International Journal on Recent and Innovation Trends in Computing and Communication ISSN: 2321-8169
Volume: 3 Issue: 7 4858 - 4868

Population Growth, Infrastructural Development and Exposure to Seismic Hazard: Challenges of East Sikkim

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Abstract- A comprehensive, analytical and numerical application of population growth, rapid building construction and associated risk is presented in the paper. East district of Sikkim (27°08′N to 27°23′N and 88°25′E to 88°45′E) constitutes 954 sq km. area and it is the most developed district in Sikkim. Unstable geostratigrphical settings along with unscientific use of heavy building materials further exaggerate risk in the fragile Eastern Himalayan landscape.

Key words- *Population dynamics, natural hazards, risk, fragile landscape*

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I. INTRODUCTION

Sikkim stands highly vulnerable seismic prone situation owing to burgeoning population along with rapid infrastructural development in eastern and southern portion. It faced several high intensity earthquake tremors in past. Population growth and urban development play a crucial role in accessing risk of certain area which is already hazard prone. The seismic risk evaluation in urban built up areas generally associated with the earthquake hazard, vulnerability of building and level of exposure. As seismic event is potential aspects, several engineering research already have done and vulnerability studies in urban centers conducted aimed to identify the building fragilities, and reduce the seismic risk

Hazard is also scientifically defined [1] that 'the potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources'. Seismic hazard is a natural phenomenon which is conditioned by the tremors of earthquake shocks and damage associated with it and the term vulnerability is a degree of loss to a given region or set of element at risk resulting from the occurrence of a given magnitude [2].

Various works has already been done regarding the architecture engineering and its relation with seismicity [3, 4, 5, and 6].

II. STUDY AREA

Fig.1. of East district in Sikkim (27°08′N to 27°23′N and 88°25′E to 88°45′E) covers an area of 954 sq km and bounded by Bhutan in east and West Bengal in south comprises of three subdivisions i.e Gangtok, Pakyong and Rongli is characterized by highly dissected terrain with steep gorges, broad valleys as well as sharp peak and ridges which already experience severe earthquake tremors and landslide which results life and property loss. The district is most high densely populated (295 people per sq km in 2011) and highly urbanized (43.19% in 2011).

