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Assessment of Landslide and Flash Flood Hazard for an Earthquake Prone Himalayan Region

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Abstract—*The seismically active Himalayas are geologically and ecologically fragile mountain ecosystem. They are frequently affected with landslides that often strike life and property and occupy a position of major concern. This research aims at identifying landslide risk in a selected Himalayan region so that appropriate risk management measures can be implemented. Narendranagar Block of Tehri-Garhwal district located in the Uttarakhand state is studied for the landslide hazard. The landslide hazard studies from secondary sources are substantiated through primary survey. Earthquake scenario studies for the Narendranagar block of Tehri Garhwal district with epicenter near Tapowan at 30^0 08'10"N and 78^0 20'30"E are used. The landslides which would be triggered due to this earthquake are analysed in GIS environment. It is found that total 85 settlements with a total population of 27462 (26.65%) would be rendered completely inaccessible and almost all other settlements would be rendered partially inaccessible because of landslides in the Narendranagar block. The landslides also have potential to cause flash floods in River Hemwal passing through Narendranagar block by formation of temporary dams. A total of 11 villages and 6 market towns with total population of 10048, which is 9.75% of the total block population, are prone to flash floods after earthquakes. The bigger settlements of Narendranagar block like Tapowan and Muni-ki-reti could also be affected if the floods are severe. It indicates that actions should be taken on urgent basis to reduce the landslide hazard in the region.*

1. INTRODUCTION

Himalayan ranges are seismically very active and if any major earthquake strikes here buildings would collapse killing and injuring hundreds of people [4, 16]. Nepal earthquake of April 2015 witnessed about 9000 fatalities and about 23,000 injuries [18]. The Himalaya is a geologically and ecologically fragile mountain ecosystem where, landslides have been a major and widely spread natural disaster that often strike life and property and occupy a position of major concern [10, 20]. The paper presents an analysis of landslide situation in Narendranagar block of Tehri-Garhwal district. The observations of the primary survey are substantiated with the landslide zone given by different studies. In an earthquake scenario the possible landslides that are triggered are located. The flash floods caused on account of such landslides and settlements that will be rendered inaccessible are analysed.

2. LITERATURE SURVEY

India has about 25% of its geographical area under mountainous terrain. The southern, central and western mountains namely the Western Ghats, Satpura and Vindhyan ranges and Aravalis are geologically very old and are stable formations as compared to the Himalayas and the Shiwalik ranges in the North [19]. An estimate of landslide generated loss in the Himalayan ranges as quoted by Naithani [9] says:

'It has been estimated that, on an average, the damage caused by landslides in the Himalayan ranges costs more than US$ one billion besides causing more than 200 deaths every year.'

Kanungo *et. al*. [5] have defined landslide risk as:

'Landslide risk can be defined as the potential for adverse consequences or loss to human population and the things that humans value due to landslide occurrence.'

Kanungo *et. al*. [5] have combined neural and fuzzy approach for development and implementation of landslide susceptibility zonation mapping and have proposed a fuzzy concept for risk assessment. The results of the landslide zonation studies are discussed with the habitation in the selected area.

The factors causing landslides can be broadly classified as geological, hyrological, seismic and land use and importantly are erosion, saturation, deforestation and excavation of hill slopes. Hence in Himalayas, people are both culprits and victims in the dismaying incidence of environmental depredation and degradation [15, 20]. According to Ghosh *et. al*. [3]

'The problem of landslides is very severe in Uttarakhand due to the adverse geologic and topographic condition supplemented by heavy rainfall.'

Krishnaswamy and Jain [6] have listed effects of landslides under four major groups viz. those affecting highways and communication routes, urban and rural settlements, location and maintenance of river valley projects and environment.

The methodology adopted by NRSA [11] for the demarcation of landslide hazard zones in the most critical areas of Uttarakhand and Himachal Pradesh states, involved integration of remote sensing based inputs from space and conventional data. A number of thematic maps like rock types, geological structure, landforms, land use / cover, slope, soil and drainage were generated using satellite data and integrated with non–spatial data in GIS environment. Further the landslide hazard zonation was arrived at employing a specially developed knowledge based decision–support module. The landslide hazard zonation maps show different categories of landslide hazard from severe to low. Separate maps with suggestive management plans for different hazard zones are also provided.

