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EARTHQUAKE RISK ASSESSMENT IN SIKKIM THROUGH GEOSPATIAL TECHNIQUES

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Abstract-A hazard turns into disaster when the risk or vulnerability of an area is very high. To prevent a disaster from taking further toll on the economy and lives of the population in a particular area it is necessary that we build a risk map of the whole area and then plan the area's livelihood accordingly, this not only increases the coping capacity of the people but also strengthens its economy. Sikkim is an area which is plagued by disasters and there is utmost need that we map the risk zones of the state for various disasters for example earthquake. Remote sensing and GIS serves as a very important platform for analysing the risk and vulnerability of any hazard.

Keywords – Earthquake, Risk, Hazard, Vulnerability, AHP

1. INTRODUCTION

Risk and vulnerability towards seismic activity worldwide is increasing many folds because of tremendous population rise, crumbling the qualities of life of communities and the destabilizing their condition because of its debasement, wherein an excess of 15 million lives have been lost and harm worth hundred billion dollars perpetrated in the written history of seismic tremors (conservative's estimate).

According to NIDM the state of Sikkim lies in the zone IV and zone V of seismic hazard zonation of India. Sikkim Himalaya shares high seismicity of north east India, which, is as of now supporting up to build up its regular assets toward enhancing the personal satisfaction of the general population, in a seismicity prone condition. Sikkim Himalaya, which is part of Northeast Himalaya, is seismically one of the six most active regions of the world. GPS measurements reveal that India and south Tibet converge at 20±3 mm/year (Nath, 2002). The article here elucidates the hazard pattern of seismic activity through AHP method and the seismic risk assessment through a model partially adapted from the Philippines Risk Model. AHP method was basically used to assess the landslide vulnerability but in this work it has been used for earthquake too. The AHP is a hypothesis of estimation for managing quantifiable and elusive criteria has been connected to various regions, for example, choice hypothesis and compromise. Earthquake risk mapping not only considers the exposure and vulnerability but it also includes susceptibility/ hazard (Jelinek, 2007). Risk mapping is an important component of hazard analysis. It includes both susceptibility and vulnerability assessments of elements taken under consideration for risk assessment (Cruden and Fell 1997; Guzzetti 2000; Dai et al. 2007).

According to Vatsa and Krimgold (2000), the greater impact of natural disasters is due to the increasing vulnerability of households and communities in developing nations making recovery process all the more cumbersome and aggravates poverty and deprivation, but Benson and Clay (2003) argued the negative impact of natural disasters while Skidmore and Toya (2002) were for positive impact leading to higher growth in future. Thus, risk mapping is a possible method to build up the coping capacity of the community.

2. REGIONAL SEISMICITY AND ITS TRENDS

The Himalayas is divided into a series of longitudinal tectonostratigraphic domains, in particular, Sub Himalayas, Lesser Himalayas, Higher Himalayas, and Tethys Himalayas, (Neogi et al., 1998) each isolated by significant dislocation zones.

