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Research Article

Earthquake Risk Assessment around Nainital in Uttarakhand Himalaya, India

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ABSTRACT

Earthquake is a major hazard for all tectonically active areas and high probability of landslides being induced by seismic ground shaking in the hilly areas makes the situation worse as these often hinder post–disaster relief, search and rescue efforts. Seismic risk is evaluated for the Himalayan township of Nainital that falls in Zone IV of Earthquake Zoning Map of India where damage during an earthquake is expected to reach MSK (Medvedev–Sponheuer–Karnik) intensity VIII. Condition of the built environment and its ability to withstand seismic tremors is assessed using RVS (Rapid Visual Screening) technique of FEMA (The Federal Emergency Management Agency) and the likely earthquake induced damage is depicted as a function of the damage grades of EMS–98.14 percent of the surveyed buildings of the township are observed to fall in Category 5 damage class while another 22 percent fall in Category 4 damage class in case of damage reaching intensity VIII on MSK scale. 604 buildings falling in high landslide hazard zone are also likely to be most adversely affected by seismogenic landslides. Total economic losses are thus estimated to be US$ 208.13 million which is around 4 percent of the current average annual revenue receipts of the state government and devastation in a seismic event is not going to be restricted to Nainital alone. Nearby located and densely populated areas of Haldwani-Kathgodam, Kaladhungi, Ramnagar, Kashipur and others are likely to sustain major losses. Actual economic loss could therefore be manifold and cause serious setback to the economy of the state. The study is intended to be utilized for effective risk communication and recommends changes in building bye laws and their strict compliance, demolition and retrofitting of vulnerable structures together with mass awareness and promotion of risk transfer tools for making the built environment safer and state's economy resilient to disasters.

Keywords: Himalaya; Uttarakhand; Nainital; Earthquake; Seismic vulnerability; Damageability; Building performance; Landslide; Hazard; Seismogenic landslides; Risk assessment

INTRODUCTION

The oceanic plate, Tethys, separating Indian and Eurasian continental plates was consumed by continued subduction of the former beneath the latter which resulted in the plate collision around 55 Ma and caused metamorphism, upliftment, deformation and shearing of the sediments deposited in hitherto intervening ocean basin together with rock mass at the margin of these plates.

Despite this Indian plate continues to drift north–northeast and as indicated by Global Positioning System (GPS) based monitoring of plate motion the Indian plate is underthrusting Tibet at a convergence rate of 45-51 mm/year [1-4]. Himalaya accommodates 18–20 mm/year of this convergence while the rest is taken care of further north in Tibet and Asia [5]. This ongoing convergence makes Himalaya, Tibet and the adjoining areas both neotectonically and seismically active [6-8].

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In the previous 120 years Himalayan region has witnessed six major earthquakes; 1897 Shillong Mw˜8.0 [9,10], 1905 Kangara Mw˜7.8 [11,12], 1934 Bihar–Nepal Mw˜8.2 [13,14], 1950 Assam now Arunachal Mw˜8.6 [15,16], 2005 Kashmir Mw˜7.6 [17] and 2015 Gorkha Mw˜7.8 earthquakes [18]. In a case study of 1905 Kangara event indicated possibility of around 80,000 persons being killed and the same has been validated by 2005 Kashmir Earthquake [19,20]. Rapid growth of population and proliferation of non-seismic safety compliant infrastructure in post-Kangara time has thus resulted in increased seismic vulnerability of the region.

Uttarakhand is located in the central sector of the Himalayan orogen and falls in Zone IV and V of Earthquake Zoning Map of India (IS1893 2002). Besides major earthquakes in 1344, 1505 and 1803 (Mw˜7.6) this region has witnessed two moderate magnitude earthquakes in 1991 and 1999 with epicenters at Uttarkashi (Mw˜6.7) and Chamoli (Mw˜6.4) respectively. This region has thus not witnessed a major earthquake for more than previous 200 years and falls in seismic gap of 1935 and 1905 great earthquakes [21,22]. This further enhances seismic risk in the state.