One more landslide hazard zonation study carried out by Mehrotra *et. al.* [7] for a Himalayan region, gives a map showing different zones of instability within a region bounded by latitudes 30^0 and $30^030'$N and longitudes 78^0E and $78^030'$E. However, as per Bhandari [1] the landslide hazard is strongly dependent on the degree, extent and rate of human intervention, and those are the hardest things to comprehend, judge and evaluate, hence the maps admittedly cannot be free from the ensuing limitations.

Vulnerability of Himalayan People

Murshed [8] brings out the vulnerability of mountain communities particularly in the Himalayan region, importantly because of the following factors:

1. The Himalayan communities are vulnerable due to physical isolation, the scattered settlement patterns, and the harsh climatic conditions.
2. The development of infrastructure for health, education, safe drinking water and sanitation is often overlooked due to the high construction costs and the physical distances and the nature of terrain involved.
3. The physical inaccessibility is further multiplied due to fragile mountain ecosystem, susceptible to soil erosion, landslides and loss of bio-diversity which exposes the residents to multiple hazards.
4. The difficult availability of land area often compels for building any house or roads on vulnerable locations.
5. The remotely located communities totally lack access to earthquake resistant building technologies and construction materials.
6. Because of the poor communication technology, the communities remain cut-off from the rest of the world.'

Murshed [8] also states that the historical record of major disaster occurrence in Himalayas demands the need of appropriate actions for ensuring adequate response system in order to reduce the loss of life and property in case another major disaster strikes here.

3. STUDY AREA

The entire Himalayan belt lies between zone IV and zone V of the seismic zoning map of India [2]. Narendranagar block of Tehri Garhwal district in Uttarakhand State of Himalayas (Fig. 1) is chosen for risk assessment of human settlements and analysis of health facilities. A population of over 1.5 lakhs is spread in 213 villages and 17 market towns.

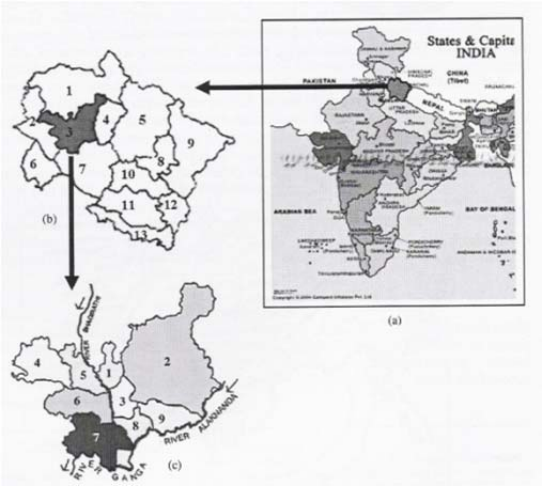

Fig. 1: (a) Location of Uttarakhand state in Map of India

(b) Location of Tehri Garhwal district in Map of Uttarakhand. **(c)** Location of Narendranagar block within Tehri Garhwal district.

Notes In (b): (1) Uttarkashi; (2) Dehradun; (3) Tehri Garhwal; (4) Rudraprayag; (5) Chamoli; (6) Haridwar; (7) Paudi Garhwal; (8) Bageshwar; (9) Pithoragad; (10) Almoda; (11) Nainital; (12) Champawat; (13) Udhamsingh Nagar; in (c): (1) Pratapnagar; (2) Bhilangana; (3) Jakhnidhar; (4) Jaunpur; (5) Thauldhar; (6) Chamba; (7) Narendranagar; (8) Devprayag; (9) Kirtinagar

4. LANDSLIDE VULNERABILITY

Narendranagar block, along with the entire hilly area of Uttarakhand state is prone to landslides because of being a part of fragile Himalayas [12,13]. Landslides in Himalayas are basically of two types–one confined to the regolith (shallow landslides) and other affecting the rock (deep landslides) [19,20]. According to Rautela and Pande [14] the triggering factors for landslides in Uttarakhand state are basically rainfall, weathering and earthquakes. Analysis of landslide hazard for the selected region is already carried out by various sources [7, 11]. The various hazard maps hence published are superimposed on the block map to find out various landslide prone settlements and important infrastructure like roads. (Fig. 2)

The factors considered for landslide hazard analysis by Mehrotra [7] and NRSA [11] are of two types. The first are geological / topographic factors viz. lithology, geological structures / lineaments, slope-dip relation, geomorphology, drainage, slope angle, slope aspect, slope morphology, land use, soil texture and depth and rock weathering. The second are triggering factors viz. rainfall, earthquake and anthropogenic factors.