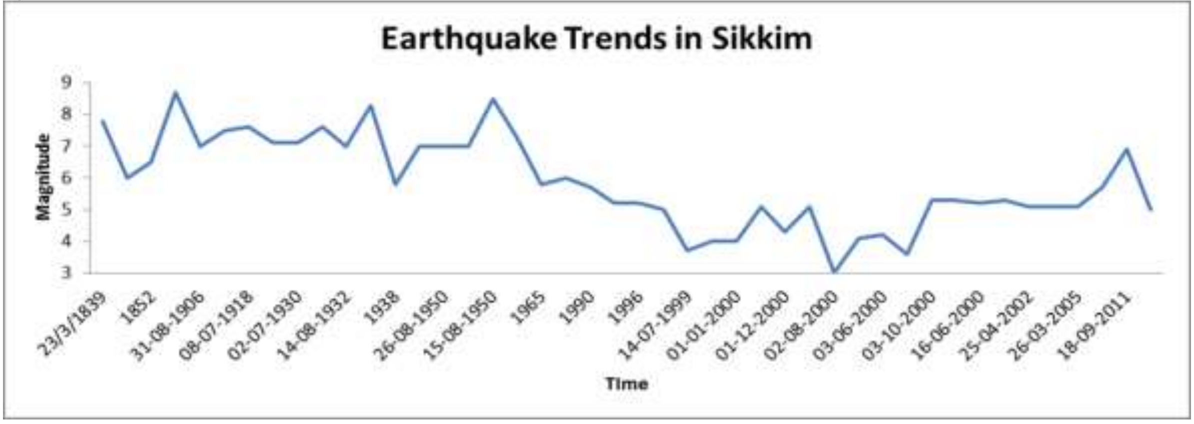

Fig. 2.1 Earthquake Trends in Sikkim

Transient variety of seismicity in the territory demonstrates that there is sudden outburst of tremors for a year or two went before by a peaceful time of 3 to 4 years (Fig.2.1) and earthquake activity amid 1964 to 1992 proposes that the regional seismicity of Sikkim Himalaya is moderately high toward the north of MBT and activity diminishes southwards from the lesser Himalayas to the fore deep area under the silt cover. Sikkim and bordering district is a piece of the seismically dynamic zone of the Alpine-Himalayan seismic belt (Fig.2.2).
Earthquakes in adjacent states too were distinctly felt in Sikkim such as the devastating Bihar earthquake of 1934 south of MBT and Bihar-Nepal earthquake of 1988. Besides, the isoseismal VII additionally goes through Gangtok in NE– SW course. The effect of destruction in state on power units, street arrangements were mostly as subsidence and landslides and a few structures in Gangtok were harmed (Nath 2004). Historical and instrumental recorded data on earthquakes show that Sikkim and adjoining area in the region were affected by numerous moderate and four massive earthquakes of 8.0 magnitudes in the past. The northward tectonic movement of the Indian Plate and followed by its abrupt release leads to strain accumulation causing earthquakes in this region.

