Nainital hills form southeastern terminus of the Krol belt sedimentaries, exposed in a number of structural basins in northwest Himalaya, constituting a succession of Nagthat-Blaini-InfraKrol-Krol and Tal Formations. The huge succession of the Krol belt sedimentaries is divisible into two groups, the lower Jaunsar Group of late Proterozoic age and upper Group of Blaini, Krol, Tal Formations of Neoproterozoic age. The geological set up of the area has been studied by many workers (Oldham 1880, Middlemiss 1880, Auden 1942, Hukku et al.1977, Valdiya 1988, etc). Lithological assemblage of the area comprise thinly bedded, sheared, variegated slates, marls with bands and lenses of limestone (Lower Krol Formation) in eastern and northern portion of the lake. The western, southern and southwest part is occupied by limestone/dolomite and red shale/slate (Upper Krol and Middle Krol Formation).

Structural layout

The rocks of the area are folded into a broad syncline plunging northward and its northern limb is dislocated by a fault referred as 'Nainital fault' that run along the lake and beyond. The NW-SE trending lake fault passes through Balia *nala* in south has differentially uplifted Sher-Ka-danda hill on east vis-à-vis Ayarpatha on the west. The sympathetic faults merging with the Lake Fault and development of criss-cross fractures and shears are responsible for number of landslides in the basin. The rocks of the Sher-Ka-danda generally dip20^0-40^{0}due SW/SSW and show isoclinal overturned folds. The lake basin lies close to the regional tectonic feature, known as the Main Boundary Fault that is responsible for highly deformed rock conditions of the area.

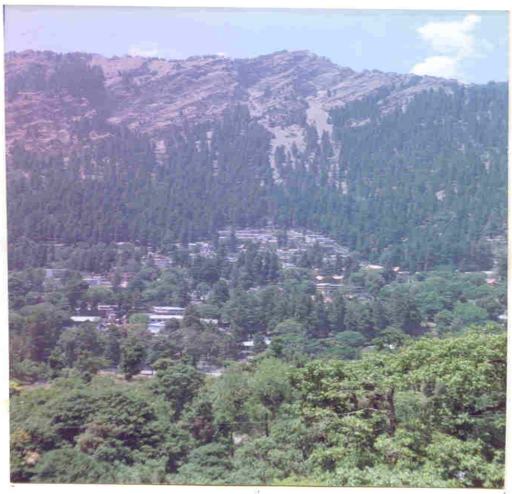

Figure 1. Naina peak slide zone and development of debris cone. Urbanization below is at risk .

MAJOR LANDSLIDE HAZARD

Nainital town has experienced intermittent landslide activity of variable magnitude ever since its formation. History of the town is replete with the landslides; five major landslide events occurred in the year 1867, 1880, 1898, 1924 and 1998 brought massive destruction to urban infrastructure and loss of lives. These episodes not only changed the landscape of the area but also impressed the need to understand the local geo-tectonic and geomorphology conditions before planning the urbanization in hilly terrain. The slip of 1866, reactivated in 1869 in the northeastern end of the town is the first recorded landslide hazard in Nainital town, which resulted into the loss of vegetation and scanty human settlements. The town, in spite of these natural warnings expanded.

The most memorable and disastrous landslide affecting the urban sprawl was on 18th September 1880, which originated from the snow view in the northeast, following continuous heavy rains for more than 36 hours. The slide debris swept number of settlements on its downstream passage towards the northern end of the lake causing death of more than 193 including 43 Europeans and 150 natives. The present hub of the town- the 'flat', which was not there prior to the landslide of 1880, came into existence on the northern fringe of the lake due to the deposition of massive pile of debris generated out of the slide. Another destructive slide occurred on 17th Aug.1898 affecting Kailakhan hill in southeast proximity of the lake. This event temporarily blocked the stream that drain the lake basin, created three lakes and caused massive destruction to the property besides 28 casualties. The landslide of 1924, occurred on the left flank of Balia *nala* damaged the cart road with heavy loss of lives, property and vegetation.

The prominent slide that occurred in the recent past was on 17th August, 1998 on the Ayarpatha hill slopes after heavy rainfall damaged the road, part of a building and the debris material affected a portion of the lake. The Naina peak slide is active slide (Figure1.) contributing debris at its base and endangering the population of the town. The old landslide debris deposited at the toe of the escarpment is accreting and may slide down. The debris is exposed at a height of approximately 2450m below the cliff and extends down to the rim of the lake in the form of a huge fan deposit, the part of which in lower reaches is inhabited.

