17th World Conference on Earthquake Engineering, 17WCEE
Sendai, Japan - September 13th to 18th 2020

SEISMIC LOSS ESTIMATION AND RISK ASSESSMENT FOR NATIONAL CAPITAL TERRITORY OF DELHI, INDIA: FIRST RESULTS

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Abstract

Threat to National Capital Territory (NCT) of Delhi, India is two-fold: firstly, from the Himalayan collision zone earthquakes like 1905 Kangra (Mw 7.8), 1991 Uttarkashi (Mw 6.8) and 1999 Chamoli (Mw 6.5), and secondly seismic events in the Indian shield region like 1720 Delhi (Mw 6.5), 1803 Mathura (Mw 6.8), and 1960 Faridabad (Mw 6.0) [1-3]. Also, this region is in the proximity of ~50 km to the active local Mahendragarh-Dehradun fault [4] and ~200 km to the Himalayan collision zone with potential for maximum Mw of 7.1 [5] and Mw >8.0 respectively [6-8]. Further, existing alluvial soils beneath, a population of ~19 million, and building exposure of ~5 million along with rapid growth in construction and industry designate NCT of Delhi as the highest seismic risk metropolitan city of India.

In this research, the seismic hazard for the study region in terms of 2% and 10% probability in 50 years is computed considering three influencing seismic zones and introducing region-specific attenuation relationship of NCT Delhi into OpenQuake hazard library. Seismic risk analysis for building inventory in NCT Delhi reveals that 30 % of the total buildings, have complete damage probability of > 0.4 for a maximum credible earthquake. The high damage probability for these building classes (AMM, MMB, BTR, BSR) are due to the temporary type of construction, which need immediate retrofitting / replacement. Further, for a Design Basis Earthquake (DBE) and Maximum Credible Earthquake (MCE), the expected economic losses might vary from 31 to 130 billion USD, and human losses might vary between 0.02 and 0.13 million, respectively.

The computed seismic risk in this study will increase the perception of the general public, policymakers, and structural engineers about the seismic threat to NCT of Delhi, and act as further guidance in effective risk management.

Keywords: Seismic Risk; SELENA; OpenQuake; New Delhi; NCT; Seismic Loss

1. Introduction

Assessment of seismic risk in a region initially involves the estimation of seismic hazard from all the influencing source zone in and around it. The seismic hazard, which is generally expressed as 2% and 10% probability of exceedance of a hazard parameter in 50 years, corresponds to maximum credible earthquake (MCE) and design basis earthquake (DBE), respectively. Once the seismic hazard is assessed, the seismic risk is computed as a product of hazard and vulnerability of exposed structural and non-structural elements.

The study region, National Capital Territory (NCT) of Delhi, is in the proximity of ~50 km to Mahendragarh Dehradun Fault (MDF) and ~200 km to Himalayan plate boundary zone. Also, MDF and Himalayas have the potential to produce a maximum probable earthquake of 7.1 and 8.5, respectively. Further, the study region is surrounded by alluvial plain formed due to the Yamuna river, a high population of around 19 million, ~5 million exposed buildings, and rapid growth in construction and industry. Hence, NCT of Delhi is taken up for assessing the risk.

There are quite a few hazard assessment works for Delhi region in literature. Iyengar and Ghosh [9] expressed hazard for Delhi city in terms of PGA contour maps for a return period of 2500 years with a self-derived attenuation relationship. Agrawal and Chawla [10] estimated seismic hazard for Delhi in terms of 10% probability of exceedance of PGA in 50 years employing [11-13, 9] attenuation relationships which are old and not applicable for Delhi. Mohanty et al [14] predicted PGA for Mw 8.5 at five locations in Delhi using recordings of the 1999 Chamoli earthquake. The maximum PGA in their work varied between 140 to 210 gals for a hypothetical earthquake of Mw 8.5. Sarkar and Shanker [15] reported seismic hazard maps for a return period of 475 and 2475 years with an emphasis that the eastern region of Delhi has the highest seismic hazard with maximum values of spectral acceleration between 0.1-0.3 s period by employing a built-in attenuation relationship, Youngs et al [16] within CRISIS2007.

