12 Seismic Vulnerability and Risk Assessment of Kolkata

12.1 Introduction

Earthquakes are major menace to the mankind killing thousands of people every year in different parts of the globe. According to an estimate from National Geophysical Data Center (http://www.ngdc.noaa.gov), earthquakes during the last 100 years accounted for more than 1.9 million deaths. An estimated average of 17,000 persons has been killed every year. Seismic vulnerability in India is well evidenced by numerous past earthquake-related calamities *viz.* 1993 Killary earthquake of M_w 6.2, 1997 Jabalpur earthquake of M_w 5.8, 1999 Chamoli earthquake of M_w 6.8, 2001 Bhuj earthquake of M_w 7.7, 2005 Kashmir earthquake of M_w 7.6, and 2011 Sikkim earthquake of M_w 6.9. The 2001 Gujarat earthquake inflicted a total economic loss of about US $4600 million approximately. The memory of the tsunami-genic 2004 Sumatra earthquake of M_w 9.1 that wiped out more than 2,27,000 lives is still very fresh. According to the Vulnerability Atlas of India published by the Building Materials and Technology Promotion Council, more than 59% of the total landcover of the country is susceptible to seismic hazard (BMTPC, 1997). On the one hand, unplanned urbanizations are expanding rapidly across the country to accommodate the burgeoning population. The fatalities in the urban agglomerations due to future great Himalayan earthquakes have been predicted to be around 150 & 200 thousands (*e.g.* Wyss, 2005; Bilham *et al*., 2001). Dunbar *et al*. (2003) put the maximum expected earthquake loss in the country to be about US $350-650 million for the next 50 years at 10% probability of exceedance.

The Kolkata metropolitan city is one of the most densely populated regions in the world and being a major business and industrial hub of east and northeast India supports vital industrial and transportation infrastructures. The population of Kolkata was 1.5 million in the year 1901 that increased to 11 million in 1991 and to a phenomenal increase to 14 million as per the Census report of 2011. Due to enormous population pressure it has encroached into the back swamp and marshy land to the east filling up extensive areas, especially in the Saltlake and Rajarhat regions and many more in an unplanned manner. More than 80% of the City has built-up areas with high rise residential buildings, congested business districts, hospitals and schools *etc.* (Nandy, 2007), some of which are very old and are in the dilapidated condition with unplanned construction adhering to non-seismic safety standards. Demography in some parts of the City exhibits population density above 100,000 per square kilometer. Figure 12.1 depicts the urban sprawl in the study region with typical urban attributions.

The metropolitan city is placed at the margin of Seismic Zones III and IV as per the seismic zoning map of India (BIS, 2002). Sitting on a sedimentary basin of 7.5 km thickness above the crystalline basement it is highly vulnerable to earthquake disasters. The City was affected by the near- and far- sources like Bihar-Nepal seismic zone in the Central Seismic Gap, Assam Seismic Gap, Shillong Plateau, Andaman-Nicobar seismic province, Bengal Basin, and the N-E Himalayan extent (discussed in greater details in Chapters 1 and 4). It is, therefore, apparent that earthquake catastrophes are waiting to happen anytime in the near future unless preventive measures are urgently taken towards disaster mitigation and management. Thus, the vulnerability analysis of the city of Kolkata has been undertaken in the present study that involves multi-criteria risk evaluation through thematic integration of contributing vulnerability components *viz.* demography, landuse/landcover (LULC), building typology, building age and building height.

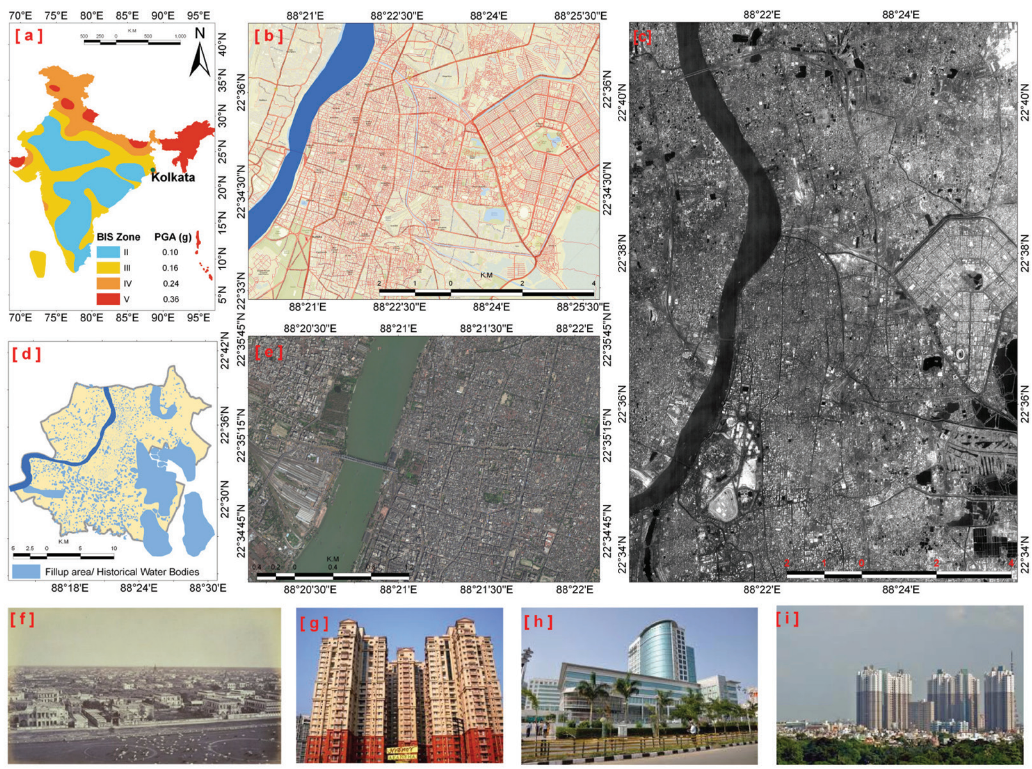


Figure 12.1 **Kolkata, the study region of the present investigation: (a) Seismic Zonation of India (BIS, 2002), (b) Road network of central part of the City, (c) Cartosat-1 DEM (2011) represents the dense urban settlement of central Kolkata and Saltlake region, (d) Fill-up area/historical water bodies captured from Landsat MSS (1973) and the available Historical maps (Rumsey, 1800 & 1958 available at http://www.davidrumsey.com), (e) GEO-eye (http://www.esri.com/data/basemaps) image of central Kolkata, and (f-i) Representative old structure, skyscraper, steel structure, multistoried structures of the City.**