Evolutionary history and high seasonal precipitation make this region highly vulnerable to landslides and flash floods and these are particularly common during monsoon period (mid-June to September); rainy season in Indian sub-continent. Significant loss is incurred due to these every year and cumulative losses are much higher than those caused by other disasters including earthquakes. In the previous 9 years (2010-18) 5,190 human lives have been lost in Uttarakhand due to landslides and flash floods (Table 1) and this is significantly higher than human loss of 768 in 1991 Uttarkashi and 102 in 1999 Chamoli earthquakes (Table 1).

Table 1: Loss of life and property in Uttarakhand due to landslides and flash floods (Source: State Emergency Operations Centre, Government of Uttarakhand).

Year	Human Loss			Loss of Animals	Total no. of houses damaged			Loss of Agriculture land in (in hectares)
	Dead	Missing	Injured		Partially	Severely	Fully	
2010	220	-	139	1,798	10,672	-	1,215	240.9
2011	83	-	71	876	5,814	-	514	806.3
2012	176	-	96	997	743	-	285	40.3
2013	225	4,021	238	11,268	11,938	3,001	2,295	1,308.90
2014	66	-	66	371	1,260	278	342	1,285.50
2015	55	-	64	3,717	1,313	125	81	15.5
2016	119	5	102	1,391	2,684	839	252	112.3
2017	84	27	66	1,020	1,067	434	101	21
2018	100	9	48	764	2,042	433	122	295.4
Total	1,128	4,062	890	22,218	37,533	5,110	5,207	4,126.10
Average	125	451	99	2,469	4,170	568	579	458.5

Landslides often accompany a major earthquake in a mountainous area [20,23,24] and besides enhancing the losses these impede post-disaster relief, search and rescue operations; thus adding to the misery of the affected population. It is therefore highly important to identify areas with high potential of earthquake induced landslides while assessing seismic risk in a hilly area. This is all the more important for urban areas in the hills that are witnessing fast pace of infrastructure development and population growth. As against population growth of 11.34 percent in rural areas the urban population of the state of Uttarakhand has increased by 41.86 percent in the period 2001-2011 [25]. This calls for detailed vulnerability assessment of urban centers in the hills so as to prepare a holistic vulnerability reduction strategy.

THE STUDY AREA

Nainital, a famous tourist destination of Uttarakhand in India (Figure 1) has been taken up under the present study. The town is located in Lesser Himalaya in close proximity of a northeast dipping regional tectonic discontinuity of the Himalayan orogen; Main Boundary Thrust (MBT) that brings Proterozoic Lesser Himalayan rocks in juxtaposition with Cenozoic Siwalik sedimentary sequence [26,27]. The area around Nainital has rugged topography and high relative relief (1440-2610 meters asl) while conifers and oak dominate vegetation of the area. Population of Nainital is 41,461 [25]. The same is however witnesses manifold increase during the peak tourist season (from April/May to September/October).

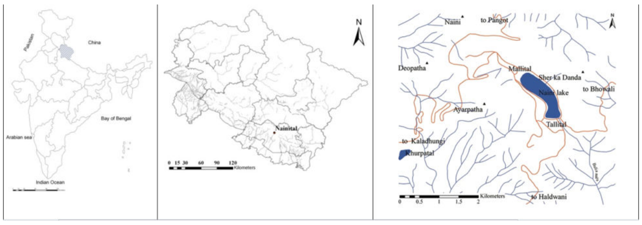

Figure 1: Location map of the area. In the left location of the State of Uttarakhand is shown while the figure in the middle shows the drainage network and district boundaries together with the location of Nainital while that on the right shows the area around Naini Lake.

Nainital was discovered in 1839 and habitation therein started thereafter. The town has witnessed a number of major landslide incidences in the past; 1867, 1880, 1893, 1898, 1924, 1989 and 1998 [28-32]. Incidences of 1880 and 1898 resulted in death of 151 and 28 persons respectively [29,33]. Based on the recommendations of the studies commissioned after these landslides detailed network of surface drains was planned and put in place and human intervention in many vulnerable slopes was banned.

Nainital has so far not witnessed a major seismic activity. There however exist records of ground fissures and cracks being observed during earthquake events in 1877, 1889 and 1934 [34]. The township however falls in Zone IV of Earthquake Zoning Map of India (IS1893 2002). Unplanned construction activities, non-compliance of earthquake safety measures and concentration of population further enhance the vulnerability. Previous landslide incidences around the town indicate high probability of landslides being triggered if a major seismic activity affects the area.