The inferences from the literature review reveal that proper attenuation relationships, which are an essential requirement in seismic hazard assessment, were either not available or considered that are applicable outside India. In this work, four latest attenuation relationships [17-20] applicable for Indo-Gangetic plains (NCT Delhi is a part of it) are selected to compute seismic hazard at nine districts of NCT Delhi. Employing the computed hazard values, the seismic risk is computed in terms of building damage probability, economic losses, and casualties.

2. Seismic Hazard and Risk

The seismic hazard for NCT of Delhi is computed in this study by considering three influencing zones around the Delhi region. Zone 1 and 2 corresponds to the seismic activity from western and central Himalayas, respectively, and zone 3 covering the local influencing faults. Fig. 1 shows the demarcation of three influencing seismic zones for the study region. The seismicity parameters for these zones acquired from literature are reported in Table 1. One of the essential steps in hazard analysis is to select reliable GMPE, which is applicable to the study region. Hence, region-specific attenuation relationships applicable for NCT of Delhi [17-20] are selected for computing hazard levels for 2% and 10 % probability of exceedance in 50 years, which corresponds to Maximum Credible Earthquake (MCE) and Design Basis Earthquake (DBE). These GMPEs are scripted into the OpenQuake Platform, and probabilistic seismic hazard analysis (PSHA) is conducted. The intensity measures predicted were Peak Ground Acceleration (PGA) and Spectral Acceleration (SA) at 25 periods