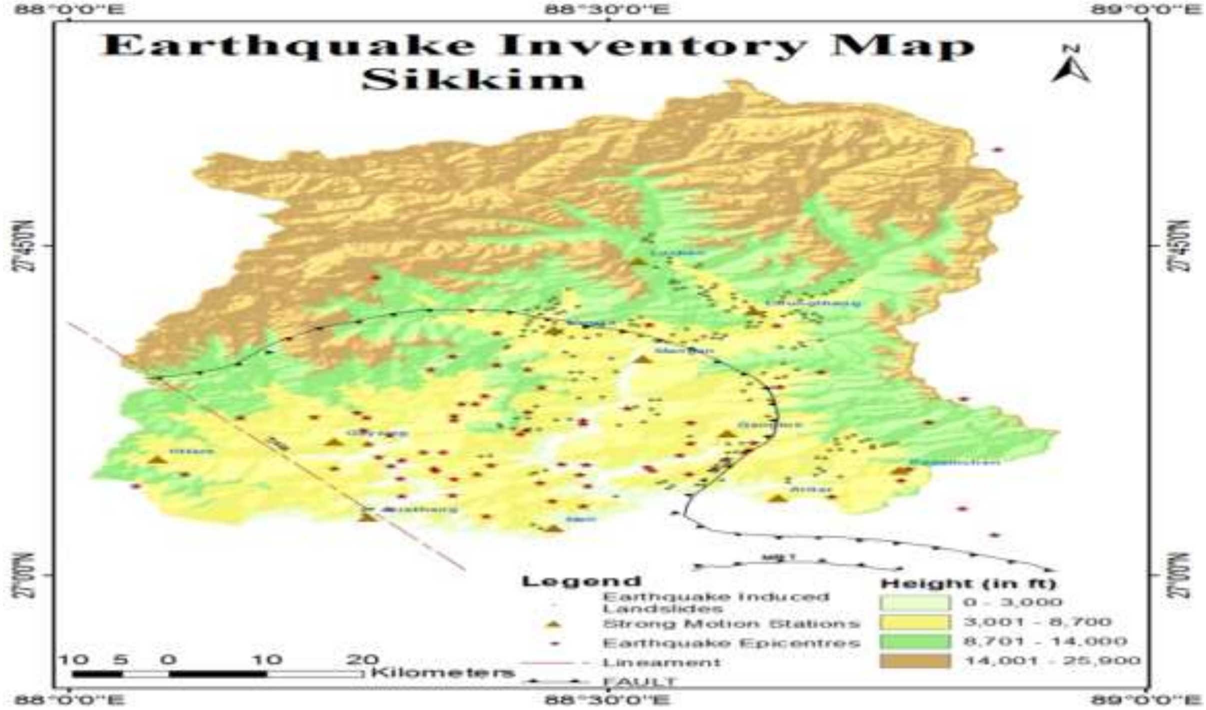

Fig. 2.2 Earthquake Inventory Map of Sikkim

Source- Seismic Hazard Mapping and Microzonation by Nath, 2002

Sikkim is quite close to Nepal revealing the importance of strain accumulation in the latter affecting the former and according to the department of mines and geology, which monitors seismicity of central Himalayas of Nepal (since 1985), serious microseismicity and continuous medium-measure quakes (mL<4) tend to group underneath the topographic front of the higher Himalaya. These 10 to 20km deep seismic tremors, which associates with the zone of localised uplift that has been demonstrated from geodetic information. From geological evidence it has been known that there is strain accumulation on mid-crustal ramp and further studies from microseismic and geodetic data proved the same (Gahalaut 2015). This slope joins a level decollement under the lesser and sub-Himalaya with a deeper decollement under the higher Himalaya, and goes about as a geometric severity where strain and stress create amid the interseismic period. The huge Himalayan seismic tremors could source there and can stimulate the entire level and-incline system till the blind thrusts of the Sub-Himalaya.
According to reports and studies by seismologists, a huge chunk of rock, which was 20 km beneath Mt. Kanchenjunga, pitched southwards causing an earthquake of 6.9 magnitude and the western edge of Sikkim slipped southwards relative to Nepal. There were numerous aftershocks of 4 to 5 magnitudes on the eastern edge of the rupture which built up additional strain in the subterranean rocks of Sikkim following which two events of 5.7 and 5.3 magnitudes occurred as a result of years of strain accumulation during the Sikkim earthquake in 2011.

3. DATA ACQUISITION

For earthquake inventory mapping, data was taken from SSDMA (from 1880 – 2011) and earthquake susceptibility mapping, predominant frequency map, peak ground acceleration map and site response map were taken from Seismic hazard and Microzonation by Nath (2002), geology and lineament map from Geological Survey of India map on scale 1:500000 and soil map from ENVIS. For exposure map of earthquake the following indicators were used - household, population density, housing structure and residential and commercial houses were taken from Census 2011 and DCH Sikkim, 2011. Infrastructure information was taken and agricultural map prepared from ENVIS, 2013 statistical journal of Sikkim and 2011 DCH Sikkim, which were then correlated with LULC map prepared from satellite images. HDI, multidimensional poverty index, poverty vulnerability, per capita household consumption potential per annum data were taken from Human Development Report 2014-2015. Residential house construction cost was calculated from the cost calculator of ACC cement agency and land area was calculated from IRDCE plan 2014.

4. EARTHQUAKE HAZARD ZONATION

The hazard map, which is prepared with 5 zones, is done to analyse earthquake threat area (as the concerned people be notified), using different layers (site response map, peak ground acceleration, predominant frequency, fault distance and geology) for which secondary data maps were taken from Nath, IIT (2002). The layers are explained according to their AHP rank (Table. 1.1, Fig.1.3).