METHODOLOGY

Detailed fieldwork was carried out in the area around Nainital to collect data on various parameters affecting the geological stability of the slopes and assessing stability of the slopes during an earthquake shaking. Data pertaining to large proportion of the built environment was also collected through door to door survey of houses and other structures.

Direct seismogenic losses

Rapid Visual Screening (RVS) has been accepted as a fast and effective methodology for assessing seismic vulnerability of the built environment [35]. Under this buildings are surveyed on the basis of primary structural lateral load-resisting system and attributes that modify seismic performance of the building expected for this lateral load-resisting system and subsequently RVS scores are assigned to the surveyed buildings. For gathering field information modified version of the FEMA-154/ATC-21 data collection form was used and QuickBird satellite imagery was utilized for mapping the structures. Database was prepared under ARC INFO GIS environment (version 9.3) that was used for analysis and correlation.

Assessment of probable seismogenic losses was done by correlating RVS scores of the surveyed structures with probable seismic damage grades of European Macroseismic Scale (EMS-98) as suggested by Sinha and Goyal [36]. Of the five damage grades (Grade 1 to 5) of EMS-98 Grade 4 and Grade 5 are important for risk assessment as life of the occupants is likely to be threatened in these together with loss of contents therein. Grade 4 or very heavy damage grade implies heavy structural damage and very heavy non-structural damage and is characterised by serious failure of walls (gaps in wall) and partial structural failure of roof and floor. Grade 5 or destruction implies very heavy structural damage and is characterised by total or near total collapse of the structure. For the purpose of present study high probability of grade 5 damage and very high probability of grade 4 damage class of Sinha and Goyal was identified as Category 5 damage class while high probability of grade 4 damage and very high probability of grade 3 damage was identified as Category 4 damage class [36].

Secondary seismogenic losses

The term landslide denotes movement of a mass of rock, debris or earth down a slope under the influence of gravity and requires an external force for initiation. Ground shaking during an earthquake provides this trigger and landslides often accompany a seismic event in the hills [37]. Major landslide induced losses have been reported in 2005 Kashmir Mw~7.6 [17,20,38] and 2008 Sichuan Mw~7.0 [39-41] earthquakes.

Landslide history of Nainital town highlights the vulnerability of the area towards earthquake-induced landslides. Geological, tectonic and geomorphic characteristics of the area together with population pressure were identified as being the main factors inducing slope instability. Theme maps of the area pertaining to (i) Geology, (ii) Geomorphology, (iii) Structure, (iv) Drainage, (v) Slope, (vi) Aspect, (vii) Lineament, (viii) Land use/ land cover (ix) Anthropogenic pressure and (x) Active landslide were therefore prepared after detailed fieldwork and study of QuickBird satellite imagery.

Weight values of various parameter classes of the individual theme layers were calculated by correlating these with active landslide map using Statistical Index Method of Van Westen under GIS environment [42]. Individual weight values were thus defined as natural logarithm of the active landslide density in the class divided by landslide density in the entire map. Weighted maps were then prepared for each theme layer and these were integrated to prepare landslide hazard map. Three landslide hazard classes; low, moderate and high were identified in the final map. The area falling under high landslide hazard was observed to coincide with areas identified in the field as having high rockfall potential. Areas falling under this hazard class were therefore deduced as being most vulnerable to earthquake-induced landslides. The infrastructure falling in this area was accounted for while calculating earthquake-induced losses.

Assessment of likely economic losses

Category 5 damage class together with high landslide hazard class were deduced to be worst affected and therefore buildings falling under these were taken as requiring reconstruction after an earthquake event. The contents of these buildings were also considered as likely to be lost. The buildings falling in Category

4 damage class were however considered as being capable of restoration. The cost of restoration of these buildings was considered as being 25 percent of their replacement value [43].

Losses likely to be incurred to the built environment due to earthquake were assessed as being the cost of reconstruction of the houses falling in Category 5 damage class and in high landslide hazard zone and the contents therein together with the cost of repair of the houses falling in Category 4 damage class. The houses falling in both Category 5 damage class and high landslide hazard zone were omitted while calculating losses due to earthquake induced landslides.