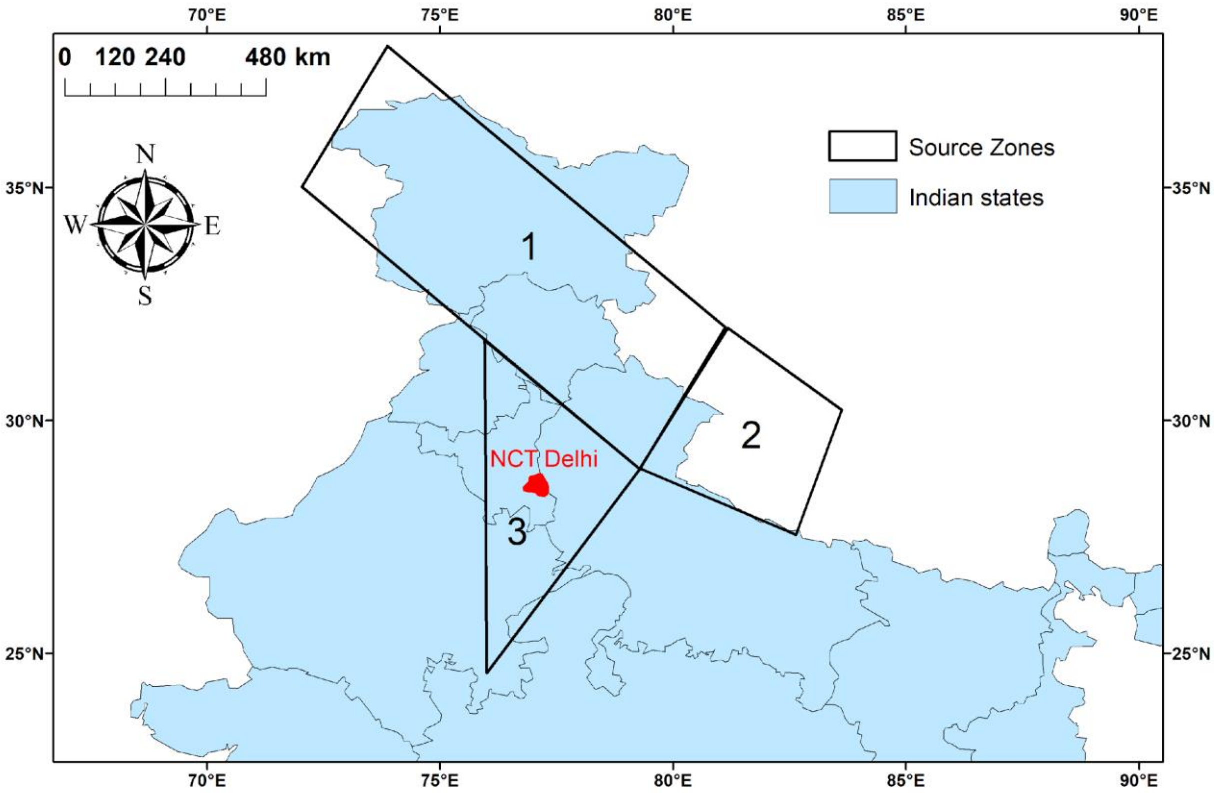

Fig. 1 – Influencing source zones for NCT of Delhi. The red shaded region denotes the study region

Table 1 – Seismicity parameters of influencing zones

S.No.	Region	a	b	M_{max}	Reference
1	Western Himalayas	5.37	0.86	8.8	NDMA (2011)
2	Central Him-1	3.15	0.69	7.8	
3	Aravali-Bundelkhand	2.79	0.69	7.2	Nath et al. (2019)

Earthquake risk estimation studies with site-specific hazard spectrum at nine districts of NCT Delhi have been computed for the first time to the best of author's knowledge. The study region is strongly influenced by the Himalaya collision zone north and northeast of Delhi and few local active faults. The soil beneath NCT Delhi, characterized by poor soils, also makes the region seismically critical, as the sediments not only amplify the ground motions but also make foundations vulnerable to liquefaction.

2.1 Seismic demand

Seismic demand for the study region is obtained from the uniform hazard spectrum (UHS) for each district from the PSHA analysis in OpenQuake. The SA values (g) at 0.0, 0.1, 0.2, 0.3, 0.5, 0.75, 1.0, 1.5, and 2.0 s are taken from the UHS for 2475 years return period, corresponding to MCE level. Soil amplification is addressed using the Vs30 parameter, which was obtained from [21]. Amplification due to topography is neglected, as the NCT of Delhi is comprised of flat territory with a slope < 10^{o}.

2.2 Building inventory and population

The building details and population information of the study region are obtained from the Census of India (2011). The population density across districts is represented in Fig. 2. From [22], building inventory details by predominant material used for roof and walls are combined to categorize into ten broad classes (Tables 2). These building classes (10 types) and their nomenclature along with replacement cost of each building in rupees is obtained from the previous work of authors [23] and reported in Table 3. The buildings are categorized into ten classes for assigning vulnerability functions based on the material and type of construction followed.