4.1 Site Response Map

It is important to investigate the nearby soil conditions as site particular ground response examinations intensification of seismic waves and subsequently can assess the ground response spectra for future plan purposes. The frequency of base movement, as well as the geometry and material properties of the soil above bedrock is essential amid a tremor and henceforth a vital objective of engineering seismology has been to attempt and measure this enhancement of ground movement to survey seismic risk. The mean spectral ratio and standard deviation at all the stations was ascertained utilizing 41 occasion information. The areas with lowest site response is south east Sikkim and the highest is near the areas along MCT (North and East Sikkim).

4.2 Peak Ground Acceleration

By and large ground movements with high PGA are more harming than those with lower PGA. During 1990 to 2002 a number of observations were made related to the peak ground acceleration and predominant frequency by Nath (2002) during which the highest PGA was recorded at Singtam with 0.87g and 0.86g in Jorethang in the south and east Sikkim respectively and PGA decreased towards North Sikkim with 0.28g in Lachen, thereby proving the greater vulnerability of the southern part of Sikkim to earthquake (Nath, 2002).

4.3 Predominant Frequency

The maximum frequency (15- 18 Hz) is in the northern region and the lowest in south and south eastern (with 4 – 6 Hz). It is pertinent to note that ground motions with high peak accelerations are more damaging than those with low and power spectrum plays a significant role in deciding the predominant frequency of it for lower the frequency higher the destruction rate.

4.4 Distance from Faults

It is imminent earthquakes occur on faults (it is a thin of crushed rock zone centimetres to thousands of kilometres long separating blocks of the earth's crust), as rock on one side of the fault slips with respect to the other. Sikkim is ridden with numerous minor faults and two major thrust faults that are the Main Central Thrust and the Main Boundary Thrust. There are three lineaments surrounding the area that is the Teesta lineament, Kanchenjunga Lineament and the Gangtok Lineament. Most of the earthquake occurs in the vicinity of these faults. The 2011 earthquake of 6.9 magnitude occurred along these faults slipping Indian plate under the Eurasian plate through the MCT. 50 metres to 300 metres is taken as the buffer distance of the faults of which 0 – 50 metres is ranked as 1 in order of highest hazard to rank 4 with lowest (distance of 200 – 300 metres).

4.5 Geology

The softer the bed material (based on the composition of the rock and their structure) more the destruction by the propagating waves and vice versa. The most vulnerable material is variegated clay, fine and medium sand pebble, pebble, boulder slate, conglomerate, phyllite, schist, gamut with mica schist and ranked one and the least vulnerable are hard material (lingtse gneiss, Pte, Pta, Ts, CPI, CPd, Ptdr) which are ranked fourth.

Table- 4.1 AHP Rank of Factors Affecting Earthquake Hazard

Class	Faults	Predominant Frequency contour	Site response Map	Peak Ground Acceleration	Landslide	Geology	Priority Vector
Faults	1	2	3	5	8	9	0.39
PFC	0.50	1	2	3	7	8	0.27
SRM	0.33	0.50	1	2	5	7	0.18
PGA	0.20	0.33	0.50	1	3	5	0.1
Landslide	0.13	0.14	0.20	0.33	1	2	0.04
Geology	0.11	0.13	0.14	0.20	0.50	1	0.02
Total	2.269	4.101	6.842	11.533	24.5	32	1

Using the above stated thematic layers all the epicentre locations were overlaid on the earthquake hazard map. The susceptibility map was made in raster calculator giving the automated rankings calculated with the AHP method; the epicentres were fitted approximately in the high and very high susceptible region. The region was divided into four vulnerable levels very high, high, moderate, and low.

