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Seismic risk zonation using geospatial tool: A case study over East and South district of Sikkim

Rachna Kachhap [a], Amitesh Gupta [b], Rajarshi Bhattacharya [b], Triparna Sett [b].

[a] *Birla Institute of Technology, Mesra, India.*
[b] *Indian Institute of Remote Sensing, Dehradun, India.*

Abstract -

Seismic risk assessment in the high mountains of Himalaya is necessary to accommodate safe and suitable sites for homing with also to direct the pathway of plan and policy for development sustainably. The continuous orogeny results in frequent earthquakes, mostly in the area around fault lines as have been documented by USGS. Hence, to prepare the vulnerability and susceptible zonation in East and South Sikkim districts Analytical Hierarchy Process (AHP) technique has been adopted. LANDSAT 8 onboard OLI multispectral data is used to prepare the Land-use Land-cover map of study area using supervised classification techniques, while CartoSAT-1 version 2 DEM has been used to look into the physiographical aspects of this region. Moreover, Geological Survey of India prepared soil and geological map is used to prepare the soil and lineament map. Not only that, ground motion data of four different parameters, have also been acquired form USGS on about of an earthquake event on 18th September 2011, which had epicenter at 27.730°N, 88.155°E. Certainly, it has been observed that, area with soil type of moderate slope in the 10 km buffer zone from the major faults has been victimized to seismic hazard mostly. By AHP comparison matrix, proximity of any area to the fault lines found to be most influential followed by the ground motion vectors while the LULC categories are the least influential. Using the weighted overlay analysis, area along the western boundary of East district and north-west of South district in Sikkim has been found to be under high seismic risk zone. Risk zones have been verified with the help of archive earthquake data from USGS and approximately 22% area in these two districts comes under high risk zone.

Introduction

Seismic hazard refers to any occurrence due to earthquake such as ground shaking, liquefaction, landslides, or tsunami which are capable of imparting potential loss and damages to environment and human society. Risk is defined as the chance of occurrence of any adverse consequences to society, here, risk due to seismic hazard is quantified by three parameters - probability, time exposure during event and vulnerability. Hence, seismic risk assessment is a predictable function of several variables most importantly disaster proneness, exposure and vulnerability [1]. In other words, seismic risk narrate about the risk of lives, chances of damage to social properties or any adverse consequences to society caused by earthquake. Hence, seismic hazard refers to any kind of natural phenomenon caused by an earthquake, such as ground shaking, liquefaction, landslides, or tsunami, which are capable of imparting potential loss and damages to built-up areas and societal environment [2]. Precisely, seismic hazard is the probability of occurrence of an earthquake in a given geographic area, within a given window of time, and with ground motion intensity exceeding a given threshold [3]. Here, present study focus on seismic hazard zonation in East and South district of the Sikkim which is located on lower and higher Himalaya ranges (Fig. 1). Basically, seismic hazard zoning is the process by which a large area is subdivided into different zones according to level of hazard proneness on the basis of different risk factors already present in that area, which also can be expressed in terms of ground motion i.e., peak horizontal ground acceleration or peak ground velocity [4]. Seismic vulnerability in India is well evidenced by numerous past earthquake-related calamities [5]. According to the vulnerability atlas of India prepared by Building Materials and Technology Promotion Council (BMTPC), more than 59 percent of the total land-cover in the country is susceptible to seismic hazard [6]. Since, Indian subcontinent would have registered large number of highly earthquake prone regions in the world, the mountainous area is highly susceptible to the seismic vulnerability because of not only its tectonic movements but also existing high population pressure due to rapid development in unplanned urbanization[7] [8]. Most of the seismicity is being found to be concentrated along the 2500 km long Himalayan arc which is extended from Sulaiman-Kirthar zone in the west to Arakan-Yoma subduction zone in the east, along the plate boundary between the Indian and the Eurasian plates. The ongoing collision between these two plates have generated some of the devastating earthquakes with magnitude above 7.0 in the past [4]. On the foothills of the recent-most and highest folded mountain range, i.e., the Himalaya urban-growth has been observed to be quite faster and most importantly, these newly urbanized areas are mostly unsystematic, unplanned and unregulated [7]. Undoubtedly, this hilly urbanization has created not only large number of