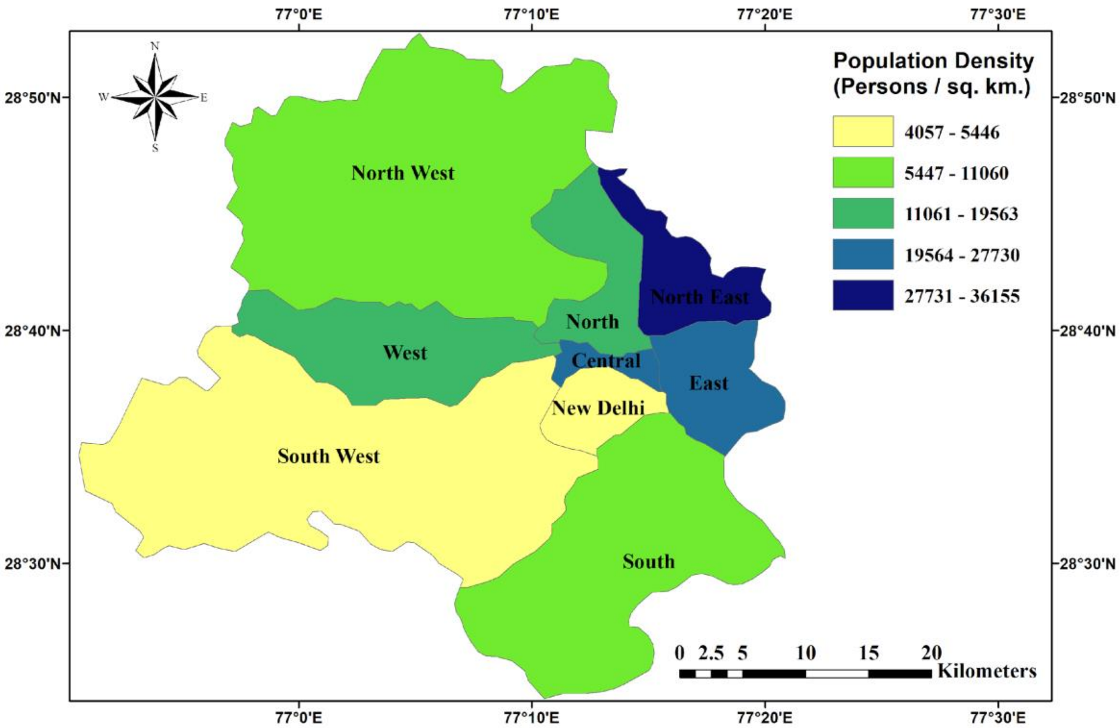

Fig. 2 – Map view of population density across nine districts of Delhi

2.3 Vulnerability functions

HAZUS-MH database provides fragility functions for different model building classes that are useful for computing damage probability and socio-economic losses. As the construction methodologies for building inventory in India vary noticeably from buildings of the United States (US), fragility functions recommended in HAZUS-MH [24] cannot be applied directly. Analytical capacity and fragility functions shall be meticulously chosen since they will bear a substantial impact on the risk and loss results [25]. The capacity and fragility functions (Vulnerability functions) of the 10 Model Building types (MBTs) are obtained from [26-29], as reported in Table 5 of [23].

Table 2 Distribution of Houses in NCT Delhi (Census 2011) to Standard Model Building classes adopted from [30]

Total Houses/ households	Distribution of households by predominant material of the wall									
32924266	Grass, Thatch, Bamboo, Plastic, Polythene, Wood, Mud, Unburnt bricks, etc.	Stone Packed with mortar	Burnt Bricks					Concrete		
% of Households	4.5	3.7	86.3					5.5		
Distribution based on the material of Roof	NIL	NIL	Grass, Thatch, Bamboo, Wood, Mud, Plastic, Polythene, others, etc.	Tiles: Handmade and Machine made	Stone/ Slate	Bricks	G.I, Metal, Asbestos Sheets	Concrete	NIL	NIL
% of Households	4.5	3.7	2.1	0.9	23.4	4.2	5.6	63.8	25	75
Model Building Type (MBT) classification	AM11, AM21	AL11, AL21, AL31, AC11, AC21, AC31	MM11, MM21, MM31	ML11, ML21, ML31	ML12, ML22, ML32	MC11, MC21, MC3L1	MC12, MC22, MC3L2	MC3M	RC1L	RC1M
% of Total Houses	4.5	3.7	1.8	0.8	20.2	3.6	4.8	55.1	1.4	4.1
MBT code	AMM	ALC	MMB	BTR	BSR	BCM	BMS	BCS	RCL	RCM

Table 3 Classification of each Model Building class along with their replacement cost selected in the study [25] (10 in total)