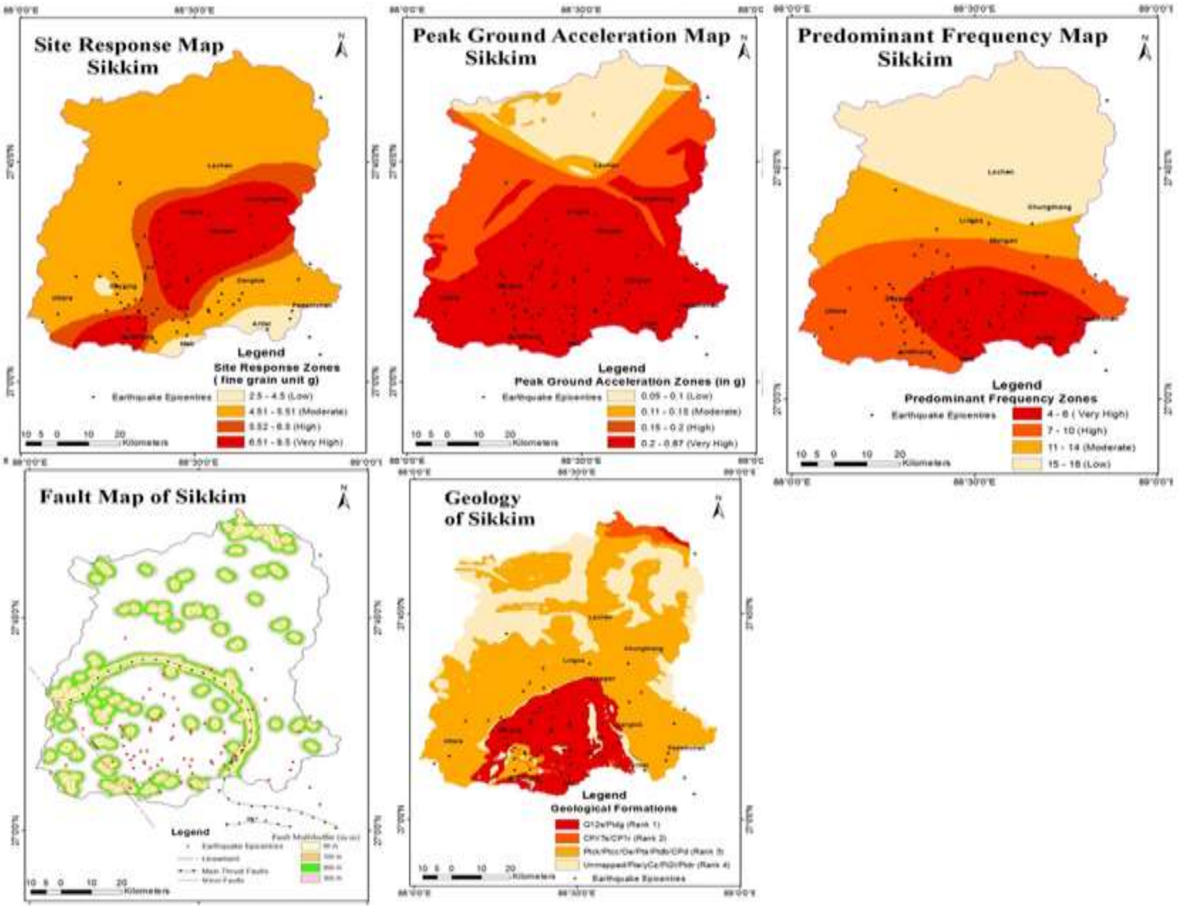

Fig. 4.1 Factors Affecting Earthquake Hazard

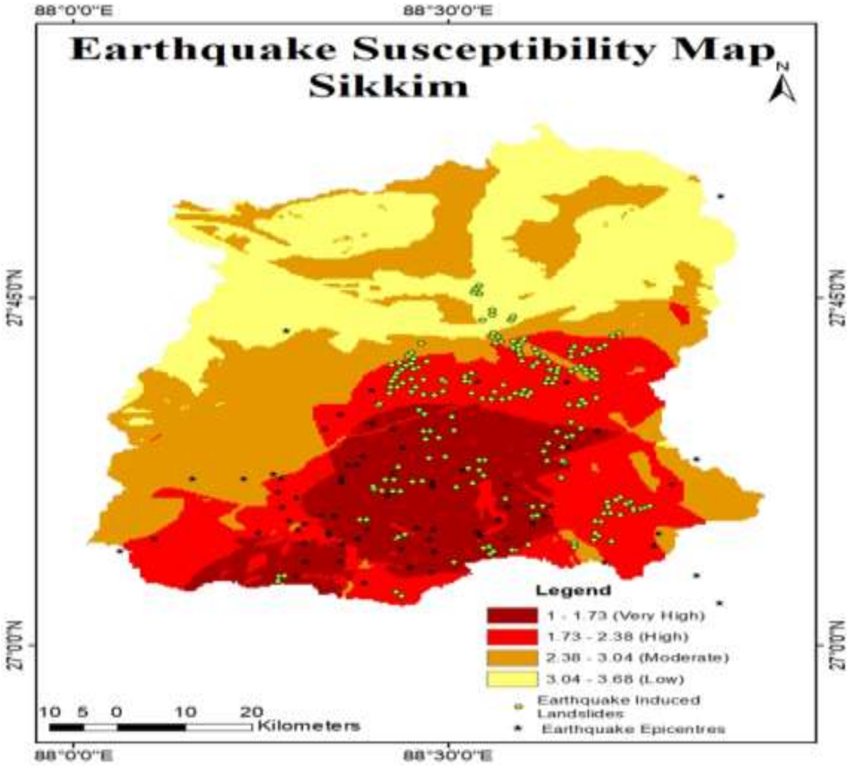

Fig. 4.2 Earthquake Hazard Map

5. EARTHQUAKE EXPOSURE MAP

Earthquake exposure map is the second step after hazard zonation, towards demarcations of the earthquake risk zones. The exposure map has been created using the thematic layers of population density, households, housing structures (permanent, semi-permanent and temporary), roads, agriculture, poverty vulnerability, infrastructure, residential and commercial buildings and per capita household consumption potential. Assessing the number and location of exposed people is mandatory in earthquake risk management and emergency planning which has also been confirmed by Promper and Glade (2016).