5. SETTLEMENTS PRONE TO LANDSLIDES

Various settlements prone to landslides i.e. the settlements which are located on severe to high landslide hazard zones of the given landslide hazard maps are considered to be highly vulnerable to landslides. (Table 1; Fig. 2)

Table 1: Landslide prone settlements of Narendranagar block

Villages		No. of Market Towns		Total Pop	% Pop-ulation
Number	Population	Number	Population		
65	15787	2	2345	18132	17.59%

Table 1 and Fig. 2 show that total 17.59% population of Narendranagar block living in 65 villages and 2 market towns viz. Duadhar and Chaka is located on high and very high landslide hazard zone.

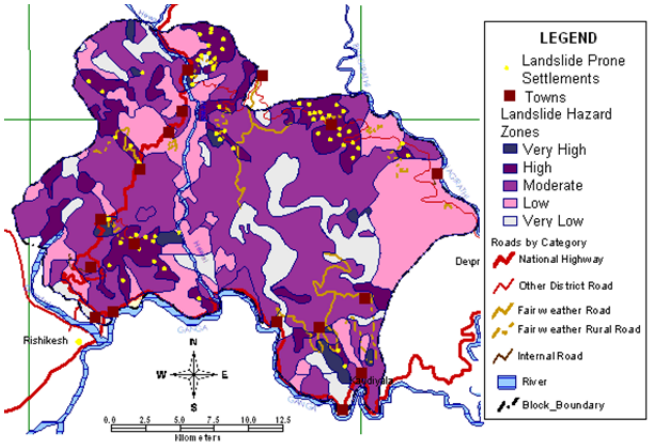

Fig. 2: Landslide hazard in the block *after*: [7]

6. ACCESS ROUTES PRONE TO LANDSLIDES

These landslides in the sub region might block the existing road network and render many settlements inaccessible. NRSA [11] has developed the landslide hazard maps along the major route corridors (Fig. 3).

Fig. 3 shows the existing road network within the block exposed to different grades of landslide hazard, which suggests that a total of 85 settlements with total population of 27462 are vulnerable due to probability of landslides blocking the access routes to them.

The numbers of stretches of roads under different landslide hazard zones are given in Table 2. Such landslides are often triggered by rainfall and photographs of some of the landslides along the major routes are shown in Fig. 4 and 5.

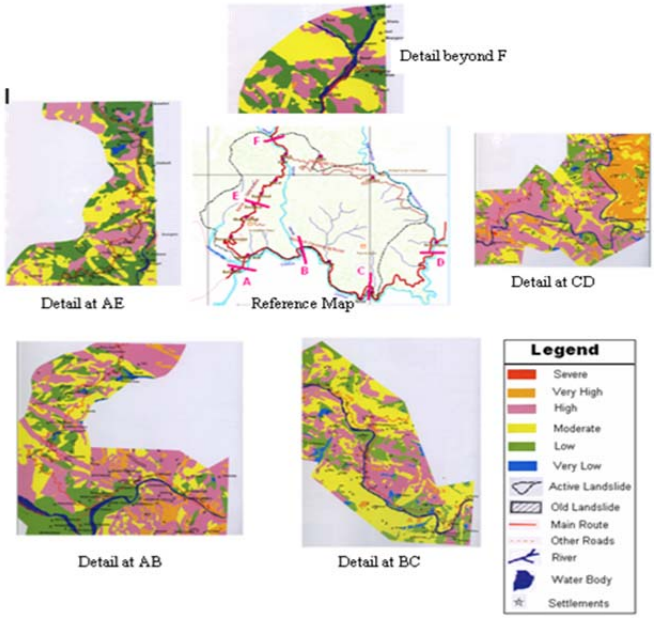

Fig. 3: Landslide hazard in the block along major roads (after: NRSA [11])