The number of fatalities due to an earthquake is associated with the vulnerability of local buildings, population density and the intensity of ground shaking. Vulnerability Exposure refers to all man-made facilities namely, the residential, commercial and industrial buildings, schools, hospitals, roads, bridges, pipelines, power plants, communication network *etc.* When exposed to seismic hazard an eventual seismic risk is predicted. The seismic hazard is generally assumed to be stable over a long geological time while the typical vulnerability (and, therefore, the risk) to the hazard changes (McGuire, 2004). The risk is assessed as a convolution function of the hazard and the vulnerability, *i.e.* Risk = Hazard * Vulnerability. For the safety and sustainability of urban regions, it is, therefore, imperative to implement long-range urban planning and risk assessment mechanisms that rely heavily on accurate and multidisciplinary urban modeling. Therefore, the decisions to mitigate seismic risk require a logical but robust approach as given in HAZUS (1999) and RADIUS (2000) for evaluating the effects of future earthquakes on both the people and infrastructure. In the present investigation, we proposed an alternative approach based on information extracted from Satellite Imagery, Google Earth and Rapid Visual Screening for a broader estimation of socio-economic and structural vulnerability of the city of Kolkata and its seismic risk thereof. The protocol consists firstly of Seismic Hazard Microzonation involving the division of a region into sub-regions considering different hazard themes *viz.* (i) Probabilistic Peak Ground Acceleration at the surface, (ii) Liquefaction Potential Index, (iii) NEHRP Soil Site Class, (iv) Sediment Class, (v) Geomorphology, (vi) Geology, and (vii) Ground Water Table integrated on a hierarchical framework with the assignment of appropriate weights to each theme and associated ranks to the features in each theme. Each hazard theme and the Probabilistic Seismic Hazard Assessment at surface consistency level have been described in greater details in Chapters 8 and 11. Secondly, the development of socio-economic and structural seismic vulnerability exposures *viz.* population density, building typology, building height, landuse/landcover, building age *etc.* using remote sensing and GIS comprises an integral component which is used to develop socio-economic and structural seismic risk themes as vector layers in GIS through the integration of seismic hazard microzonation with socio-economic & structural vulnerability elements of exposure.

The spatial distribution of different vulnerability and risk entities are generated on a GIS platform and subsequently integrated through Analytical Hierarchal Process (AHP) (Saaty, 1980). The ultimate goal of both the socio-economic and structural seismic risk analyses is to develop the elements that can be used for urban seismic safety. Thus, the study of seismic hazard microzonation of the cities and the urban centers enable in characterizing potential seismic vulnerability/risk that needs to be taken into account while designing new settlement and lifeline facilities or retrofitting the existing ones. The risk appraisals, aimed at promoting reasonable hazard mitigation regulations, are generally based on vulnerability aspects such as socio-economic aspects of landuse and demographic distribution and the structural aspects of building typology *etc.*

12.2 Vulnerability Exposures and Thematic Data Layer Preparation

Unplanned urbanization defying building codes are continuously increasing the earthquake vulnerability of Kolkata necessitating an assessment of the same by identifying those factors contributing to seismic risk in terms of socio-economic and structural aspects. To understand the vulnerability of the built-up environment and infrastructure, a spatial/non-spatial database of building typology, building height, building age, landuse/landcover, population density and lifeline utilities has been created. These elements at earthquake risk have been studied for different vulnerability level in the seismic hazard microzonation perspective. Vulnerability Index (VI) of different factors is calculated by defining an ordinal scale and overall vulnerability index maps of the study region have been prepared representing both the socio-economic and structural entities. Figure 12.2 depicts a framework for seismic vulnerability and risk assessment protocol for the city of Kolkata.

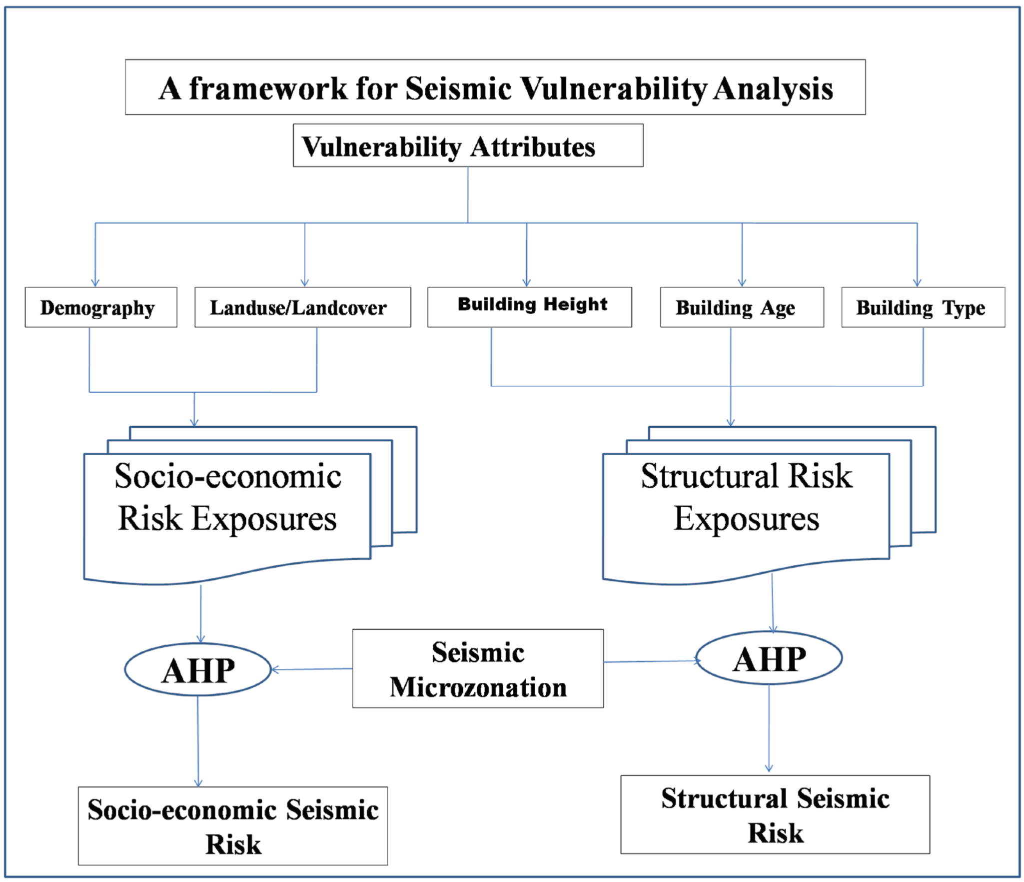
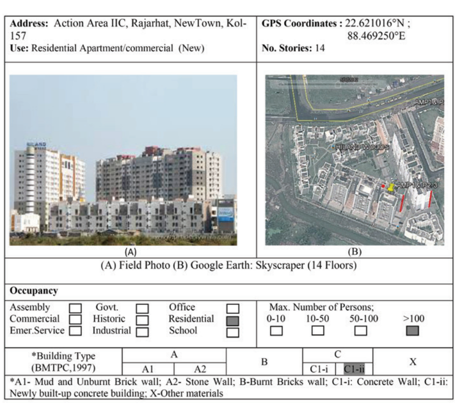


Figure 12.2 Seismic Vulnerability Assessment Protocol used in the present analysis.