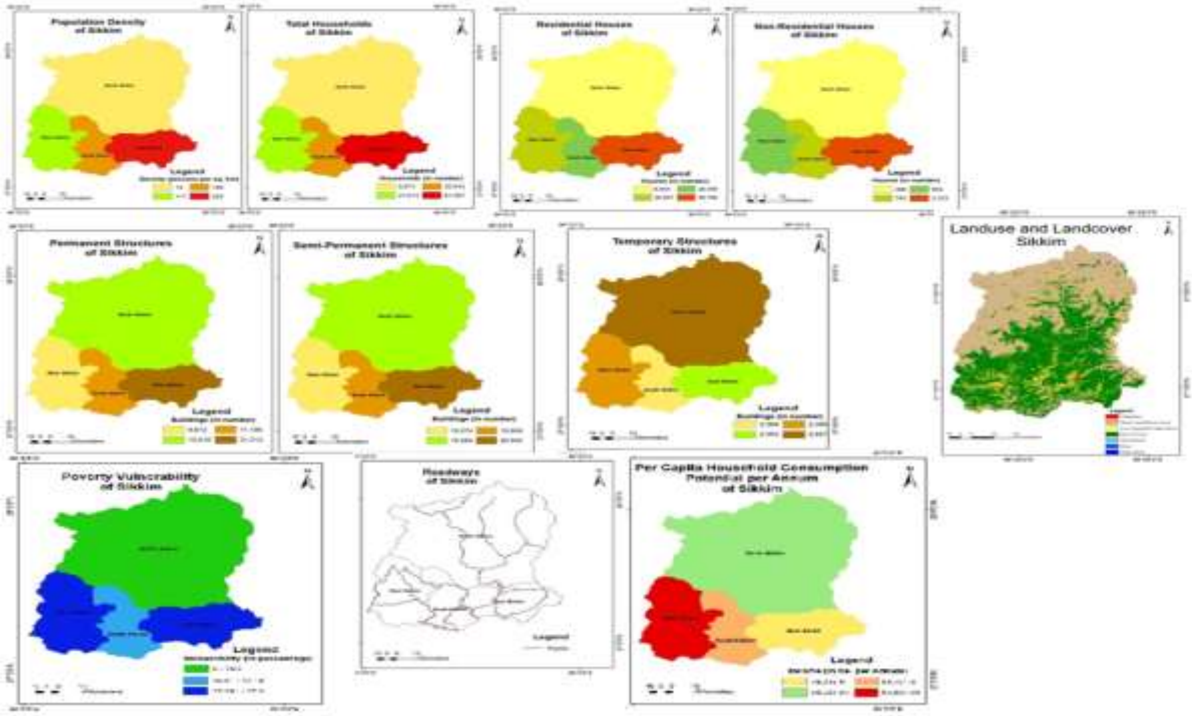

Fig. 5.1Factors Affecting Earthquake Exposure

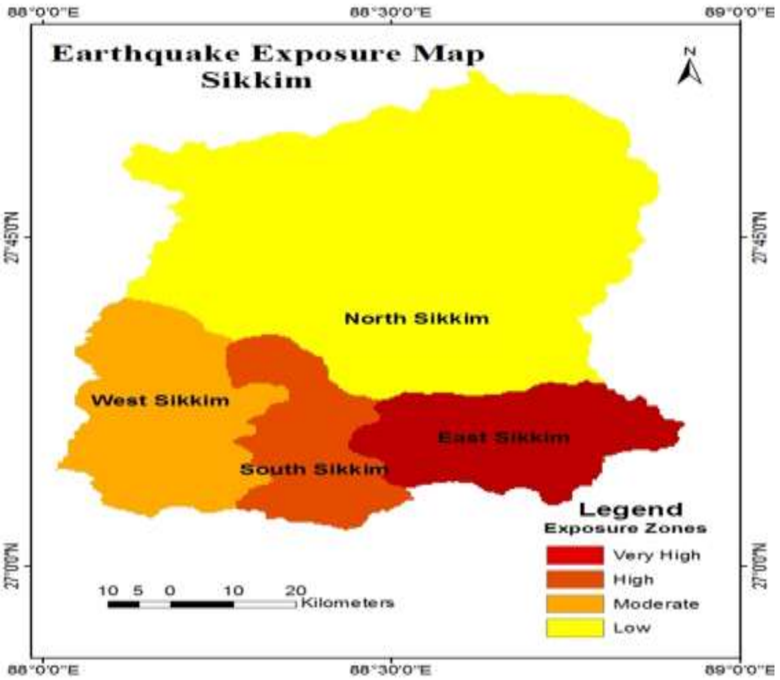

Fig. 5.2 Earthquake Exposure Map

6. EARTHQUAKE PHYSICAL EXPOSURE ZONES

This map is the third step towards the construction of the earthquake risk map. The physical exposure map is made by multiplying the raster maps of the earthquake susceptibility and exposure map. This map shows the actual exposed population according to that of the hazard map.