Model Building Class	Nomenclature	Replacement cost in Rupees, per m^2
AMM	Adobe Mud Mortar walls with Temporary roof	4500.0
ALC	Adobe lime and cement Mortar walls with Temporary roof	4500.0
MMB	Mud Mortar Bricks with Temporary roof	8937.5
BTR	Bricks and tiles roof	8937.5
BSR	Bricks and stone roof	8937.5
BCM	Bricks in cement mortar for walls and roof	8937.5
BMS	Bricks wall with metal sheet roof	8937.5
BCS	Bricks wall with concrete slab	10350.0
RCL	Reinforced wall and slab-low rise	10350.0
RCM	Reinforced wall and slab-medium rise	10350.0

3. Results and Discussions

Seismic hazard for NCT of Delhi is computed for 2% and 10% probability of exceedance in 50 years, covering nine districts of the study region. Fig. 3 depicts the seismic hazard in terms of PGA and SA at 0.2 and 1.0 s as map view. The hazard levels are high for SA at 0.2 s compared to other periods, which denotes the vulnerability of low-rise building to earthquakes in NCT Delhi. Also, west, northwest and southwestern districts of Delhi have higher hazard levels compared to other regions. Further, high-rise buildings are more vulnerable in the north and north east districts. These computed intensity levels are utilized for evaluating risk in NCT Delhi.

Figure 4 emphasizes the average damage probability of ten model building types across all districts, for five damage states: None, Slight, Moderate, Extensive, and Complete. The figure confirms that out of ten building types, four (AMM, MMB, BTR, BSR) have more than 40% probability of complete damage for a maximum credible earthquake. The high damage probability for these building classes, comprising of 29.2% of buildings, is due to the temporary type of construction, which need immediate retrofitting / replacement measures to curb financial cost and human losses. Understandably, the building types RCL and RCM are dominated by slight and moderate damage respectively, as they are made of reinforced concrete.

Economic losses computed for nine districts reveal that the northwestern district has high economic losses due to close proximity to the Himalayan collision zone. For a MCE (2% in 50 years) and DBE (10% in 50 years), the economic losses might be 130 and 31 billion USD, respectively. Similarly, the total human losses are about 0.13 and 0.02 million, respectively, out of which 68% of casualties occur when an earthquake hits late hours, at 2:00 AM (Fig. 5).