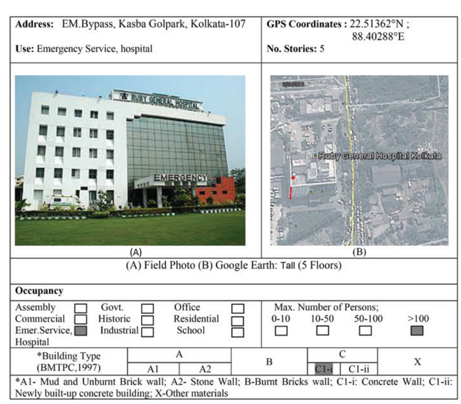
The most common way of representing the confidence level in the assessment of remote sensing data is in the form of computing an error matrix (Congalton, 1991). We derive error matrices for both the structural and socio-economic vulnerability exposures for comparisons. It is based on the widely used accuracy assessment technique of statistical correlations between two map data –one categorized from the Rapid Visual Screening (RVS) which we term as 'reference' and the other derived exclusively from remote sensing data which is termed as 'classified' (Story and Congalton, 1986; Jensen, 1996). The correlation indicators used in the present analysis include "overall accuracy" *i.e.* the percentage of matched data between the 'reference' and the 'classified' maps, "user's accuracy" *i.e.* the percentage of matched data in the 'classified' map, "producer's accuracy" *i.e.* the percentage of matched data in the 'reference' map, and the *kappa* value defining a measure of the differences between the 'reference' and the chance agreement between both the maps (Jensen, 1996; Congalton and Mead, 1983). The *kappa* value is expressed (Bishop *et al*., 1975) as

$$k = \frac{N\sum_{i=1}^{r} X_{ii} - \sum_{i=1}^{r}(X_{i+}X_{+i})}{N^2 - \sum_{i=1}^{r}(X_{i+}X_{+i})} \tag{12.1}$$

where, N is the total number of sites in the matrix, r is the number of rows in the matrix, X_{ii} is the number in row i and column i, X_{i+} is the total for row i, and X_{+i} is the total for column i. The *kappa* statistics >0.80 suggests 'strong' agreement, a value within a range of 0.60-0.80 suggests 'good' agreement and the chance of agreement is remote while *kappa* is close to 0 indicating 'poor' agreement (Landis and Koch, 1977). The 'Margfit' procedure has also been used on each error matrix through the application of a FORTRAN code "Margfit" available in Congalton (1991). The underlying methodology utilizes an iterative proportional fitting to conform to the sum of each row and column in the error matrix to a predetermined value. A normalized accuracy is calculated by summing the values on the major diagonal and dividing it by the sum of the total values in the normalized error matrix (Congalton and Green, 1999). As a result, both the producer's and user's accuracies have been incorporated in the normalized cell value which is based on a balanced effect of the two accuracy measures (Congalton and Green, 1999). In the present study, the structural and socio-economic vulnerability exposures derived from satellite imagery in case of building typology & landuse/landcover and that generated from Google Earth 3-D aspect for building height are used as 'classified' data while those derived through Rapid Visual Screening from 1200 survey locations being considered as 'reference' data have been used for the accuracy assessment of all the themes. For Rapid Visual Screening a hand held GPS (Global Positioning System) is used for coordinate generation at each of the 1200 locations and the survey is conducted on the vulnerability types as has been depicted in Figure 12.3 for sample RVS of building heights, building types and utility of urban structures in the City.


Address: Action Area IIC, Rajarhat, NewTown, Kol-157
Use: Residential Apartment/commercial (New)
GPS Coordinates : 22.621016°N ; 88.469250°E
No. Stories: 14

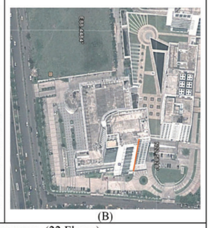
(A) (B)
(A) Field Photo (B) Google Earth: Skyscraper (14 Floors)
Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ■
Emer.Service ☐ Industrial ☐ School ☐
Max. Number of Persons; 0-10 ☐ 10-50 ☐ 50-100 ☐ >100 ■
*Building Type (BMTPC,1997): A (A1, A2); B; C (C1-i, C1-ii ■); X
*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials


Address: EM.Bypass, Kasba Golpark, Kolkata-107
Use: Emergency Service, hospital
GPS Coordinates : 22.51362°N ; 88.40288°E
No. Stories: 5

(A) (B)
(A) Field Photo (B) Google Earth: Tall (5 Floors)
Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☐
Emer.Service, Hospital ■ Industrial ☐ School ☐
Max. Number of Persons; 0-10 ☐ 10-50 ☐ 50-100 ☐ >100 ■
*Building Type (BMTPC,1997): A (A1, A2); B; C (C1-i ■, C1-ii); X
*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: DLF IT park,Thakdari Rd,BP Block, New Town **Use:** Commercial (New)	**GPS Coordinates :** 22.58248°N ; 88.44954°E **No. Stories:** 22


(A)


(B)

(A) Field Photo (B) Google Earth: Skyscraper (22 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;				
Commercial ■	Historic ☐	Residential ☐	0-10 ☐	10-50 ☐	50-100 ☐	>100 ■	
Emer.Service, ☐ Hospital	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ■	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Akankha, Action Area IIC, Rajarhkat, New Town, Kol-157 **Use:** Residential Apartment (New)	**GPS Coordinates :** 22.62167°N ; 88.46822°E **No. Stories:** 23


(A)

(B)

(A) Field Photo (B) Google Earth: Skyscraper (23 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;			
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Emer.Service, ☐ Hospital	Industrial ☐	School ☐				

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ■	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Sashi Sekhar Bose Road, Bhowanipore, Kolkata **Use:** Residential Apartment	**GPS Coordinates :** 22.53240° N ; 88.33875° E **No. Stories:** 4


(A)


(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;			
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ■	50-100 ☐	>100 ☐
Emer.Service, ☐ Hospital	Industrial ☐	School ☐				

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 15 Belverede Road, Sri Ram Garden Apartment, Alipore Kolkata-700027 **Use:** Residential Apartment	**GPS Coordinates :** 22.52685° N; 88.33220° E **No. Stories:** 14


(A)


(B)

(A) Field Photo (B) Google Earth: Skyscrapers (14 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;			
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Emer.Service, ☐ Hospital	Industrial ☐	School ☐				

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ■	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: The Calcutta Medical Research Institute, Kolkata **Use:** Emergency Services, Hospital	**GPS Coordinates :** 22.53277° N; 88.32852° E **No. Stories:** 10


(A)


(B)

(A) Field Photo (B) Google Earth: Multistoried Building (10 Floors)

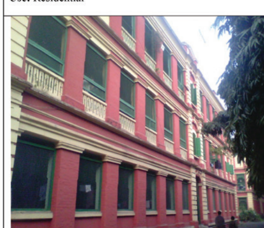
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;			
Commercial ☐	Historic ☐	Residential ☐	0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Emer.Service, ■ Hospital	Industrial ☐	School ☐				

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Port Quarter, Remount Road , Kolkata **Use:** Residential	**GPS Coordinates :** 22.52505° N; 88.32371° E **No. Stories:** 4


(A)


(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;			
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Emer.Service, ☐ Hospital	Industrial ☐	School ☐				

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B ■	C1-i	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: New Little Apartment HSG Co-Op. Society Ltd.140, J. K. Pal Rd, Kolkata-38
GPS Coordinates : 22.51045° N 88.32561° E
Use: Residential
No. Stories: 4


(A)

(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

Occupancy

				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ☐	10-50 ■	50-100 ☐	>100 ☐
Commercial ☐	Historic ☐	Residential ■					
Emer.Service, Hospital ☐	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: M. M. Memorial School,78 D, Pathak Para Rd, Behala, Azad Hind Vidhyalaya (High) Kol-60
GPS Coordinates : 22.50671° N 88.31572° E
Use: School
No. Stories: 4


(A)


(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

Occupancy

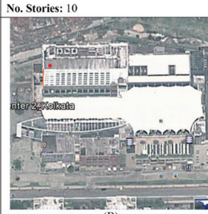
				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Commercial ☐	Historic ☐	Residential ☐					
Emer.Service, Hospital ☐	Industrial ☐	School ■					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: City Center 2 , Rajarhat, Kolkata
GPS Coordinates : 22.622321° N 88.449719° E
Use: Commercial
No. Stories: 10