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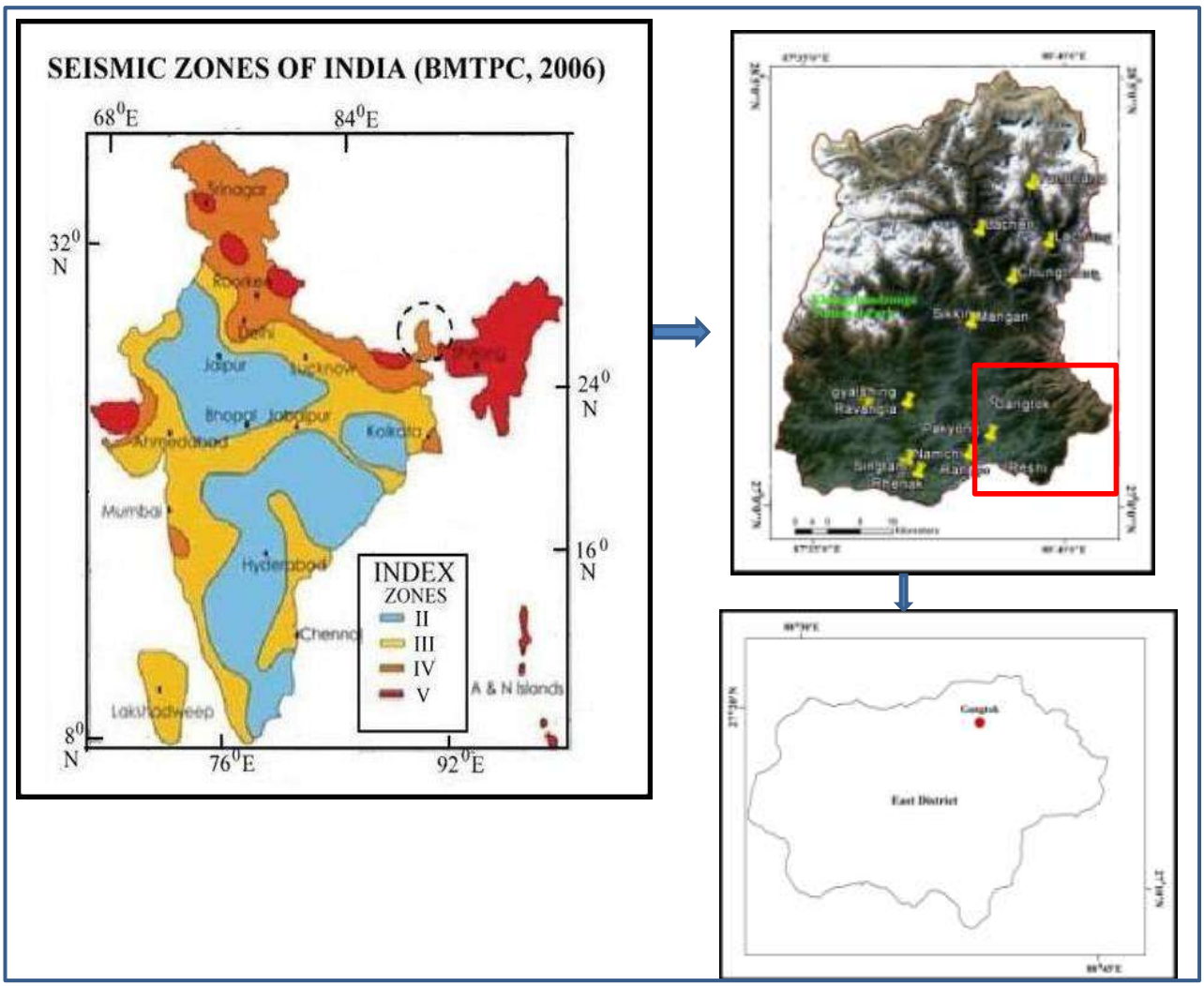

Fig.1 Location of study area (based on BMTPC, 2006 and Google earth image)

III. GEO-STRATIGRAPHICAL STRUCTURE OF EAST DISTRICT

There is a lateral extension of Sikkim-Darjeeling Himalayan complex which is associated with occasional Himalayan pinching and local truncation. The three type of formation i.e Daling formation, Buxa formation and Streaky Biotite Gneiss (Lingtse Granite) formation. In this part, the Gondowana group of rock is exposed as 'window' in Pache khola and Kali khola, surrounded by the Buxas and the Daling group of rocks successively [8]. The rocks of Gondowana group are coarse to medium-grained sandstone, grey shale, carbonaceous shale, pebble slate. The Geological sequence of Juluk-Nathang-Kupup-Chhangu areas of East District of Sikkim indicate that Lithologically, the area consists of a sequence of high grade gneisses with inter bands of Metasedimentaries. Despite broad compositional similarities the gneisses show variation in textures from augen gneiss to streaky gneiss to banded gneiss. The passage from one variety to the other is gradational and not separated by any recognizable thrust plane. The gneisses are occasionally intruded both concordantly and discordantly by foliated and unfoliated tourmaline bearing Granites, Pegmatite and Epidotic Quartz veins and some basic bodies [8].

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IV. OBJECTIVE OF THE STUDY

i) Population dynamics of East district
ii) Most prominent natural hazards and associated risk induced by high population and urbanisation
iii) Rapid infrastructural development and associated risk
iv) Planning for future sustainability

V. MATERIALS AND METHODS

Materials which are included in the work are secondary data from Census of India 1991 [7], 2001 [7] and 2011 [7]. Sikkim Multi Hazard Risk and Vulnerability Assessment (MHRVA, 2010) [8], District Disaster Management Plan (DDMP) East district, Gangtok [9], Building Material and Technology Promotion Council (BMTPC) [11], National Disaster Management Agency (NDMA) [12], Urban development and housing department in Sikkim (UDHD) [13], Mines, Minerals and Geology (MMG) [14], Department of Gangtok, Sikkim, School of Planning and Architecture (SPA) [15]. Statistical techniques are used for data analysis purposes. Maps are prepared by using Arc-GIS software (Version 9.3).