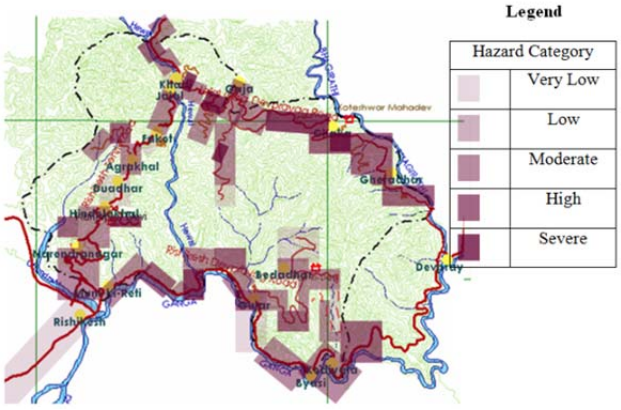

Fig. 4: Landslide hazard along the roads in the block

Table 2: Number of road stretches under different landslide hazard zones

Landslide Hazard Zone	National / State Highways	Other District Roads	Fair Weather Roads	Rural roads
Very Low	4	1	2	1
Low	3	2	3	1
Moderate	10	3	2	2
High	3	2	3	0
Very High	1	2	1	0

Fig. 5: View of landslides

7. VULNERABILITY DUE TO RIVER PROXIMITY

The settlements located very close to rivers are at risk of facing flash floods after earthquakes. The reason for this is - the debris falling into the river due to the landslides form temporary dams which eventually burst resulting in flash floods. This phenomenon was observed during Uttarkashi earthquake of (1991). However the blockage formed was cleared in time and the flash floods were prevented [17]. Hence settlements located on rivers banks are more vulnerable (Fig. 6; Table 3).

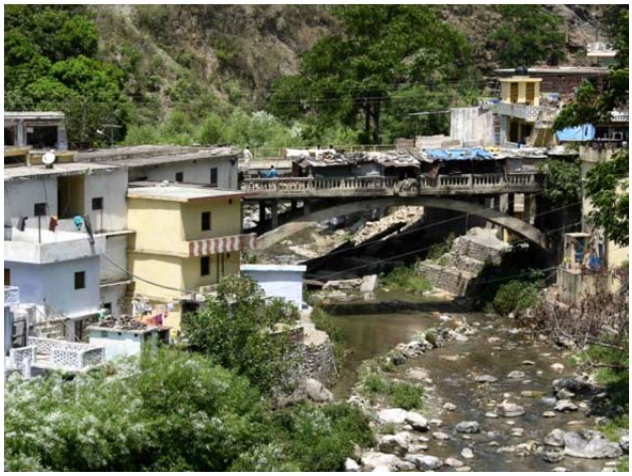

Fig. 6: River Hemwal passing through market town, Khadi

8. A HYPOTHETICAL EARTHQUAKE SCENARIO IN STUDY AREA

Gupta et. al [4] have generated an earthquake scenario in the study area. A hypothetical epicenter for earthquake of magnitude 7.5 is considered near Tapowan at 30^0 08'10"N and 78^0 20'30"E. Peak Ground accelerations (PGA) are computed for different hypo central distances covering the selected region. Iso acceleration contours plotted are elongated parallel to the trend of Main Boundary Fault to account for regional tectonics (Fig. 7). The intensity levels are determined considering the topographic effect.

9. LANDSLIDE OCCURRENCE AND INACCESSIBILITY

The landslide hazard assessment within Narendranagar block emphasizes the need to predict the most probable landslides in the region and their effect on the emergency operations. The assumed earthquake has the potential to trigger many landslides in the region. The most probable landslides will be expected in the most hazardous landslide zones. The expected landslides in Narendranagar block triggered by assumed earthquake are given in Fig. 8. These landslides would block the transport routes, hampering the rescue and relief activities.