(A)


(B)

(A) Field Photo (B) Google Earth: Multistoried Building (10 Floors)

Occupancy

				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Commercial ■	Historic ☐	Residential ☐					
Emer.Service, Hospital ☐	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ■	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: IIT Kharagpur extension centre, Salt lake, Sector 3.HC Block, Kolkata
GPS Coordinates : 22.57368° N 88.41779° E
Use: Residential
No. Stories: 4


(A)


(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

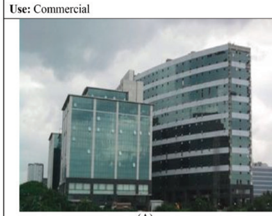
Occupancy

				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ☐	10-50 ☐	50-100 ■	>100 ☐
Commercial ☐	Historic ☐	Residential ■					
Emer.Service, Hospital ☐	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Godrej Waterside, IT park, Sector V, DP Block , Saltlake City, Kolkata
GPS Coordinates : 22.57399° N 88.43805° E
Use: Commercial
No. Stories: 25


(A)


(B)

(A) Field Photo (B) Google Earth: Skyscraper (25 Floors)

Occupancy

				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ☐	10-50 ☐	50-100 ☐	>100 ■
Commercial ■	Historic ☐	Residential ☐					
Emer.Service, Hospital ☐	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ■	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 40/3B, Ekbalpur Lane, Kolkata-23
GPS Coordinates : 22.53256° N; 88.32018° E
Use: Residential
No. Stories: 2


(A)


(B)

(A) Field Photo (B) Google Earth: Building (4 Floors)

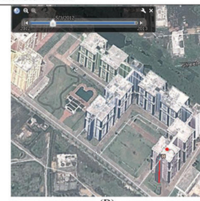
Occupancy

				Max. Number of Persons;			
Assembly ☐	Govt. ☐	Office ☐		0-10 ■	10-50 ☐	50-100 ☐	>100 ☐
Commercial ☐	Historic ☐	Residential ■					
Emer.Service, Hospital ☐	Industrial ☐	School ☐					

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ■	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: CE Block, Newtown, Kolkata
Use: Residential
GPS Coordinates : 22.57653° N 88.45336° E
No. Stories: 16


(A)

(B)

(A) Field Photo (B) Google Earth: Skyscraper (16 Floors)

Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☒
Emer.Service, ☐ Industrial ☐ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ☒	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: CE Block, Newtown, Kolkata
Use: Residential
GPS Coordinates : 22.57744° N 88.45505° E
No. Stories: 16


(A)

(B)

(A) Field Photo (B) Google Earth: Skyscraper (16 Floors)

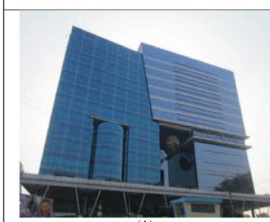
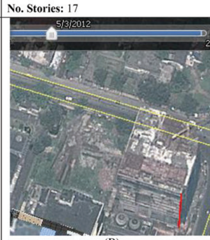
Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☒
Emer.Service, ☐ Industrial ☐ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ☒	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Sector V,Saltlake City, Kolkata
Use: Commercial
GPS Coordinates : 22.58047° N 88.43697° E
No. Stories: 17


(A)

(B)

(A) Field Photo (B) Google Earth: Skyscraper (17 Floors)

Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☒ Historic ☐ Residential ☐
Emer.Service, ☐ Industrial ☐ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i	C1-ii ☒	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: BEML ltd.35/1A,Taratala Road,Kolkata-88
Use: Industrial
GPS Coordinates : 22.51546° N 88.30794° E
No. Stories: 2


(A)

(B)

(A) Field Photo (B) Google Earth: Building (2 Floors)

Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☐
Emer.Service, ☐ Industrial ☒ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ☒	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Hindustan Unilever ltd,P-44,Hide Road, Kolkata-88
Use: Industrial
GPS Coordinates : 22.52061° N 88.30438° E
No. Stories: 1


(A)

(B)

(A) Field Photo (B) Google Earth: Houses (1 Floors)

Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☐
Emer.Service, ☐ Industrial ☒ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ☒	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Jayshree Tea & Industrial ltd,P7,Transport Rd, Kolkata-88
Use: Industrial
GPS Coordinates : 22.52066° N 88.31174° E
No. Stories: 2


(A)

(B)

(A) Field Photo (B) Google Earth: Building (2 Floors)

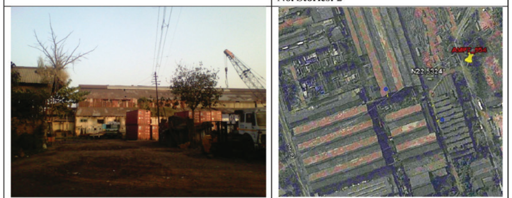
Occupancy
Assembly ☐ Govt. ☐ Office ☐
Commercial ☐ Historic ☐ Residential ☐
Emer.Service, ☐ Industrial ☒ School ☐
Hospital

Max. Number of Persons; 0-10	10-50	50-100	>100
☐	☐	☐	☒

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2		C1-i ☒	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Industrial Area, Sonai Road, Kolkata
Use: Industrial
GPS Coordinates : 22.53262° N 88.30519° E
No. Stories: 2



(A) Field Photo (B) Google Earth: Building (2 Floors)

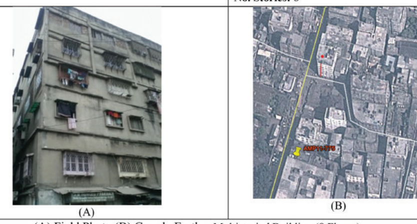
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ☐	Historic ☐	Residential ☐	0-10 ☐	10-50 ☐	50-100 ☐
Emer.Service, Hospital ☐	Industrial ■	School ☐	>100 ■		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2 (■)	B (■)	C1-i	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 427/1,G.T.Road,(North) Howrah-711101
Use: Residential
GPS Coordinates : 22.59195° N 88.33826° E
No. Stories: 8



(A) Field Photo (B) Google Earth: Multistoried Building (8 Floors)

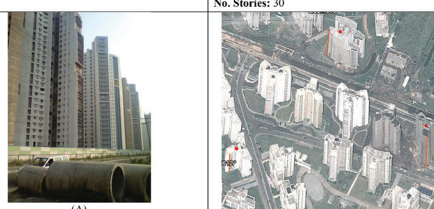
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ☐
Emer.Service, Hospital ☐	Industrial ☐	School ☐	>100 ■		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B	C1-i (■)	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: Uniworld City,Newtown, Kolkata
Use: Residential
GPS Coordinates : 22.56280° N 88.49188° E
No. Stories: 30



(A) Field Photo (B) Google Earth: Skyscraper Building (30 Floors)

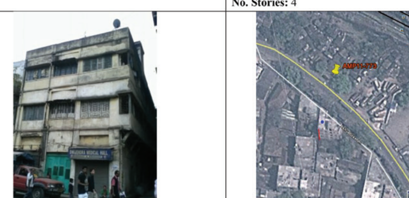
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ☐
Emer.Service, Hospital ☐	Industrial ☐	School ☐	>100 ■		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B	C1-i	C1-ii (■)	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 106,Ashubose Lane, Howra-711101
Use: Residential
GPS Coordinates : 22.59607° N 88.32976° E
No. Stories: 4