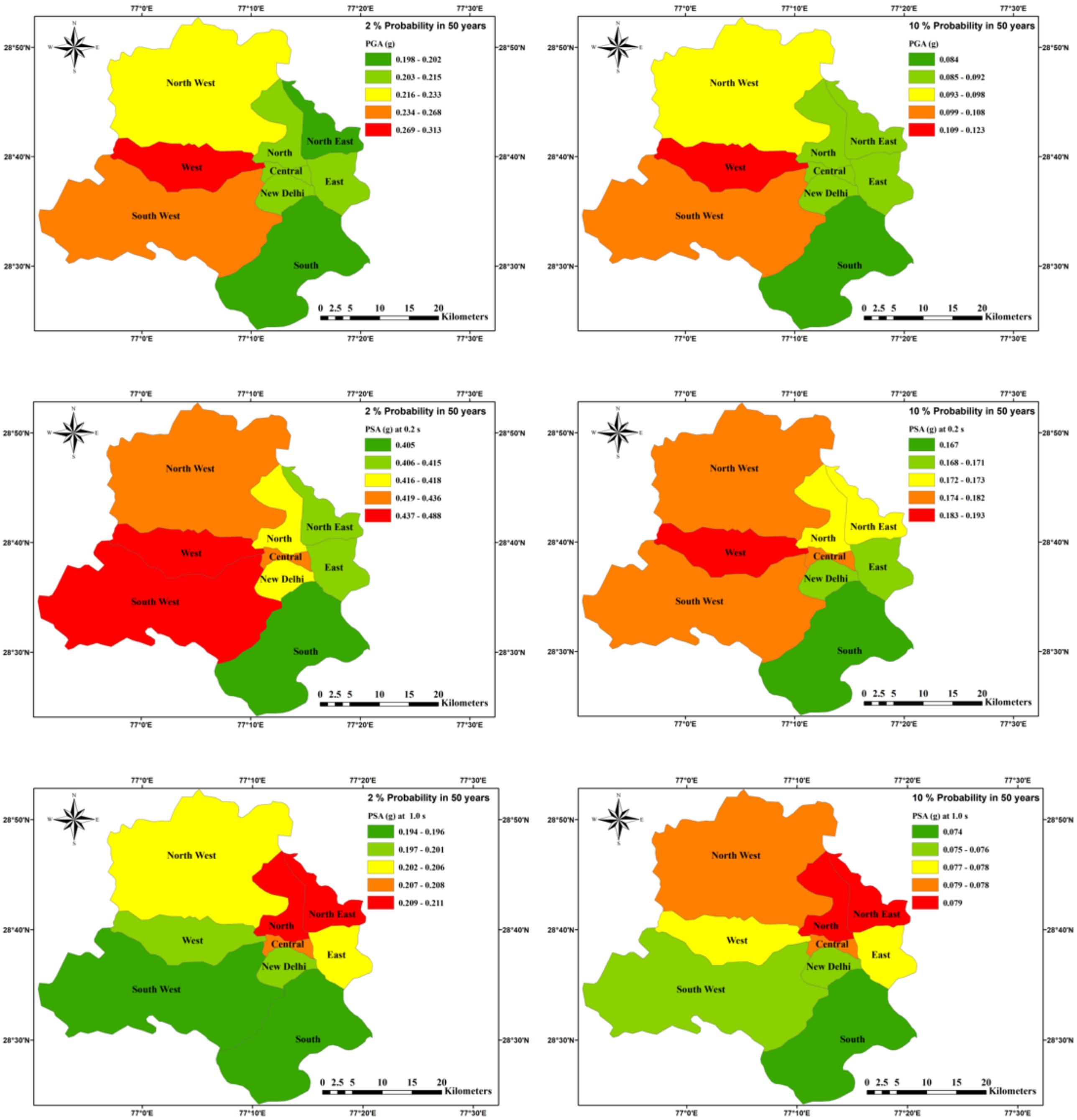

Fig. 3 – Seismic hazard distribution across nine districts of the study region in terms of PGA, SA at 0.2 and 1.0 s, for return periods of 475 and 2475 years