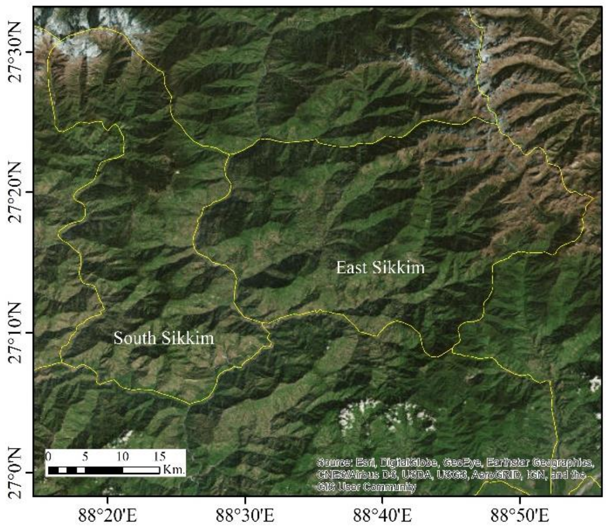

Fig. 1 Location of the study area.

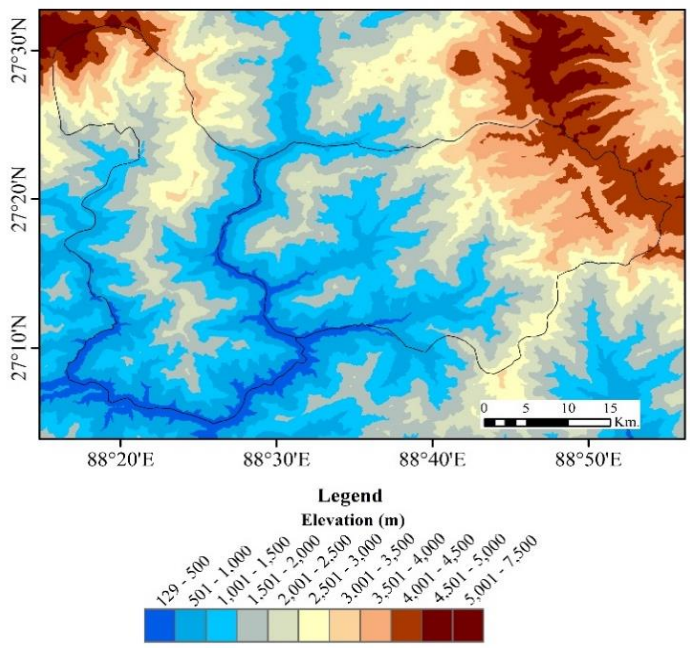

Fig. 2 Relief Map showing the topographic undulation of study area using CartoSat-1 v2 DEM

settlements but also it has provided employment opportunities, provided a variety of socio-economic services and contributed towards the development of infrastructure which is disseminated socioeconomic growth in their vast hinterland through trickledown effect [7] [9].

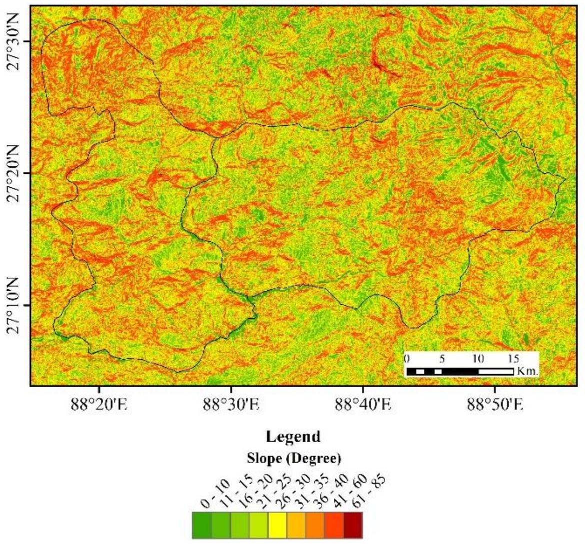

Fig. 3 Slope Map representing the ruggedness of topography of study area.

However, the sprawling and unplanned urban growth in fragile mountains has disrupted the critical ecosystem services, depleted natural resources, increased socio-economic inequalities and increased vulnerability of both towns and their fringe areas to a variety of natural risk like earthquake, flash flood etc. [10]. No matter what is the type occurrence, but it is for surely, the seismic risk is a natural caused phenomenon which become hazardous because of human ascendency.