VI. RESULTS AND DISCUSSIONS

A. Population dynamics, major hazards and associated risk

Fig.2 shows that, Population density and level of urbanisation of East district increases from 89.74 persons per sq in 1971 km to 297.25 persons per sq in 2011 and level of urbanization correspondingly increases from 19.87% in 1971 to 43.19% in2011 due to continuous population growth. East district of Sikkim also comprises of 2, 83,583 total population with 64.53% household density in 2011.

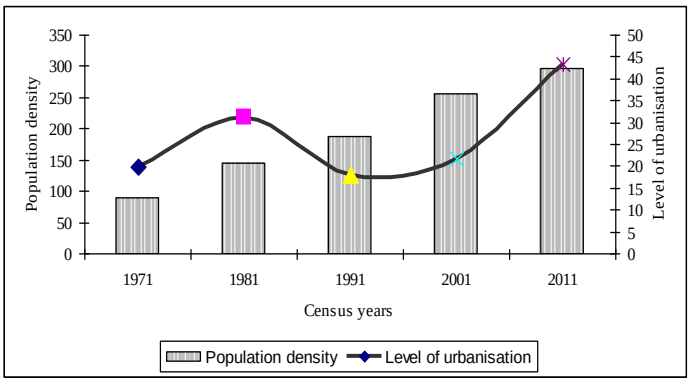

Fig.2 Change of population density and level of urbanization in East district. Based on Census of India [7], calculated by authors

Among three subdivision of East district, Gangtok subdivision is most urbanized one (53.13% in 2011) where Gangtok Municipal Corporation (GMC) is only class I town in whole Sikkim with 1,00,286 total population (25,024 in 1991 and 29,354 in 2001). There are 15 wards in GMC and highest populated ward is Syari/Tathangchen ward (11,028 in 2011). People engaged in service sector found to be high (73.94% in 2011) also in East district. Because of state capital and large tourism activities in Gangtok, it becomes the major economic hub in entire Sikkim. Due to the continuous migration, tourism and natural growth of population, it becomes the growth pole in Sikkim. Population of Gangtok exploded in last 10 years with an increase of 258.37% which is extremely high [5]. In terms of density distribution, high population density is found in city core areas [5]. The city mobility plan of Gangtok claims that almost 2, 00,000 tourists visit Gangtok every year and it induce burden of the city and lead the population to expose in seismic hazard.

Fig.3 depicts the data from Census, it is found that population of this town increase exponentially and the growth rate increase from 17 in 2001 to 258.37 in 2011.

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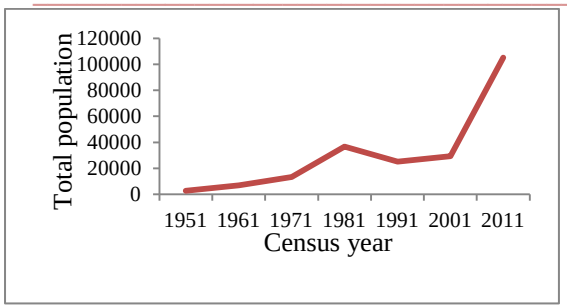

Fig.3 Exponential population growth of GMC. Source. [13]

Urban land cover in East district is increasing day by day and large hotels, residential and commercial buildings are constructed randomly. On the other hand, the geo starigraphical settings already showed a high hazard prone situation.

The multi hazards of east district shown in Table.1

Table.1. Multi hazards and their occurrences in East district

Natural Hazards	Month of Occurrences											
	January	February	March	April	May	June	July	August	September	October	November	December
Earthquake	←	—	—	—	—	—	—	—	—	—	—	→
Landslide				←	—	—	—	—	→			
Cold wave	↔									←	—	→
High speed wind		↔	↔						←	—	→	
Flash flood				←	—	—	—	—	→			
Drought	←	—	→							←	—	→
Forest Fire									←	—	—	→

Source. [9]

Almost all hazards have more or less effect on life and property loss but frequency of earthquake and landslide is very common and they have a huge effect in human beings and infrastructure development.