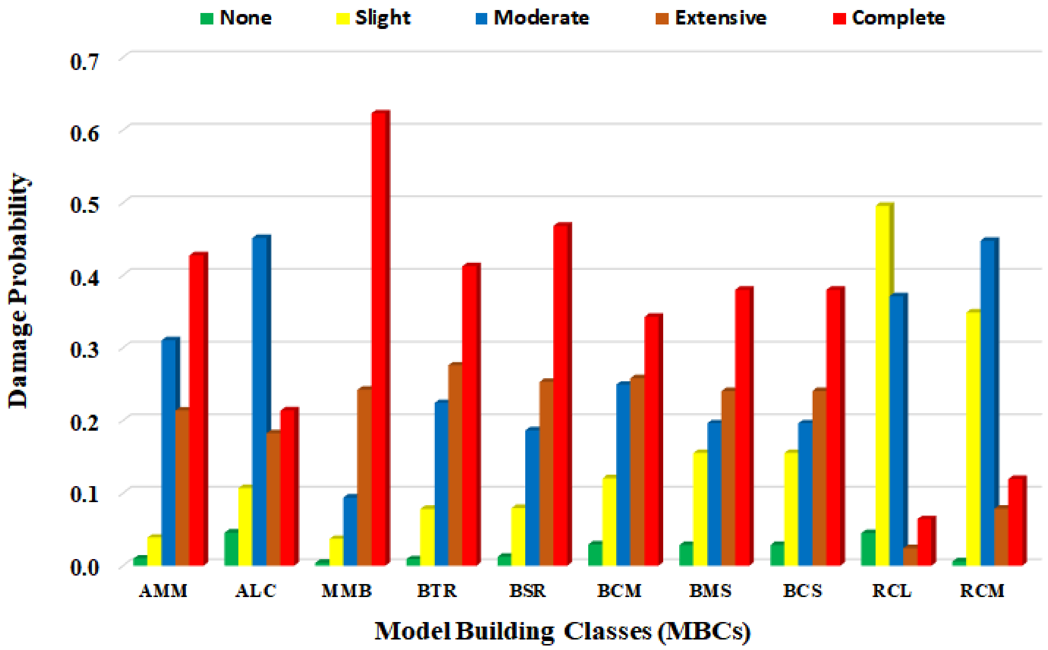

Fig. 4 – Histogram plot showing the damage probability of each model building class adopted in this study for MCE at five damage states: None, Slight, Moderate, Extensive and Complete

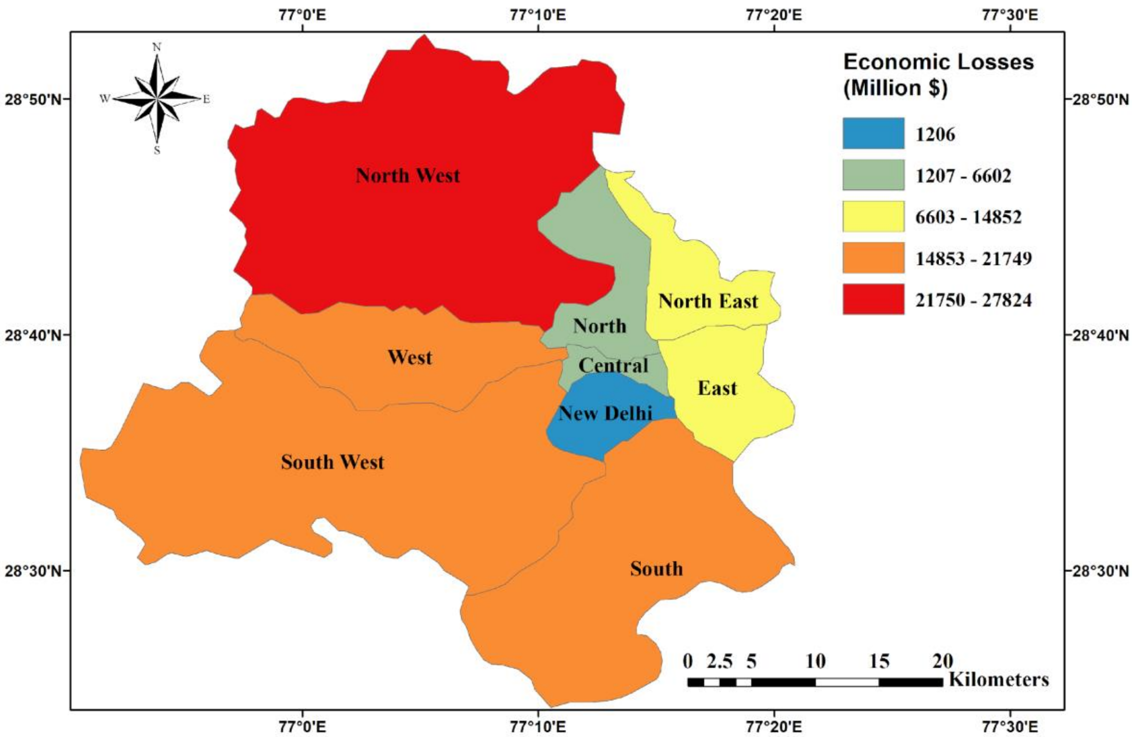

Fig. 5 – Economic losses for a MCE across nine districts of NCT Delhi with maximum losses occurring in the northwestern district