The imprints of pre-historic landslides in at least three episodes of catastrophic dimension have been established in the area and dating of carbonized wood (C14) in a drill hole revealed approximately 1510 years to a major landslide event, well co relatable with major hill face scar in the basin (Sharma 2005).

LANDSLIDE HAZARD ZONATION MODEL

The key parameters relevant for the spatial landslide analyses of a terrain are combination of topographic, geological, structural, hydro-meteorological and anthropogenic features in a specific seismo-tectonic domain. These key parameters form the basis of proposed zonation modeling for spatial categorization of the terrain in terms of landslide proneness of varying intensity. The data for the purpose are generated in the form of pre field and field thematic maps on slope, slope forming material and details on existing slope failures. The interacting parameters are derived from the interlayering of these maps. The details of the thematic maps are as follows.

Slope facet maps

The slope facet map is prepared on the topographical sheet on 1:5000 scale maps by dividing the number of slope facets. Each facet have uniform slope and delimited by natural boundaries such as break in slope, ridge line, drainage lines etc. the measured angle of slope inclination and direction of slope are marked on each facet. Measurement of these parameters on the base facet map forms an important input for the slope morphometric model of the area.

Slope forming material map

The map demarcates distribution of geological formations and Quaternary deposits on the mountain slopes. The areas occupied by bedrock lithology have been studied in terms structural details, their disposition and rock mass strength. The *in –situ* strength of rock mass determined by the use of Schmidt Hammer, classify the area into three categories-accordingly Upper Krol Formation has rock strength of the order of 180-300 Kg/cm^2, Middle and Lower Formations of 120-150 Kg/cm^2 and less than 120 Kg/cm$^{2.}$ The Quaternary overburden deposits generally comprise debris materials, fan deposits, talus and all other drift material.

Landslide scatter map

Failure of slope as manifest in the form of landslides on natural slope is an important component of the study model. The geological conditions responsible for the slope failure are determined with preparation of inventory of all the incidences of slides having information on location, type, dimensions, nature of material involved, causative factors and slope angle at which the slide occurred. The identified slide incidences have been compiled and plotted on the slope forming material map and integrated with slope morphometric map data to derive angles of slope failures in specific domain of geological formation.

Slope and bedding relation

The relationship of slope direction with bedding/foliation dip direction is an important aspect in stability analysis especially in structurally controlled slopes. Hence, in order to determine the slope type, slope facets have been further classified into five classes as per table 1. The categorization facilitates statistical evaluation of slope behavior taking into account the relationship of slope and bedding which is recognized as one of the key parameters.

Table 1.Slope type categorization

Slope type	Difference between slope direction and bedding dip direction
Cataclinal	0°-30°; 331°-0°
Ortho-cataclinal	31°-60°; 301°-330°
Orthoclinal	61°-120°; 241°-300°
Ortho-anaclinal	121°-150°; 211°0-240°
Anaclinal	151°-210°

Probabilistic computations

The failure probability value is computed for each component of slope angle in a specific domain of geological formation, lithological assemblage, slope type and expressed as –

$$P_f = N_{fs} / N_s \times 100$$

Where N_{fs} is number of unstable slopes and N_s is the total number of slopes in the same domain. The calculated sets of values of Pf are arranged in a matrix to classify in groups.

LANDSLIDE HAZARD ZONATION MAP

The Landslide Hazard zonation model of the area is thus evolved by depicting zones of varying degree of landslide proneness taking into account the probable response of the geological environment and slope disturbances. The zonation is based on the evolved scheme (Figure2), which takes into account the incidences of landslides and their critical angles of failures. The probability of slope failure in each geological domain, slope type and increments of slope angle has been worked out and then extrapolated to all similar situations on passive slopes. Thus, probabilistic values obtained are utilized to classify the slopes into hazard prone zones. The critical ranges of probability values have been used as a guide for assessing hazard categories to all the slopes identified in the area. The values for a given set of conditions is evaluated and the test case is then applied to slope facets showing similar geological and slope conditions with the presumption that similar slopes under similar conditions would behave similarly and would have the same probabilistic values.

The slopes where failure probability values are over 80% are grouped as very high landslide prone zone and that range 80% to 50%, 50% to 20% and less than 20% were classified into High, Moderate and Low hazard prone category respectively on the map. Based on this criteria, the area has been demarcated into: Very High Hazard (VHH), High hazard (HH), Moderate Hazard (MH) and Low Hazard (LH) prone zones (Figure 3.) on the map. The zonation maps, used for the future development of the hill town also provide geotechnical data input for guiding remedial scheme in the vulnerable areas.