The main focus of this research paper is geological hazards especially earthquake. Several earthquake tremors already hit several parts of east district. Recent times in 18th September 2011, entire Sikkim was shaken by high magnitude earthquake tremors (6.8 Mg). Areas in Sikkim with high congestion of large multistoried buildings and high populated are affected very much. Gangtok in East district suffered with serious loss of life and property. Continuous increasing population pressure along with tourists flow increase the risk and randomly increasing large multistoried building also initiate the risk probability. Table.3 shows the different building typology in Gangtok and their characteristics features.

B. Building typology, fragility of buildings and exposure to seismic risk

The economic boom brought by tourism has created tremendous infrastructure requirement in East district of Sikkim (especially GMC). This led to the expansion of road network, construction of bridges, building of dams and tunnels for power generation in different parts of district. Generally

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six types of houses are observed in eastern one (Table 3). In rural areas, people used bamboo and wood (wood from chestnut, locally known as *uttis* and alder locally known as *kattus*) to make the traditional houses (*ekra*). But in urban areas, most of the buildings are made by reinforced concrete. So, a clear typology of building is found in East Sikkim varying from rural to urban areas.

Table.3 Building typology and their characteristics

Building Typology	**Characteristic Features**
Traditional House-*Ekra* House	Single or two-storied huts, Asbestos used as roof supported by wooden frame, wooden columns are cross-woven *Ekra* or Bamboo split matting which plasted with mud or cement
Asbestos temporary structures	Temporary and light weight, bamboo posts and beams are connected by asbestos sheets
Un-Reinforced Masonry Structure	Single storied unreinforced brick, stone and concrete masonry without Earthquake resistance power, Infill material includes cement concrete blocks joined by cement mortar
Low Rise concrete frame structure	1-2 storied, floor made by concrete, Roof either concrete flat slab or sloping asbestos light roof materials, Walls built from floor to roof as per requirement of the openings,
Mid-Rise concrete frame structure	3-7 floors, sloping asbestos roofs, concrete frame without structural features, observed in areas with high population density.
High Rise concrete frame structure	7 floors or more without any seismic resistance design, construction mainly by concrete, mainly found in Gangtok in East Sikkim

Source. [11]

Table.4 Different categories of houses and building materials, East district

Categories of House Types	**Characteristics**
Category “A”	Building in field stone, rural structure, unburnt brick house, clay house
Category “B”	Ordinary brick building, building of the large block and pre fabricated type, half-timbered structure, building in natural hewn stone
Category “C”	Reinforced building and well being wooden structure
Category “X”	Light building materials not covered A,B and X type

Source. Census of India, 1991 [7]

Table 4.shows the houses in different categories based on wall made with different materials. Each type of buildings needs different kind of building materials. The roof, wall and floor of the buildings made with different materials and wall and roof are very susceptible to damage. Thus, they need to be made with earthquake resistant materials.

In Table.5, building categories and their level of risk are shown.

Table.5 Classification of building under the risk of earthquake hazard

Building Categories	**Zone IV (Severe Intensity Zones)** **(MSK VIII, Damaging**
A	High
B	Medium
C	Low
X	Very Low

Source**.** [10], Note: MSK Scale=Medvedev-Sponheuer-Karnik, 1964

During last two decadal years, housing has also evolved and undergone significant transformation in East district. Earlier, it was common practice to construct residential buildings using bamboo/wood, but economic development in early nineties prompted the transformation of RC structure from traditional housing. Moreover, due to urbanization, the tremendous increase in housing requirement and lack of availability of suitable lands forced the people to construct houses in vulnerable areas like sloped ground, sinking area and also improper extension of existing buildings. Most of the buildings do not follow the guidelines regarding number of floors, plan area, etc., provided by the urban development authorities. Most settlement and housing pattern in urban areas in east especially GMC is unplanned and inadequately supervised. Gangtok lies in steep slope and land stability plays a crucial role in building construction and architectural planning.

In Fig.4. land under different conditions are shown [13] and it is found that 24% to29% land are suitable for building construction because they are relatively stable to stable situation but day by day continuous encroaching of land, people are compelled to construct building to the unstable land.