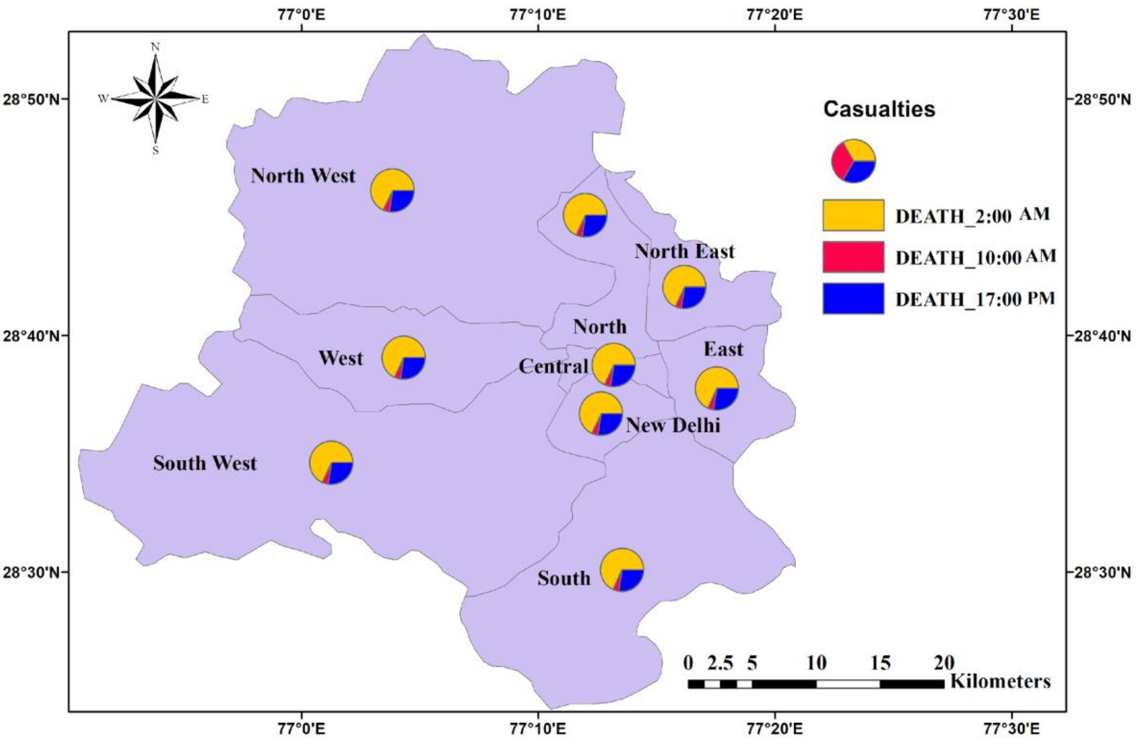

Fig. 6 – Human casualties for MCE in terms of pie diagram at 2 AM, 10 AM and 5 PM in a day

4. Conclusions

Site-specific seismic hazard in terms of PGA and SA (5% damping) for a return period of 475 and 2475 years is computed at the district level in NCT of Delhi. These results are utilized for computing risk at all nine districts of the study region.

Earthquake loss estimation studies from the computed site-specific hazard in this work serve as an initial attempt in assessing the damage probability of residential buildings at the district level in NCT Delhi. The key findings for effective disaster mitigation are as follows:

- Nearly 30 % of the buildings under model building types AMM, MMB, BTR, BSR has more than 40% of complete damage in the capital. These building types need immediate attention. Further, from this study, it was predicted that 38% and 6% of total buildings might collapse for MCE and DBE, respectively.
- For a DBE and MCE, the expected economic losses might vary from 31 to 130 billion USD, and human losses might vary between 0.02 and 0.13 million, respectively.

The computed seismic risk in this study will increase the perception of the general public, policymakers, and structural engineers about the seismic threat to NCT of Delhi, and act as further guidance in effective risk management.

5. Acknowledgments

Funding from the Ministry of Earth Sciences India through grant number MoES/P.O.(Seismo)/1(304)/2016 is greatly acknowledged.

6. Copyrights

7. References

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