The most critical blocks where instability is governed by the poor lithological conditions and adverse disposition of structural elements, Slope Mass Rating (SMR) technique (Romana1988, Sharma1996) have been analyzed on still larger scale to classify the terrain and guiding remedial measures.

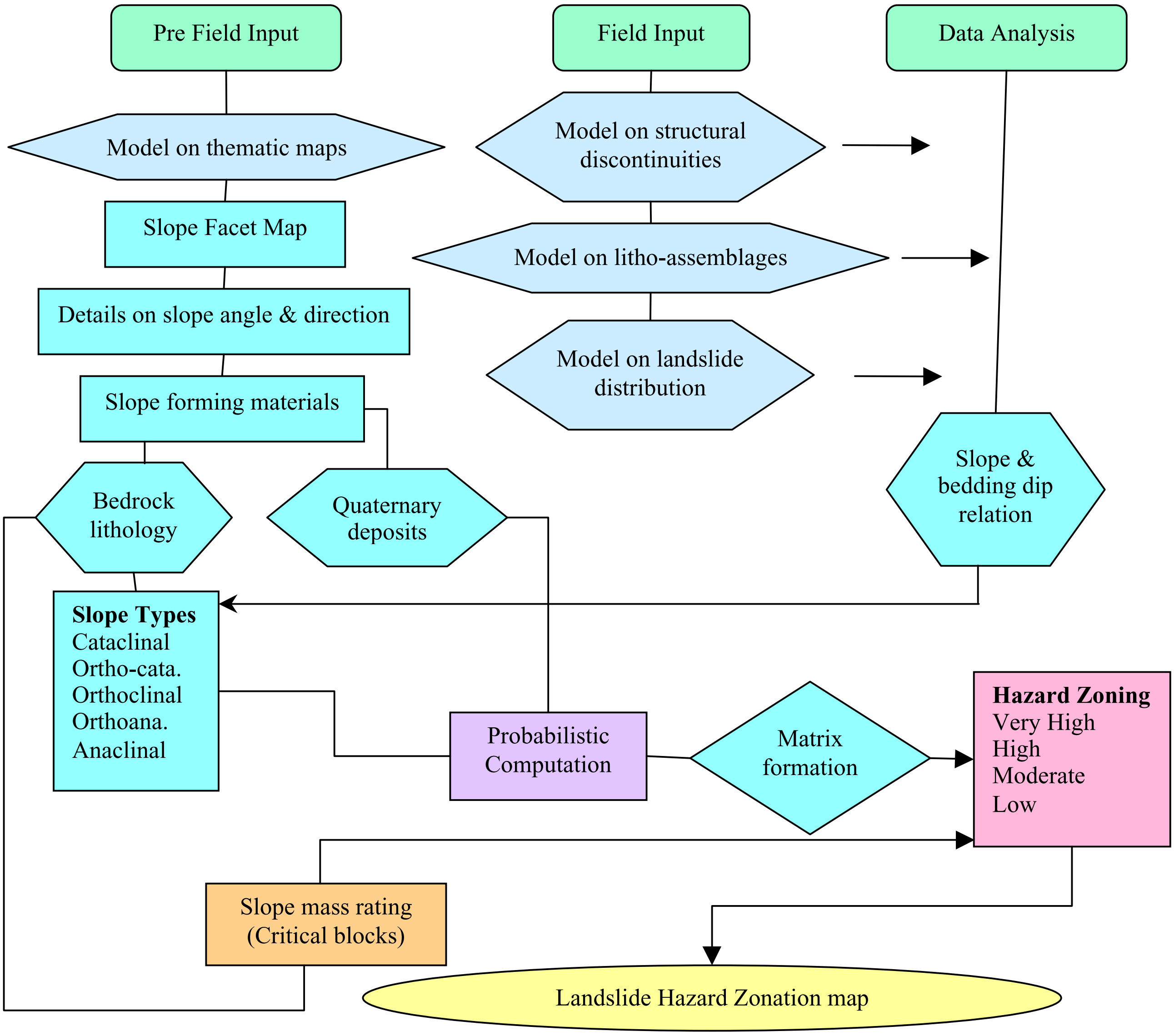

Figure 2. Scheme of probabilistic model of Landslide Hazard Zonation in mountainous terrain.