In Fig.5, it is found that, Gangtok has mixed land use pattern Among 19.2 sq km total area of Gangtok town [14]. 4.416 sq km area in is covered by residential buildings which is much high in hilly terrain. and there is 8.256 sq km area where no development is found. It includes vacant land, forested areas and army areas [14]. Apart from that, whole town is completely congested and this alarming situation endowed the seismic risk of the town in East district, this is the only area which become highly vulnerable and risk prone and suffered huge loss during earthquake shaking.

Use of different building materials and building design become major focus for urban planners and earthquake engineers because unplanned uses of them exaggerate the risk of a seismically active hilly town. As per the recommendation given by MMG department of Government of Sikkim, and the sanction of plans and permission for construction by the urban development and housing department, the

Maximum height of the building permitted is 5 ½ ft. storey. But this is not followed properly. Now it become essential to find the spatial distribution of different categories buildings and find out the most risk prone building materials and types. Table.6 shows the district wise distribution of different categories of buildings which include rural and urban areas both. It is found that, in east district there is a more concentration of ‘B’ category building which is made by ordinary brick, large block and pre fabricated type, and

 ISSN: 2321-8169
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buildings are half-timbered structure, and natural hewn stones.

In table.5, the buildings have high to medium level of risk under earthquake Concentration of 'X' category building is found to be very low (5.23% in 2001). Though it is found in very small percentage in rural areas of east district, it become almost negligible in urban areas. Thus randomly constructions of risk prone buildings initiate the risk.

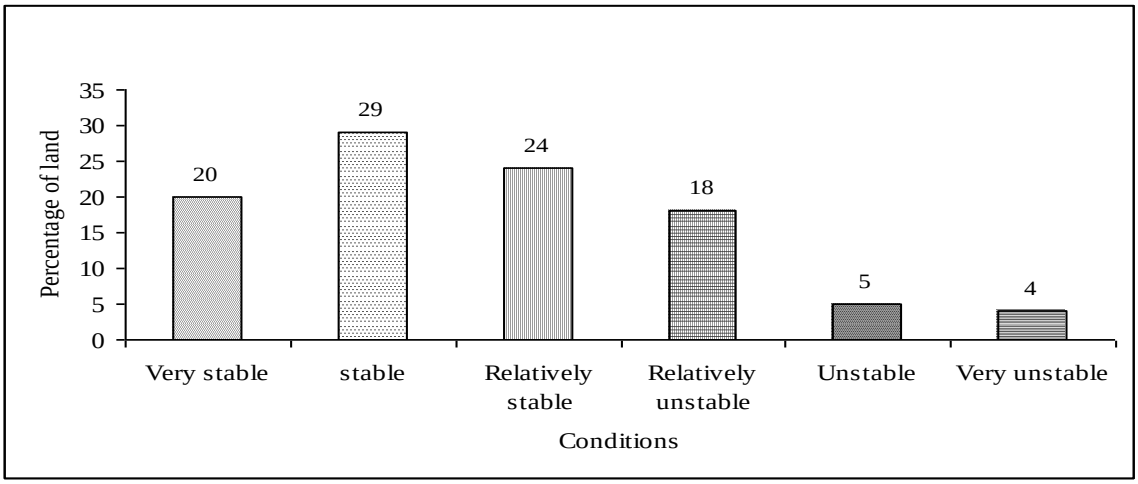

Fig.4 Percentage of land under different condition, Source. [14]