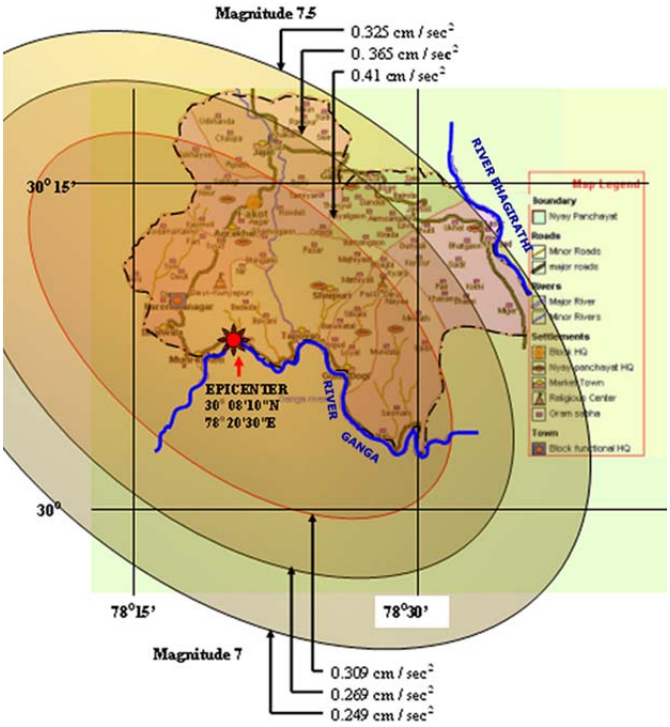

Fig. 7: Acceleration contours with epicenter at Tapowan (30^0 08'10"N and 78^0 20'30"E) for different hypo-central distances elongated parallel to the trend of Main Boundary Fault. [4]

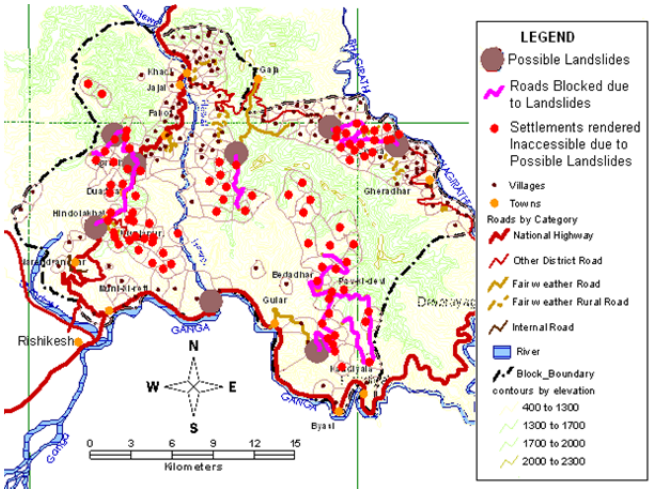

Fig. 8: Possible Landslides in Narendranagar Block

As results of these landslides total 85 settlements with a total population of 27462 (26.65%) would be rendered completely inaccessible (Fig. 9). It can be said that almost all other settlements would be rendered partially inaccessible because of landslides in the Narendranagar block. It indicates that actions should be taken on urgent basis to reduce the landslide hazard in the region.

Table 3: Settlements prone to flash floods after earthquakes

Villages		No. of Market Towns		Total Pop	%
Number	Population	Number	Population		Population
11	2103	6	7945	10048	9.75

A total of 11 villages and 6 market towns with total population of 10048, which is 9.75% of the total block population, are prone to flash floods after earthquakes. The flash floods due to formation of temporary dams if not cleared in time would eventually lead to flash floods. The bigger settlements of Narendranagar block like Tapowan and Muni-ki-reti could also be affected if the floods are severe.

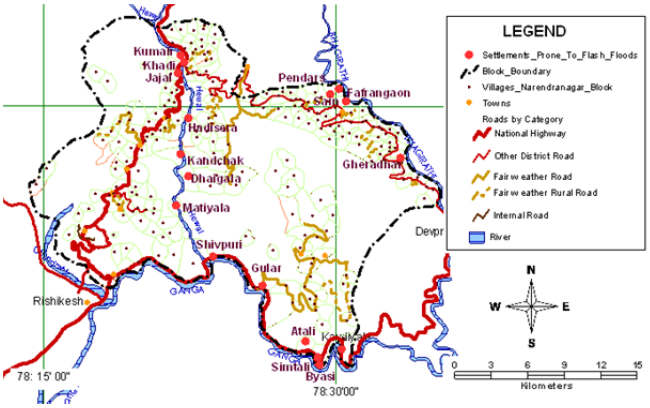

Fig. 9: Settlements of Narendranagar Block prone to flash floods due to landslides after earthquakes

10. CONCLUSION

Narendranagar block of Tehri-Garhwal district is highly prone to earthquakes. Any earthquake happening in this region can trigger many landslides which can cause severe disruption to the transport routes. This can render almost 26% of the block population completely inaccessible. The landslide can also cause flash floods in Hewal river and the settlements located on the banks would be severely affected. This landslide risk, identified in this paper needs to be managed through various structural and non-structural measures.

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