(A) Field Photo (B) Google Earth: Building (4 Floors)

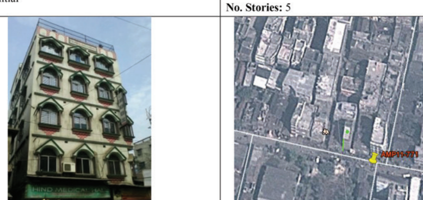
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ■
Emer.Service, Hospital ☐	Industrial ☐	School ☐	>100 ☐		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B	C1-i (■)	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 112,Belilious Road,Howrah-711101
Use: Residential
GPS Coordinates : 22.59207° N 88.32963° E
No. Stories: 5



(A) Field Photo (B) Google Earth: Tall Building (5 Floors)

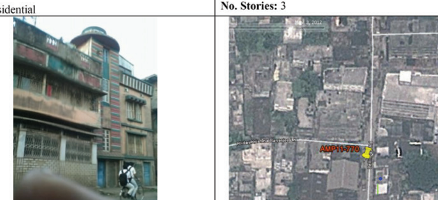
Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ■	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ■
Emer.Service, Hospital ☐	Industrial ☐	School ☐	>100 ☐		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B	C1-i (■)	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Address: 178,Belilious Road, Howrah.(Opposite Venus Steel Corporation)
Use: Residential
GPS Coordinates : 22.59304° N 88.32405° E
No. Stories: 3



(A) Field Photo (B) Google Earth: Building (3 Floors)

Occupancy

Assembly ☐	Govt. ☐	Office ☐	Max. Number of Persons;		
Commercial ☐	Historic ☐	Residential ■	0-10 ☐	10-50 ☐	50-100 ■
Emer.Service, Hospital ☐	Industrial ☐	School ☐	>100 ☐		

*Building Type (BMTPC,1997)	A		B	C		X
	A1	A2	B	C1-i (■)	C1-ii	

*A1- Mud and Unburnt Brick wall; A2- Stone Wall; B-Burnt Bricks wall; C1-i: Concrete Wall; C1-ii: Newly built-up concrete building; X-Other materials

Figure 12.3 **Rapid Visual Screening (RVS) survey (at about 1200 sites) for field and Google Earth comparisons of existing building height/building type in Kolkata for seismic vulnerability assessment.**

The key issue for studying the earthquake vulnerability and seismic risk of urban areas is the availability of maps and statistical information that concern the infrastructure of urban centers (Sarris *et al*., 2010). For the best possible assessment of the vulnerability exposures and hence risk of an earthquake prone district, it is necessary to gather maximum possible information such as the ones proposed for the HAZUS risk assessment model that require detailed inputs on structural configuration in terms of design, shape, height & number of stories, building proximity, lateral strength, stiffness, ductility, foundation, material and its construction practice *etc*. (Sarris *et al*., 2010). The focus is definitely on building-specific study from building inventory of group of buildings with similar characteristics and classification. However, in the present investigation, we proposed an alternative approach based on information extracted from Satellite Imagery, Google Earth and Rapid Visual Screening for a broader estimation of socio-economic and structural vulnerability of the city of Kolkata and its seismic risk thereof.

12.2.1 Demography

India has highly populous cities and second most populous country in the world, located in zones of high seismic risk. India's urban population has grown tremendously in the last five decades from 79 million in 1961 to 1.221 billion in 2011. The last census count in 2011 reveals that about 28 percent of the population in India is urban. Population vulnerability exposure can easily be estimated with the help of census data, which will normally provide the average number of persons per parcel/ward and also relation to building types. Total population, population density, female population, age-wise population below 7 and above 65, day and night time population, illiterate and unemployment population are more vulnerable to earthquake disaster.

The advent of the British raj and the prospect of trade gave an impetus to the growth of Kolkata's population, which was estimated between 10,000 and 12,000 inhabitants in 1710. In 1831 it was 187,081 with 70,076 houses, increasing to 229,714 in 1837 and 415,063 in 1850. The decennial growth of urban population in Kolkata was 22 percent in 1981 and 33.7 percent in 1991 while the decennial population growth rate in the State of West Bengal was 24.7 percent in 1981-91 and the average urban population growth rate was 29.5 percent during the same time period. The flow of migration from other states and from within the state of West Bengal to Kolkata is increasing due to the concentrated development in business outsourcing, information technology, information technology enabled services, medical transcription *etc.* Urban population of India, West Bengal and Kolkata during the last five decades is presented in Table 12.1.

Table 12.1 **Urban population of India, West Bengal and Kolkata during 1961-2011 (Urban Statistics, TCPO, 2011)**

No.	Years	Urban Population (in millions)		Kolkata (Urban Area)
		India	West Bengal	
1	1961	78.16	8.54 (10.93)	5.98 (70.02)
2	1971	107.82	10.97(10.17)	7.42 (67.64)
3	1981	159.46	14.45(9.06)	9.19 (63.60)
4	1991	217.61	18.71(8.60)	11.03(58.95)
5	2001	285.36	22.43(7.86)	13.21(58.89)
6	2011	377.16	22.43 (7.86)	14.51(58.96)

The population of Kolkata increased from 1.5 million in 1901 to 14 million in 2011 as illustrated in Table 12.2. The annual growth rate of population in Kolkata during the last century was 7.75 percent. The highest decadal growth of population in Kolkata was observed during 1941-51 at 69.34 percent and the lowest was in 1911-21 at 8 percent. After 1961 the growth rate of population in Kolkata has been declining as shown in Table 12.2. Growth of population not accompanied by proportionate increase in areas has resulted in an increase in population density in the City. Consequently land prices also witnessed a substantial rise. About one third of the population of Kolkata lives in slums. Figure 12.4 depicts the decadal change in the total population and slum population in Kolkata.

Table 12.2 Growth of urban population in Kolkata during 1901-2011 (Population of Urban area and Towns, TCPO, 2011)

No.	Years	Population	Difference	% Increase
1	1901	1510008	-	-
2	1911	1745198	235190	15.58
3	1921	1884584	139386	7.99
4	1931	2138563	253979	13.48
5	1941	3621413	1482850	69.34
6	1951	4669559	1048146	28.94
7	1961	5983669	1314110	28.14
8	1971	7420300	1436631	24.01
9	1981	9194018	1773718	23.90
10	1991	11021918	1827900	19.88
11	2001	13205697	2183779	19.81
12	2011	14112536	906839	7.6