Total constructed area of the houses was considered while estimating the cost of reconstruction which was calculated using the present schedule of construction rates of Public Works Department (PWD) of the state government. The value of the contents in the houses was assessed as being a function of the reconstruction cost and building use. For residential buildings the content value was taken as 50 percent of the replacement cost while for school, commercial, mixed (commercial and residential), hotel, hospital, religious and office buildings the economic worth of the contents likely to be lost was taken to be 25, 200, 100, 25, 400, 10 and 50 percent of the cost of replacement of these structures respectively [43].

SEISMIC VULNERABILITY OF BUILT ENVIRONMENT

2,865 buildings of Nainital were surveyed under the present study using the RVS technique. Vulnerability of the built environment generally increases with aging due to non-application of modern construction technology, lack of maintenance, weathering and decay. 17 percent of the surveyed buildings were observed to be constructed in the nineteenth century.

Unless special measures are taken seismic vulnerability of the building stock also increases with building height. Though 13 surveyed buildings were observed to be more than five storeyed, most surveyed buildings were low rise; 33 percent single storeyed, 57 percent double or triple storeyed and 10 percent more than three storeyed. Most construction (94 percent) was observed to be Unconfined Rubble Masonry (URM), mostly stone and brick masonry with slate/CGI (Corrugated Galvanised Iron) roofing. Most buildings of the town were thus classified as being non-engineered [44].

Based on the analysis of the collected data of the surveyed buildings 14 percent were deduced to fall in Category 5 damage class in case of earthquake intensity reaching VIII on MSK scale. These buildings were observed to be located mostly at the northern and southern extremity of the Naini Lake (Figure 2). Most buildings falling in this damage class were observed to be constructed in pre–1951 phase; 42 percent in pre–1900 period and 32 percent between 1901 and 1950. It is important to note that most structures falling in this damage class were low rise; 14 percent single storeyed and 54 percent two or three storeyed [45]. This however does not suggest that particular care was taken while constructing taller buildings as only 6 percent of the surveyed single storeyed buildings were observed to fall in Category 5 damage class. As against this, 13 percent of two or three storeyed buildings together with 48 percent of more than three storeyed buildings were falling in Category 5 damage class.

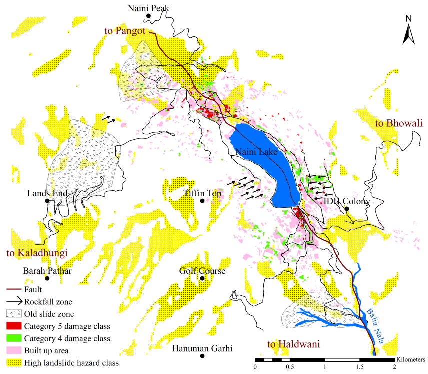

Figure 2: Map showing risk posed to the built environment of Nainital from an earthquake.

22 percent of the surveyed buildings of Nainital were deduced to fall in Category 4 damage class. Most of these (72 percent) were two or three storey high while only 4 percent were more than three storey high. Large proportions of these buildings (51 percent) were constructed in the period 1951-84 while 38 percent were constructed in pre–1951 period.

SECONDARY SEISMIC HAZARD

Landslides constitute major secondary seismic hazard in all hilly areas and often account for significant proportion of the earthquake induced losses [20,23,24]. These at the same time hamper post–earthquake search, rescue and relief operations. It is therefore necessary to identify areas likely to be affected by earthquake-induced landslides.

Landslides have tendency of getting reactivated with suitable trigger and therefore it is important to pay adequate attention towards zones having history of slope instability. Some significant old slide zones were observed on the hill slope to the east of the Lake Fault in Nainital. The rocks in this area were observed to have closely spaced foliations (rock type being slate/phyllite) and the hill slope was observed to be in a critical state of equilibrium. Anthropogenic interventions in this area were observed to disrupt hydrological regime and a number of instances of disposal of excavated material in the drains, blockade of drains by construction and obliteration of drains for site development were also observed during the course of fieldwork. These have the potential of initiating slope instability. Creep movement was also observed on the hill slope to the east of the Lake Fault. Blockade of drains as also overloading of vulnerable slopes with heavy infrastructure has the potential of accelerating the creep rates.