This study came up with seismic risk map of South and East Sikkim area which also indicate the suitable area for land-use purposes. Indeed to mention, it is not only useful in the terms of saving lives and avoiding damages of constructions but also it bring up with few micro-zonations within the study area which ensure potential seismic vulnerability, which should be taken into account while designing new structures or retrofitting the existing ones.

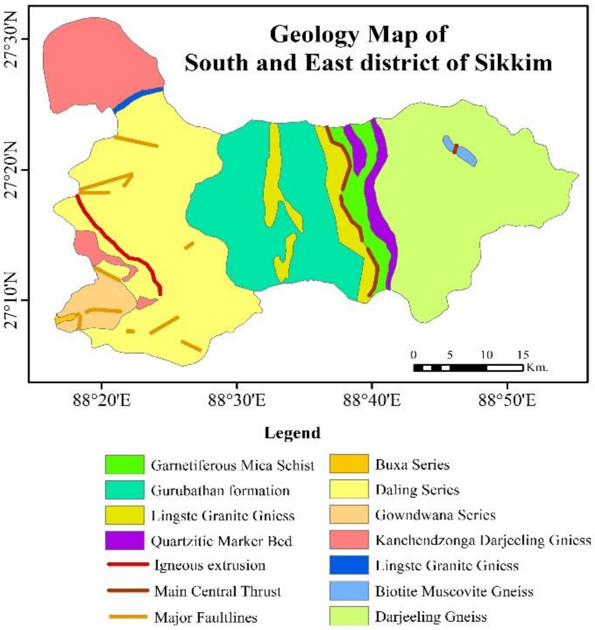

Fig. 4 Geology map showing the underlying structural complexity.

The present study area has very high undulating terrain characteristics the altitude ranges 129m to 6863m. (Fig. 2) and slope varies 0 to 85 degree (Fig. 3) which suggest presence of steep slope areas which are often susceptible for large scale landslide which may also cause small scale local earthquakes. The geology map (Fig. 4) reveals that high grade granite gneiss and quartz-biotite metamorphosed sedimentary rocks are amply found in this region which are basically the signatures of tythian sedimentation. Moderately deep, well-drained loamy skeletal soil of dark brown to dark reddish brown colour is the predominant soil type in this area which is also high erodible in the areas of high slope (Fig. 5). 15% of the total area in these two districts is snow covered during whole year, while the 80% among the rest is under forest and river (Fig. 6). Since, 65% of the total population of this area is adjoined with agricultural practice, hence, large areas under hilly slopes are converted in farmland by step cultivation. The total population exceeds 6lakhs within Sikkim and 70% of total population are resident in south and east district only, which leads to the motivation to carry out such study in this particular area.

Materials and Methods

LANDSAT - 8 satellite on-board Operational land Imager (OLI) multispectral data acquired on 17th January 2017 accessed from USGS has been used for the preparation of land use land cover map. CARTOSAT-1 Digital Elevation Model (DEM) data 30m resolution accessed from BHUVAN has been used to calculate the physical parameters such as slope and elevation.

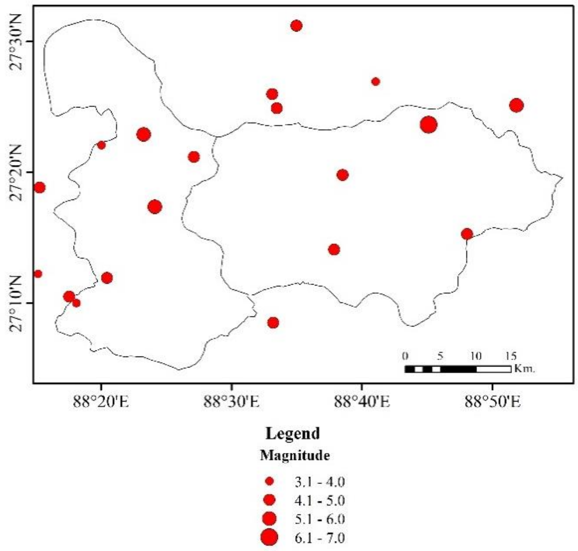

Fig. 5 Earthquake inventory map

Ground Motion Data namely Peak Ground Acceleration (PGA), Pseudo Spectral Acceleration (PSA), Peak Ground Velocity (PGV), Modified Mercelli Intensity (MMI) has been acquired form United States Geological Survey (USGS) for the events occurred in this area during 2011-2016.