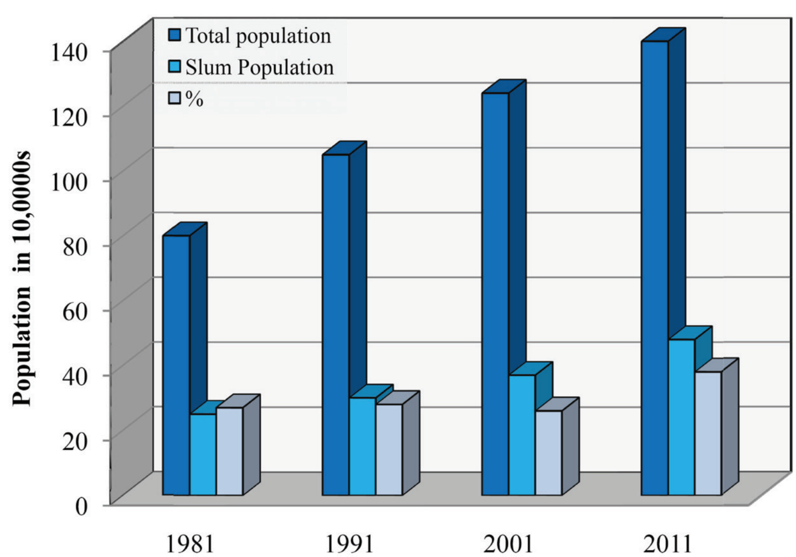
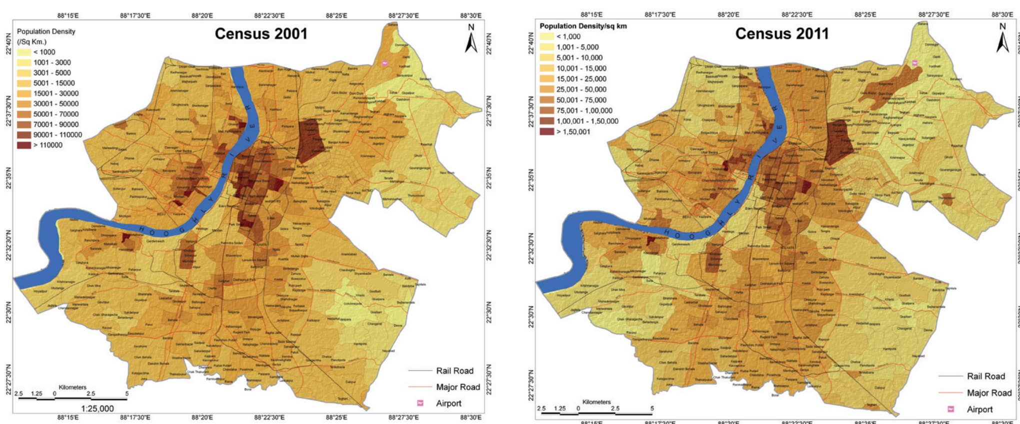


Figure 12.4 Decadal Change in the Total population and Slum population in Kolkata.

Density of population is another important indicator that can be used for analyzing the pace of development. Table 12.3 presents the density of population in Kolkata and West Bengal during 1991 to 2011. The population density in Kolkata per km^2 in 1961 was 28,144 and in 1971 and 1981 was 30,279 and 31,615 respectively. Figure 12.5(a & b) depicts the population density map of Kolkata after 2001 & 2011 census data respectively. From Figure 12.5 it is observed that the population density is very high in the central Kolkata region like Barabazar, Taltala, Esplanade and Shyambazar.

Table 12.3 **Density of Population (Persons/km^2) in West Bengal and Kolkata during 1991 to 2011 (Census of India, 2011)**

No.	District/ State	1991	2001	2011
1	Kolkata	23783	24718	24252
2	West Bengal	767	903	1030



(a) (b)

Figure 12.5 **(a) Population Density map of Kolkata according to 2001 Census data, and (b) Population Density map of Kolkata according to 2011 Census data.**

12.2.2 Landuse/Landcover (LULC)

LULC provides information about the predominant urban land cover and socio-economic attributes that can be extracted by carrying out an object-oriented LULC classification on National Atlas and Thematic Mapping Organization (NATMO) nomenclature. LULC classes are mainly defined by the alignment of buildings, streets, agricultural land, vegetation, plantation, water body, open-spaces, forest *etc*. In the present study, LISS-IV and PAN 2010 data (NRSC data centre, ISRO) have been classified based on maximum likelihood method. LULC map of Kolkata is shown in Figure 12.6 that depicts nine major LULC units *viz.* residential commercial and industrial area, river/pond/water body/canal, plantation, open space, vegetation, swampy land, dry fallow land, cultivated land and arable land. The accuracy statistics between the RVS derived 'reference' and the LISS IV derived 'classified' maps presented in Table 12.4 establishes the confidence level of this thematic classification.

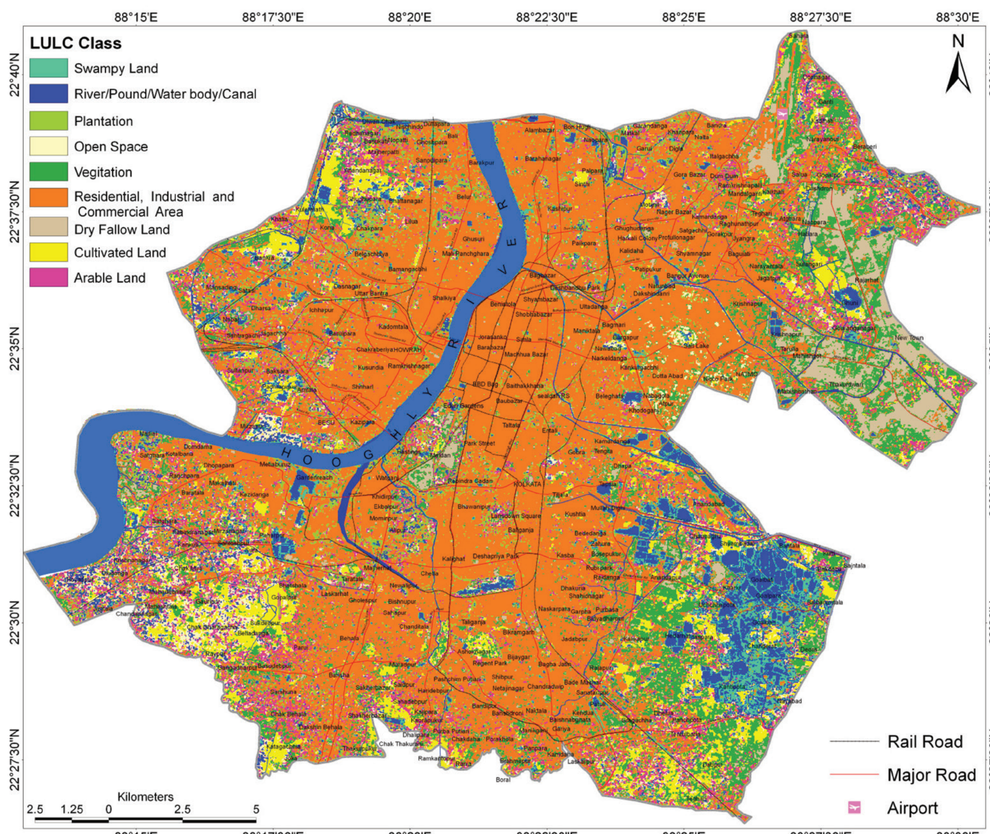


Figure 12.6 **Landuse/Landcover map of Kolkata generated using LISS IV and PAN imagery.**

Table 12.4 **Error matrix derived for landuse/landcover mapping in Kolkata**

Satellite Image (LISS-IV) based LULC (classified data)	GPS based ground truth (reference data)											User's Accuracy (%)
		RCIA	RPWC	PL	OS	VG	SL	DFL	AL	CL	Total	
	RCIA	452	0	0	5	0	0	0	10	0	467	96.78
	RPWC	0	43	0	0	0	15	0	0	0	58	74.13
	PL	0	0	37	0	11	0	0	2	5	55	67.27
	OS	12	0	0	32	0	3	11	3	1	62	51.61
	VG	0	0	17	0	89	2	5	7	3	123	72.35
	SL	0	7	0	0	3	98	11	5	3	127	77.16
	DFL	0	0	0	5	0	0	37	9	3	54	68.51
	AL	17	0	0	3	5	7	13	71	18	134	52.98
	CL	0	0	2	1	9	3	5	11	85	116	73.27
	Total	581	50	56	46	117	128	82	118	118		
Producer's Accuracy (%)		93.97	86.00	66.1	78.0	76.0	76.6	45.1	65.7	72.0		
Overall Accuracy (%)										78.92		
Normalized Accuracy (%)										70.00		
Kappa value										0.733		
Kappa Variance										0.0002		

RCIA: residential commercial and industrial area; RPWC: river/pond/water body/canal; PL: plantation; OS: open space; VG: vegetation; SL: swampy land; DFL: dry fallow land; AL: arable land; CL: cultivated land.