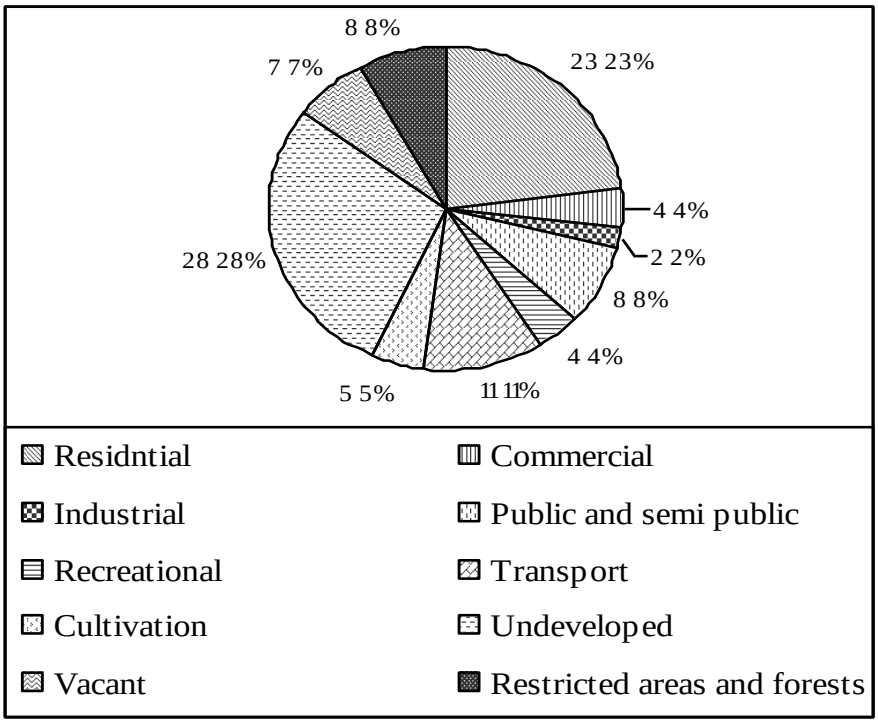

Fig.5 Land use classification of Gangtok Town., [15]

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Table.6 District wise distribution of different building categories

Building Categories	Concentration of buildings (in percentage) and probable risk											
	North District			East District			South District			West District		
	Urban areas	Rural areas	Risk Level	Urban areas	Rural areas	Risk Level	Urban areas	Rural areas	Risk Level	Urban areas	Rural areas	Risk Level
A	2.94	13.50	16.44	6.12	19.99	26.11	5.87	21.80	27.67	4.51	30.39	34.9
B	40.96	9.1	50.06	61.45	16.12	**77.57 (M)**	66.43	12.64	**79.07 (M)**	56.77	8.96	65.73
C	42.96	52.88	**95.84 (L)**	25.53	44.75	70.28	24.73	44.50	69.23	34.10	37.15	**71.25 (L)**
X	5.2	5.0	10.2	1.23	4.11	5.23	1.0	1.47	2.47	0.79	2.2	2.99

Source. Census of India 2001 [7], calculated by authors. Notes: M-medium level of risk under earthquake and L-low level of risk under earthquake

Table. 9 and Fig. 6 shows that, there is a positive correlation between population density of urban centers and use of fragile building materials. Fragile building materials include only 'A' and 'B' categories of buildings which have high probability of seismic risk. By analyzing the data, it is found that, Singtam (Nagar Panchayet,NP) and Rangpo (Nagar Panchayet,NP) are newly emerging towns in East district. Now days, the huge population from main city Gangtok started to flow towards others newly emerging towns namely Singtam and Rangpo. Thus the population density increasing day by day. Jorethang in South district also an emerging town and population pressure from main city Namchi flow towards Jorethang thus it results the same i.e continuous construction of multistoried-multipurpose buildings with risk prone building materials.

Table.9 Density of towns in Sikkim and percentage use of fragile building materials

Numbers	Towns	Population density	Fragile building materials
1	Mangan (NP)	2638.60	47.13
2	Gyalshing (NP)	1114.70	70.64
3	Nayabazar (Notified bazar area)	10739.10	47.16
4	Namchi (M cl)	1704.90	70.73
5	Jorethang (NP)	20020.00	80.09
6	Gangtok (M corp.)	5223.20	69.68
7	Singtam (NP)	33340.90	62.92
8	Rangpo (NP)	5838.00	65.78