Geology map and soil type map were obtained from Geological Survey of India and Environmental Information System Sikkim, respectively. Risk is the qualitative information infer the probability of destructive consequences due to hazards in vulnerable areas, hence, to assess the risk, the hazard zonation as well as demarcating the proneness of vulnerability is essential. Therefore, for the study area, the seismic hazard map has been prepared using different thematic layers. Very firstly, the geological and soil maps are digitized to prepare different layers. 4 different buffer layers have been created on the basis of distance from the fault lines.

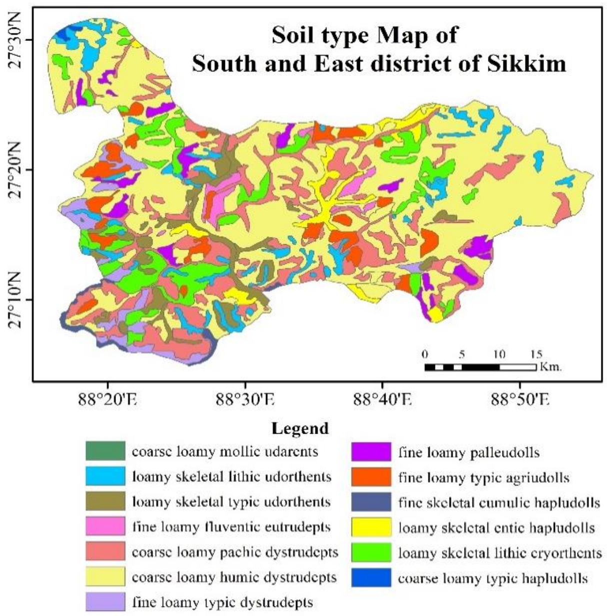

Fig. 6 Soil type map.

Using USGS provided data, the earthquake locations are plotted over Sikkim area and thereafter 3 buffers have been created, assuming that the buffer of 0-10km from the epicenters of past earthquakes are highly susceptible for the earthquakes in future, the respective buffers of 10-50km and 50-100km are respectively moderate and less prone. Not only that, using ground motion data, the PGA, MMI, PGV, PSA layers has been prepared put into the Analytical Hierarchical Process (AHP). The output from AHP shows the influencing factors to the seismic hazard, therefore, using weighted overlay tool the hazard map has been prepared. Meanwhile, the LULC map has been prepared using LANDSAT data using K-mean unsupervised classification technique to get 6 different layers of LULC. Thereafter, using weighted overlay tool, the risk map has been generated.

Results and Discussion

The LULC map (Fig.6) show that 67% of this study area is under dense forest on highly undulating terrain while 3.75% area is built-up and the rest is either barren land or fallow land or snow covered. The relief map shows that there are only approximately 37% of land area has the altitude of less than 1000m while approximately 26% of land area has altitude of more than 2000m.

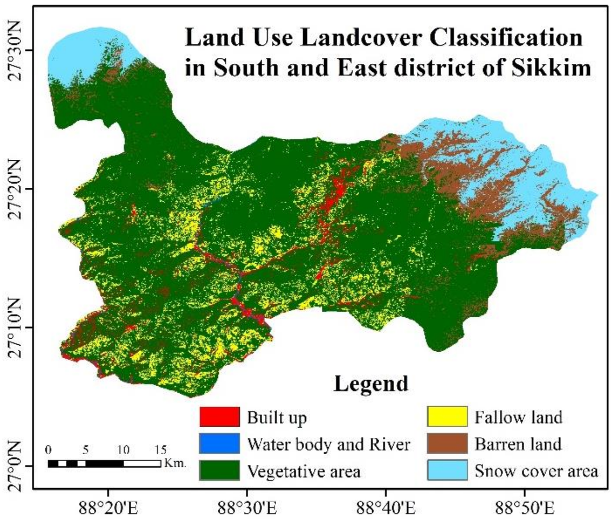

Fig. 7 Unsupervised classified LULC map.

Importantly, the rest approximately 37% of study area is under moderately high to very high slope area. The slope map exhibits that approximately 34% of area has the slope of less than 20 degree, which may be suitable for the land use purposes.

However, the historical data framed in Fig. 7 shows that 40% of past earthquakes had occurred in the area where slope varies from 31-60 degree. Therefore, the moderate to high slope of the mountains might be the result of intense geological process during the fold formation. This assumption become more confident while it has been found that 64% of the past earthquakes have occurred within the 20km buffer from the existing fault lines in this region. Mention worthy, geological map of this study area also shows that Gurubathan formation and Daling series of geological formation is predominant in the earthquake prone areas as well as all the faults are located in this two geological formation areas.