12.2.3 Building Typology

Built-up regions are considered to be more vulnerable to seismic impact. The damage of a building depends on a number of factors including the method of construction, material type used, building configuration, age of the building, number of stories, size of the building *etc.* Seismic resistant capability of a building is closely related to its structural type. For the purpose of earthquake risk assessment of buildings, it is important to study the relation between the damage of a building and the seismic strength. So, a classification of seismic resistant capabilities of buildings must be made in accordance with their structures (BMTPC, 2006). It is very complicated to identify different types of structural construction such as building typology, building age, building height *etc.* For this purpose remotely sensed imagery is ideally used to monitor and detect landcover changes that occur frequently in urban and peri-urban areas as a consequence of incessant urbanization. Extraction of urban features is difficult due to the presence of mixed built-up areas. Moreover, when imaged with coarse spectral resolution, various urban materials produce almost similar spectral reflections. So it is difficult to separate one specific urban class of information from the other based on spectral characteristics. Thus, the demarcation of each and every building is quite subjective as it depends on an interpreter's ability of discrimination of one building from the other.

Through visual interpretation techniques, using image elements such as tone, texture, shape, size, shadow, pattern, association and location, the building footprint map can be prepared with the help of poor spectral and spatial resolution imageries. Landsat™ imagery has been used in this study because of its finer spectral resolution than other commonly used images such as SPOT and Multi-Spectral Scanner (MSS). However, LISS IV imagery has also been used for its finer spatial resolution and better enhancement of urban attributes. In the present study, we have performed PCA (Principal Component Analysis), Textural Analysis and Normalized Differences Building Index (NDBI) for the identification of building materials (Geneletti and Gortea, 2003; Lu and Weng, 2005; Zhang *et al*., 2002; Zha *et al*., 2003). The building materials have been categorized into 5 classes (A1-mud and unbrick wall, A2-stone wall, B-burnt bricks building/buildings of the large block and prefabricated type/building in natural hewn stone, C1-i concrete building and C1-ii newly built-up concrete building) are followed according to BMTPC (1997) and among them the use of reinforced concrete blocks is dominating the area as depicted in Figure 12.7. The accuracy statistics between the RVS derived 'reference' and the LISS IV 2010 & Landsat™ 2010 derived 'classified' maps have been presented in Table 12.5.

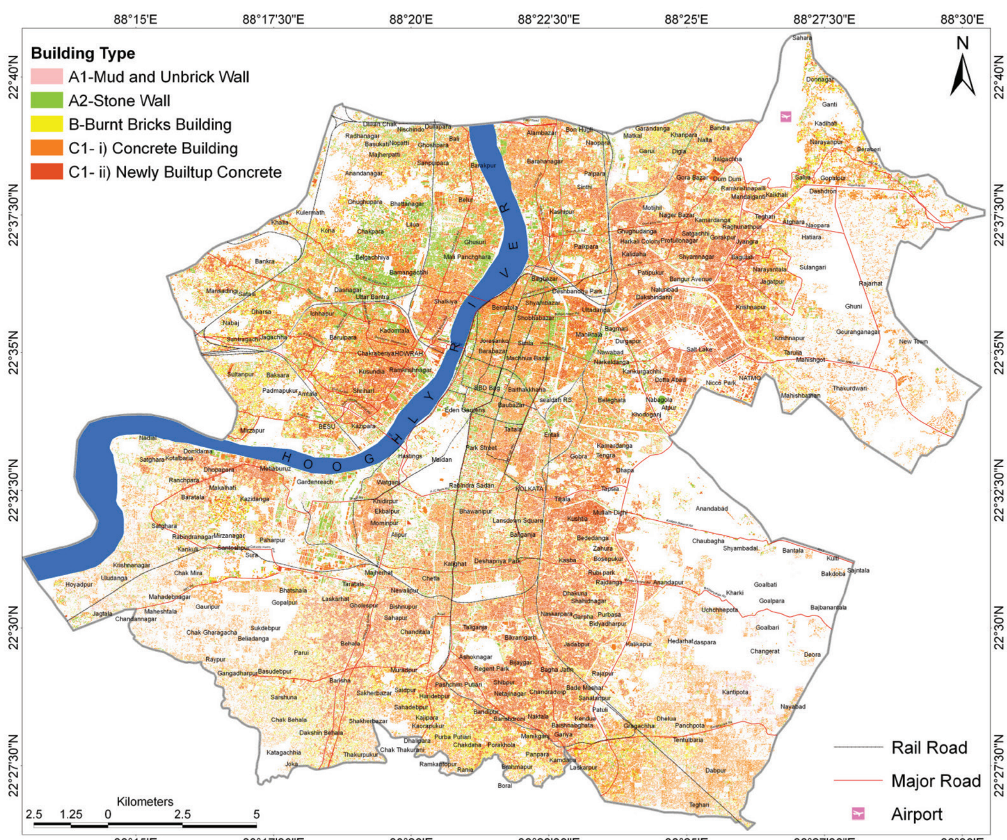


Figure 12.7 **Building Typology distribution map of Kolkata derived using LISS IV 2010 and Landsat™ 2010 imageries.**

Table 12.5 **Error matrix derived for building typology in Kolkata**

Satellite Image based building typology (classified data)	Rapid Visual Screening based building typology (reference data)							User's Accuracy (%)
		A1	A2	B	C1-i	C1-ii	Total	
	A1	105	29	19	11	7	171	61.4
	A2	27	128	25	15	11	206	62.1
	B	11	19	93	13	6	142	65.5
	C1-i	12	17	26	243	37	335	72.5
	C1-ii	5	9	13	42	271	340	79.7
	Total	160	202	176	324	332		
	Producer's Accuracy (%)	65.6	63.3	52.8	75.0	81.6		
	Overall Accuracy (%)							70.4
	Normalized Accuracy (%)							68.1
	Kappa value							0.61
	Kappa Variance							0.00028

A1-mud and unburnt brick wall; A2-stone wall; B- burnt bricks wall; C1-i: concrete wall; C1-ii: newly built-up concrete building.

The Vulnerability Curves for the observed damage due to 1934 Bihar-Nepal earthquake of M_w 8.1 (GSI, 1939) for RCC, Steel, Masonry and Non-engineered structures in Kolkata and adjoining region have been constructed following Sinha and Adarsh (1999) as presented in Figure 12.8.