Source. Provisional Census of India, 2011 [7], calculated by authors

 ISSN: 2321-8169
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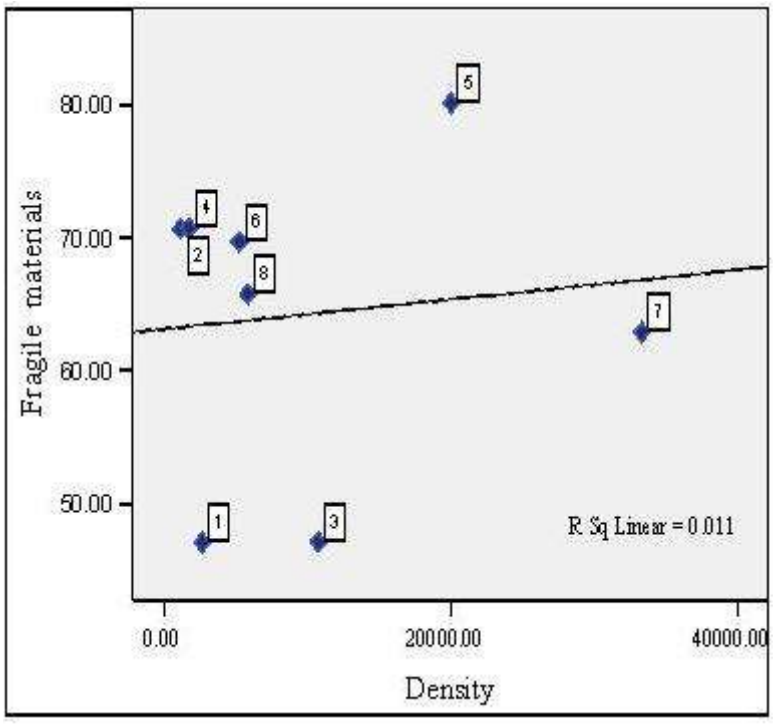

Fig.6 Scatter of fragile building materials and population density

Table.9 District wise damage data of 2011 earthquake, Sikkim

Districts	Death number	Estimated Homeless	Houses/Building				Schools			Hospital
			Destroyed	Severely damaged	Partially damaged	Slightly damaged	Destroyed	Partially damaged	Slightly damaged	Destroyed
East	**13**	**20160**	**6000**	**NA**	**9000**	**NA**	**201**	**NA**	**NA**	**23**

Source. [12]

In Table.9, a huge damage of the areas in each district depend not only geophysical settings but also anthropological factors like rapidly increasing human habitation and construction of the large multistoried building with risk prone building materials. Due to rapid urbanization and modernization, people change their living style and multistoried-multifunctional buildings are randomly constructed without proper earthquake resistant design which possesses huge damage. With rapidly increasing population density, people use concrete buildings and non engineered structure enhances the life and property loss.

Gangok town in east district have 178.09% population growth in 2011 which exceeds from 25.52% in 2001. The continuous demand for housing lead to 173.1% growth of permanent house [13] from 31.5% in 2001 and only 4.99% growth [13] of temporary house. When the earthquake in 2011 occurred with 6.9 mg scale, buildings of the town severely shaken with intensity of VI (Modified merceili index) MMI scale particularly the buildings were in edge of the steep slope causing panic and distress. Majority of the building are RC types with coloumn-piller structure and masonry wall. Most of the building experienced hairline cracks in their infill wall [5]

VII. CONCLUSION

Disaster disrupted the development by pushing the developmental progress in back. The natural hazards cannot be completely diminished from Sikkim but the matter should concern that by implication of some sustainable planning, the intensity of the hazards may be minimized.

NDMA, BMTPC, and several civil engineering department of India already proposed several earthquake resisting building construction strategies; but the problem is that, lack of awareness among people exaggerates the situation which enhances damage probability.

Population projection of 2021 already warned that, the total population of Gangtok town will reach 3, 38,624 which is really high for a hilly terrain. Thus, proper urban planning is needed in organized manner on the particular physical environment that the mankind lives by maintaining socio cultural and economical needs. Before the planning all geoenvironmental limiters, geohazards, geological-geotechnical data are must be evaluated as geologic thresholds because these thresholds effect the development and settlements. So, people and government should have more concerned about this, and development through holistic planning should be urgently needed in proper way which will minimize the earthquake risk and maintain the sustainable livelihood of east district.

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