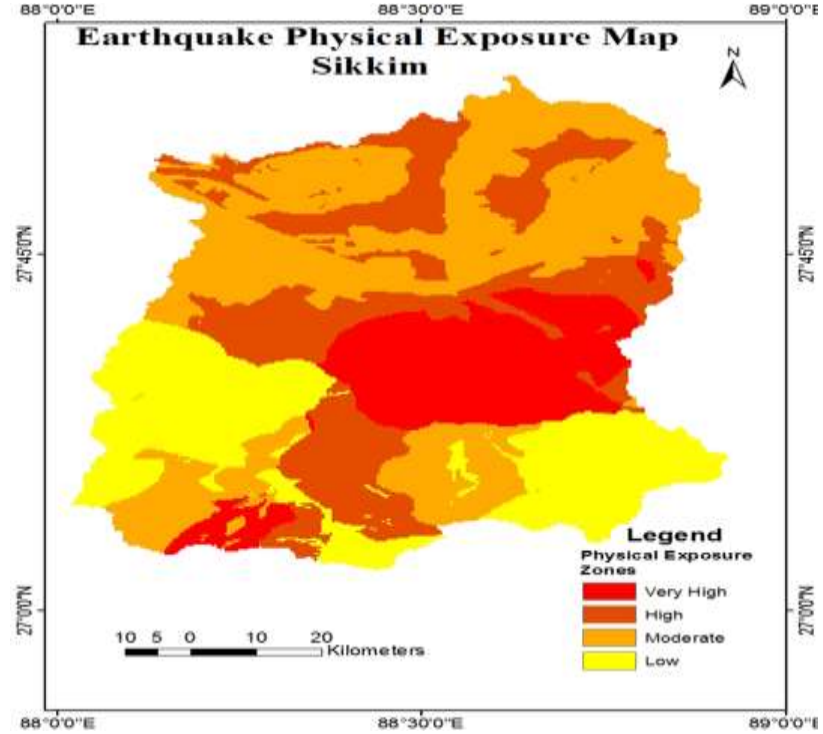

Fig. 6.1 Earthquake Physical Exposure Map

7. EARTHQUAKE RISK MAP

Risk map explains the impact of disasters on the socio-economic conditions of the people and the danger posing or already posed to human, economic, infrastructural as well as the environment of a region. It has been calculated by multiplying HDI, GDP and MPI of each district converted to raster map and then multiplied with the physical exposure. Risk is not only vulnerability but also the rate of coping capacity of the residents.

RISK = HAZARD (Layers in 3.3) * EXPOSURE (layers in 3.4) * VULNERABILITY (HDI*MPI)

8. RESULTS AND DISCUSSIONS

Whole of East and South and parts of North and West districts, mainly the areas which are inhabited, are most susceptible to earthquakes. The areas of North and West district are the next most susceptible while the far eastern and most of the northern parts the least. According to the AHP calculation, 41 percent area falls under very high hazard area and 31 percent under moderate and 28 percent under low. It was found that the central portion is more susceptible to earthquake because of MCT and numerous other local faults concentrating in the area. The material of the beds present in the region is soft explaining more proneness to severe destruction. The only part more or less stable in this zone is the tectonic window which consists of hard igneous rocks. As the whole area is tectonically very active early warning and local training would be highly beneficial (Fig.1.4). The potentially exposed population to earthquake risk was assessed using 2011 census data and quantitatively integrating the 12 raster layers (Fig.1.5). The least exposed or least vulnerable was North District and maximum East (Fig. 1.6). The highly exposed areas are that of the south and south eastern part of North district; north and north east part of East and southeast part of West followed by north, west and north-west of North district; South district as a whole and major parts of West district and eastern part of East are least exposed to earthquake hazard. Gangtok (capital) falls in the moderate exposure zone (Fig.1.7).

It is very clear from the risk map of Sikkim (Fig.1.8), that central part of Sikkim is the highest risk zone comprising of southern part of North District, northern part of South, south eastern part of West and central and western part of East followed by various parts of North District which is experiencing population growth in recent decades. Except for a circular region, south of the highest risk region, whole of South Sikkim comes under lowest risk which comprises of eastern part of East and most of West District.

The reason for East District being in lowest risk is because of moderate hazard expectation and better coping capacity of people, which is because of higher HDI, GDP and lowers MPI, whereas greater risk faced by North and South Districts is because of its high hazard, very low HDI, GDP and higher MPI leading to lower coping capacity of people.

Although the epicentre of the earthquake, which was (place and distance), was in a sparsely populated area (population density was 4 to 10 people per square kilometre), but the ripples of the event affected the whole population of Sikkim because of their low coping capacity. Indigenous methods of building construction saved the buildings during earthquake rather than those constructed in modern ways because of faulty construction methods.

CONCLUSION

It is best to increase the coping capacity of the population to reduce the vulnerability. There are few suggestive ideas to start with the building of coping capacity, which are - promotion of building houses according to stipulated rules for earthquake hazard areas, promoting building of indigenous houses which are safer during an earthquake, to increase gaps in between houses, as maximum death is caused by the building destruction through insufficient gaps in between them.

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