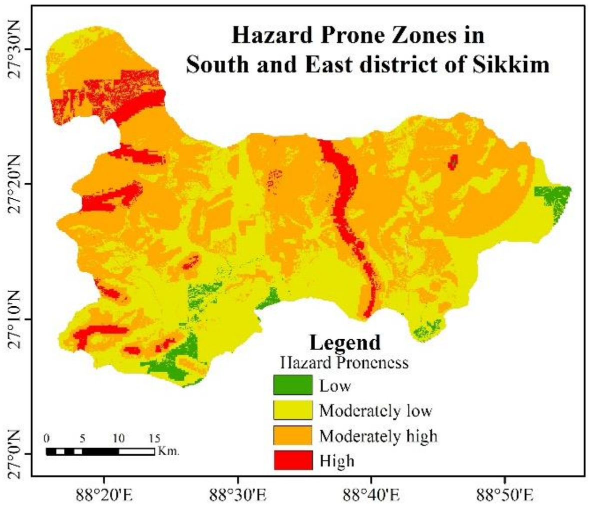

Fig. 8 Hazard prone zones in study area.

Therefore, it also deduce that the geology of this area is under high tectonic influence. Interestingly, the ground motion data is showing high values in northern side of these two districts which is notable along the fault region. The AHP pairwise comparison matrix and the output of resultant influencing factors exhibits that nearness to the fault lines is the highest influencing factor, followed by the ground motion factor. Therefore, using the AHP output as the weightage layer the prepared hazard map (Fig. 8) shows that middle and north-west of these two districts come under the highly hazardous zone. Comparatively, the southern valley regions are less hazard prone indeed. The inventory also justified on the hazard probable zones. Indeed to mention, the ground motion vectors might not be the most influencing factor, even though this aspect can't be ignored because it has been found during the investigation that the accuracy of prepared hazard prone zone decrease while ground motions are not taking in to AHP. In other words, it brings the handshaking agreement to previous studies like [11] that reveals the importance of ground motion vectoring for predicting the hazards prone zone. Therefore, by applying weighted sum overlay tool, the risk map (Fig. 9) has been prepared which show that north-west and the east side of this region are not suitable at all for human construction as this area come under highly risk zone. The central valley and south foothills are the better choice for human rehabilitation.

Conclusions

Seismic Zonation demarcates the sites of strong ground shaking characteristics or such structural response [4]. The ultimate goal of such seismic risk assessment related study is to develop the key elements that can be wielded to make rational decisions on seismic safety measures [12].The fatalities due to earthquakes and associated environmental disaster results collapse of building and infrastructures, disruption in economic productivity, etc.[13] therefore, these socio-economic losses can be better managed by long term prevention policy which depends on assessment of seismic risk [2]. Implementation of safe building construction codes [14] and strategy in such regions will be very inevitably for land use policies and resettlement planning considering the venture of various environmental hazards especially seismic hazard for the areas like south and east Sikkim district. Manifestly, this study will help the local authority in south and east Sikkim districts for better land use planning for long term sustainable development. Not only that, this study will also guide the planners to make plan and policy in other area of Sikkim as well as other areas like Sikkim where the tourism and human settlement is highly increasing day by day.

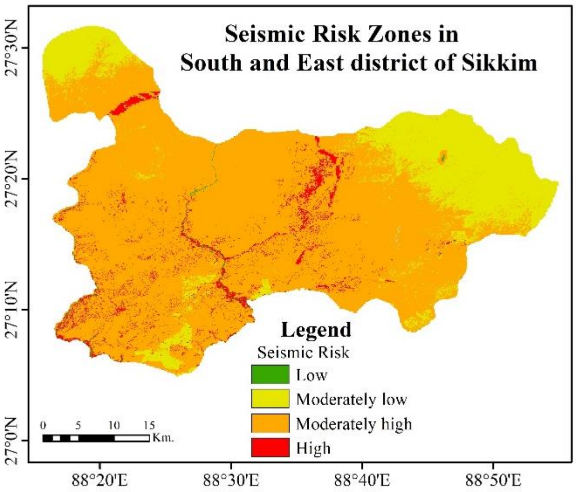

Fig. 9 Seismic risk zonation of study area.

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