For identifying slopes with different probability of being affected by landslides in the event of a major earthquake statistical index method of Van Westen was used [42]. Landslide hazard map so prepared showed large area around the Naini Lake to fall in low and moderate hazard classes. High hazard class was observed to run NW-SE in a linear fashion between Naina Peak and the northern fringe of the Naini Lake (Figure 2). This was affected by mass movement in the past and the presence of phyllitic rocks in the area makes it susceptible to slope failure. This class also included areas around Barah Pathar and Tiffin Top that were observed to be vulnerable to rock fall incidences.

The areas around Balia Nala-Brewery, IDH Colony and Golf Course were also observed to fall in high hazard class. In these areas active slope movement was observed to be taking place and in the absence of appropriate mitigation measures the pace of erosion is likely to enhance. The hazard map showed most area to the east of the Naini Lake to fall under moderate hazard class while that to the west of the lake to fall mostly under low hazard class.

Tectonic discontinuities around the Naini lake were observed to given rise to steep cliffs with well-developed scarp along Balia Nala, Hanumangarhi, Golf Course, Lands End, IDH Colony and all these areas were observed to fall in high landslide hazard class. The Naini lake area was thus deduced to face constant threat of landslides and therefore it is highly recommended that anthropogenic activities on these vulnerable slopes be regulated.

604 surveyed houses in Nainital were observed to fall in high landslide hazard class and likely to be damaged by earthquake induced landslides. Of these 42 percent were reportedly constructed in 1951-84 period, 30 percent in 1985–2002 period, 2 percent in post-2002 period and the rest in pre-1951 period. Majority of the houses (55 percent) falling in high landslide hazard class were either two or three storeyed and only 6 percent were more than three storey high while the rest were single storeyed.

SEISMOGENIC LOSSES

Total built up area of the surveyed buildings falling in Category 5 damage class in Nainital was deduced to be 1,18,645 m^2 while built up area of those falling in high landslide hazard class was 2,06,214 m^2. Of those falling in high landslide hazard class 289 buildings having built up area of 68,370 m^2 also fell in Category 5 damage class. Only 1,37,844 m^2 built up area was therefore considered as being affected by seismogenic landslides.

At prevailing schedule of rates for new construction (Rs. 30,000 per m^2) of PWD of the state government and existing conversion rate (1 US$=Rs. 70) cost of reconstruction works out to be US$ 429 per m^2. The replacement cost of these buildings damaged by earthquake and earthquake induced landslides was thus estimated to be US$ 50.89 million and US$ 59.13 million respectively. This however is a gross underestimation, as it does not include cost of demolition, debris clearance and site development. It was further estimated that contents worth US$ 39.72 million and US$ 38.89 million respectively would be lost in these structures. Loss of US$ 188.63 million was thus estimated to the buildings falling in Category 5 damage class and those affected by seismogenic landslides.

Total covered area of the surveyed buildings of Nainital falling in Category 4 damage class was 1,86,035 m^2. These buildings were deduced to suffer major non–structural damages together with some structural damages. For bringing these damaged structures under normal use some repairs would be required. The cost of repair of these buildings was estimated to cost around 25 percent of the cost of new construction (US$ 429 per m^2); US$ 107.25 per m^2. Restoration of the buildings damaged in the likely earthquake event was thus estimated to cost US$ 19.50 million.

Total direct economic loss of US$ 208.13 million was thus estimated to incur to the surveyed structures in the Himalayan townships of Nainital in the event of earthquake induced damage reaching intensity VIII on MSK Scale.

DISCUSSION AND CONCLUSION

Earthquake and earthquake-induced landslide are major threat to human interests in all tectonically active mountainous regions. Assessment of vulnerability of an area to these hazards is a necessary precondition for realistic planning and effective mitigation. Together with detailed fieldwork, GIS and remote sensing tools were utilized in the present study for assessing seismic vulnerability of the area around the township of Nainital in Uttarakhand, India.

Of all the surveyed 2,865 buildings of Nainital 14 percent were observed to fall in Category 5 damage class while another 22 percent fall in Category 4 damage class in the event of a seismic activity reaching intensity VIII on MSK Scale. Most of these buildings were located near the northern and southern ends of the Naini Lake and constructed in pre–1951 phase when seismic codes were not in practice. Apart from these 604 buildings were located in the zone likely to be affected by earthquake-induced landslides.