CONCLUSIONS

The Nainital town has a long history of landslides that has left potential problems for future urbanization and land use planning. Summary of key geological considerations and evolved probabilistic model allows an assessment of potential hazards related to slope instability for planning and development of the hill town. The approach provides an overview of the area where risk is high and zones where further investigations may be needed. The most critical zones of landslide hazards are confined mainly in north and northeastern sector of the lake basin and *Balia nala* zone in south of the lake area wherein the generated debris may endanger the urban infrastructure. The High and Very high hazard zones may be considered for restrictions in development works. The instability is generally governed by the poor geotechnical properties and cataclinal slope situations. The model may be used for urban planning in mountainous environment to mitigate the landslide hazard.

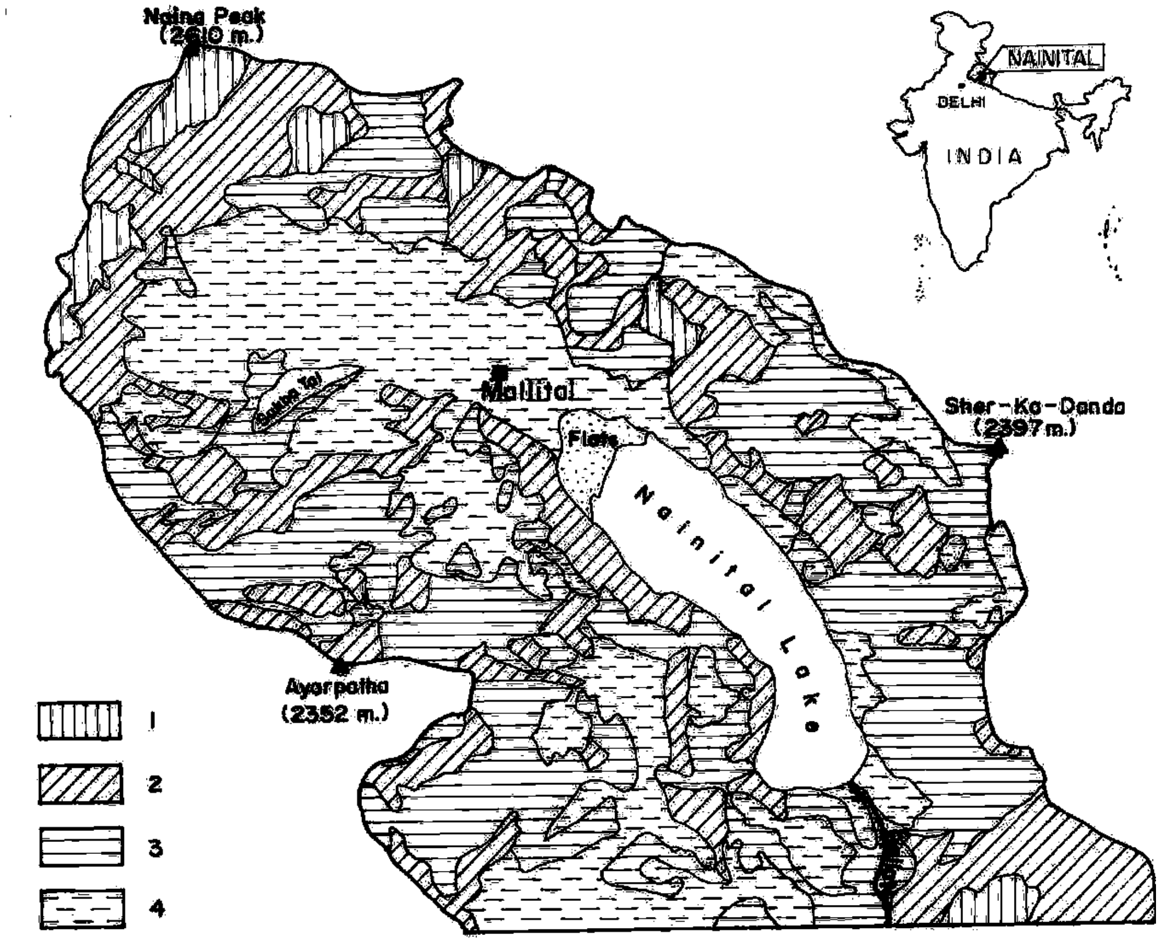

Figure 3. Landslide hazard zonation map around Nainital town. Key: 1-Very High landslide prone zones; 2-High landslide prone zones; 3 - Moderate landslide prone zones; 4 - Low landslide prone zones.

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