Total direct earthquake-induced economic loss in Nainital was thus estimated to be US$ 208.13 million. This is however a gross underestimation as an earthquake causing intensity VIII ground shaking on MSK Scale in Nainital would cause similar destruction in a large region and nearby situated densely populated areas of Haldwani-Kathgodam, Kaladhungi, Ramnagar, Kashipur and others is likely to have major devastation. The likely magnitude of the economic losses in such a situation can well be assessed from the fact that the economic loss calculated for the surveyed structures of Nainital alone amounts to around 4 percent of the total average annual revenue receipts of the state government. Such an earthquake would be a major threat for the economy of the state and these calls for taking this issue seriously. Measures have therefore to be planned and implemented immediately to improve the state of built environment not only in Nainital but also in other urban areas of the state as well so as to ensure minimal losses during an earthquake.

The study reveals that the building stock of Nainital is old, ill maintained and constructed with little consideration to seismic safety. The losses in case of a major earthquake could therefore be much more than estimated in the study. Even the lifeline structures of the township are not observed to be seismically safe. The state of affairs is likely to be similar in other cities and towns of the state as is reflected in the studies carried out in the past [35].

This is a cause of major concern and it is therefore recommended to undertake detailed seismic vulnerability assessment of all lifeline structures in the state as their collapse would hamper post–disaster relief and rescue operations and add to the trauma of the affected population. Detailed strategy of improving performance of these buildings would then have to be prepared and this would include combination of seismic retrofitting and reconstruction.

Urban local bodies in the state of Uttarakhand routinely identify buildings and other structures posing threat to public and declaring these as girasu (needing demolition). The girasu buildings together with those identified through other surveys as posing high risk should necessarily be demolished as their collapse could jeopardize the safety of the occupants together with those in nearby buildings [35]. Provision of Section 24 (i) and 34 (k) of the Disaster Management Act, 2005 can be invoked by State Executive Committee and District Disaster management Authority respectively for doing so.

Aggressive and massive awareness drive has also to be taken up for risk communication and for popularising appropriate seismic safety measures. People routinely invest on the maintenance of their buildings and if convinced of the risk they are exposed to and provided required technical support they would certainly agree to dovetail maintenance with retrofitting. Tax benefits and soft loans for the complying house owners would further motivate people to participate in this mitigation drive.

Promotion of suitable, affordable and tailor made risk transfer options with differential hazard tagged premium would also motivate people to participate in risk reduction drive of the state government.

It is highly important for the state government is to pay more attention towards building bye laws; both their regular updating and compliance. The present practice of compounding that amounts to regularization of non-compliant buildings by payment of a penalty should be immediately done away with as it is a major disincentive for following the prescribed by laws. All non-compliant constructions should necessarily be demolished as these pose a major threat not only to the occupants therein but also to general public.

Nainital is a major tourism and educational center of Uttarakhand and has a number of residential schools, hotels, resorts and other recreational centers where people routinely gather in large numbers. Ensuring seismic safety of these should be a priority area for the government as disaster impact on these is sure to adversely affect the economy of the state. It is therefore recommended that seismic safety should be made a necessary precondition of obtaining permission for operating all commercial establishments in the state.

In the areas earmarked as being affected by rock fall incidences dislodged, fragmented and loose rock mass at higher reaches of the hill slope that are found to be in critical stage of equilibrium should be mechanically removed. All ongoing construction related activities on the vulnerable slopes, the areas falling in high landslide hazard class, should be stopped and suitable curative action should be taken in consultation with geotechnical engineers. Particular attention should be paid towards Mallital and Krishnapur that have high risk of seismogenic landslides and are densely populated with people of low socio-economic background.

Driven largely by commercial interests and covered up by the alibi of catering to the needs of the fast growing tourist traffic, Nainital together with other tourist destinations of the state is presently witnessing a situation where disaster safety related concerns are consciously being relegated to backstage. This is resulting in enhanced vulnerability of the entire state to various hazards of which earthquake is the most significant. It is therefore urgently required that all developmental initiatives, both planned and under implementation, in the state be objectively weighed in the light of their long term geo-environmental consequences and disaster safety.

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