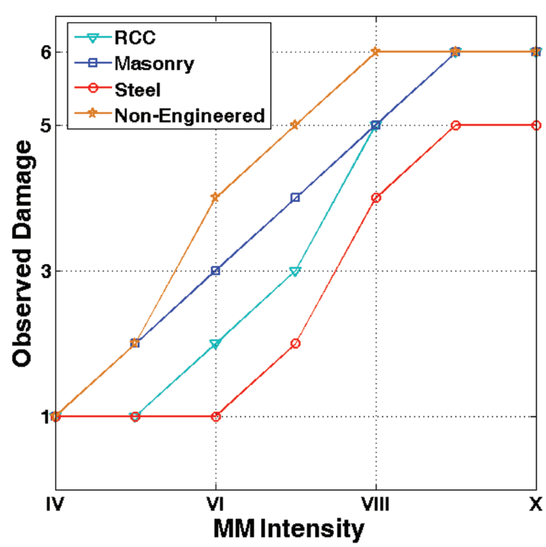


Figure 12.8 **Vulnerability Curves for observed damage inflicted by the 1934 Bihar-Nepal earthquake of M_w 8.1 (GSI, 1939) on various Building Typology in Kolkata and adjoining regions based on Sinha and Adarsh (1999).**

The growth of household and census houses in urban West Bengal was higher than Kolkata district during 1991-2001. The main reason behind this may be attributed to saturation level of population and census houses in Kolkata district or deficiency of area for the development. The population grew most rapidly in the early years of British rule, multiplying nearly tenfold during the 40 years from 1710 to 1750. Housing statistics shows that, although the population in the old town area increased by about 50 times, the number of houses increased only 11 times during the same period. It also appears that the increase in the number of houses during the 19th century was only 14 percent, although the population multiplied not less than 5 times. Even in the most modern times, buildings have multiplied at a much lower rate than the population. The enlargement of houses in length, width and altitude accommodated excess population to some extent. While pukka (solidly-built) buildings increased from 14,230 in 1821 to 38,574 in 1901, *i.e.* by 178 percent, and huts decreased from 53,289 to 49,007.The population density in the City increased due to the enlargement of the Calcutta Metropolitan Corporation (CMC) area (from 100 wards to 141 wards) and the subsequent urban development in the extended area. Standard of living of people in a particular area can be assessed on the basis of household by number of rooms occupied. This clearly reveals the development pattern of the area. The number of rooms occupied in Kolkata during the year 2001 is presented in Table 12.6.

Table 12.6 **Households by number of rooms occupied in Kolkata During 2001 (Households and amenities, census of India, Ministry of home Affairs, Government of India, 2001)**

No.	Rooms/Households	Kolkata	Percent
1	Non-Exclusive Room	11309	1.23
2	1 Room	459165	49.93
3	2 Rooms	227816	24.77
4	3 Rooms	122892	13.36
5	4 Rooms	52715	5.73
6	5 Rooms	16642	1.81
7	6 Rooms Plus	29144	3.17
Total Households		**919683**	**100.00**

12.2.4 Urban Growth/Building Age

Urban population of Kolkata has grown tremendously in the last four decades. This fast rate of increase in urban population is mainly due to large scale migration of people from rural and smaller towns to bigger cities in search of better employment opportunities and good life style. Remote Sensing imagery is ideally used for monitoring and detecting urban land cover changes that occur frequently in urban and peri-urban areas as a consequence of incessant urbanization (Zha *et al*., 2003). Landcovers in urban areas tend to change more drastically over a short period of time than elsewhere because of rapid economic development and urban sprawl. In the present study, the built–up areas were extracted from Landsat MSS (1975, 1980), TM (1985, 1990, 2005, 2010) and ETM (2000) classified images of seven different periods in order to monitor the dynamic changes in the urban sprawl (Small, 2002; Zhang *et al*., 2002). For this purpose, we used PCA and NDBI for the classification of built-up areas (Zha *et al*., 2003). Change detection analyses describe the differences between the images of the same scene at different periods of time. The building age/urban growth of Kolkata as depicted in Figure 12.9 have been estimated employing the change detection technique by using ERDAS IMAGINE 8.5 software package. For the map validation purposes we selected a sample block in the New Town financial and infrastructural hub of Kolkata where Landsat™ and Google Earth imageries of 2005 & 2010 have been considered as 'classified' & 'reference' data sets for both the categories for the assessment of urban growth and its allied error statistics. Figure 12.10 depicts the urban expansion during the period 2005-2010 based on both Landsat™ and Google Earth Imageries.

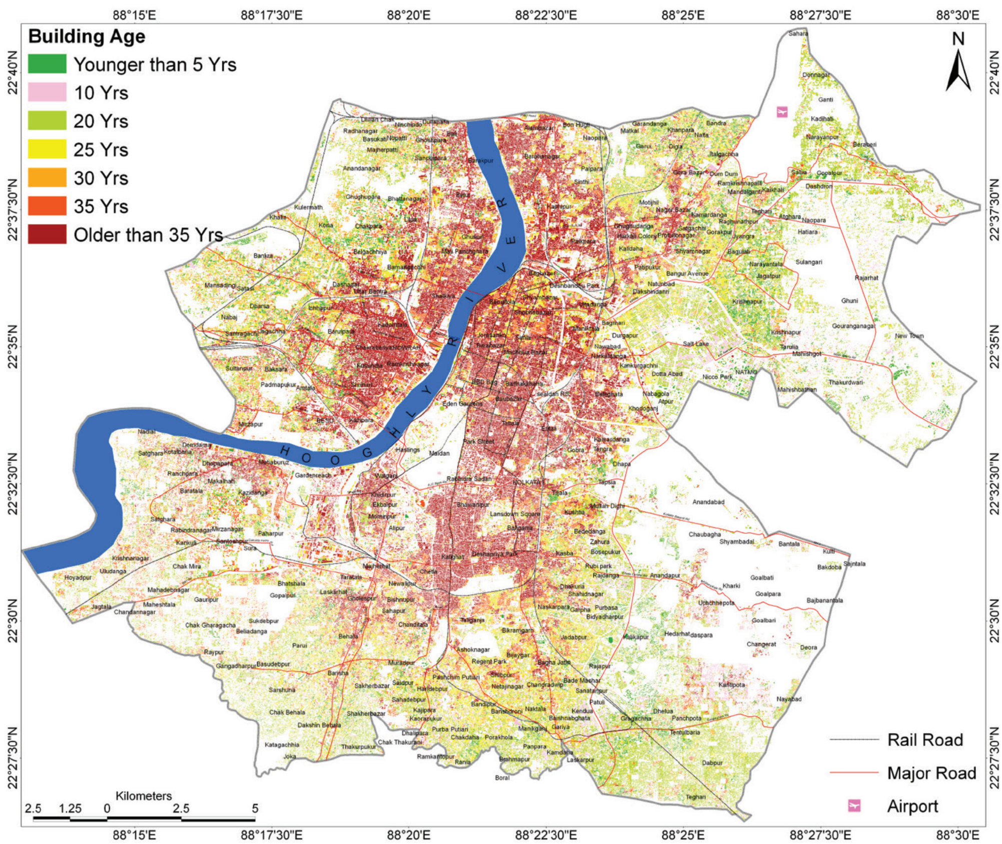


Figure 12.9

Building Age distribution map of Kolkata using multi-temporal Landsat MSS (1975, 1980), TM (1985,1990, 2005, 2010) and ETM (2000) data for the period of 1975-2010, wherein, the older buildings (>35 yrs) have been adopted from the "Atlas of the City of Calcutta & its Environs" (Kundu and Aag, 1996).

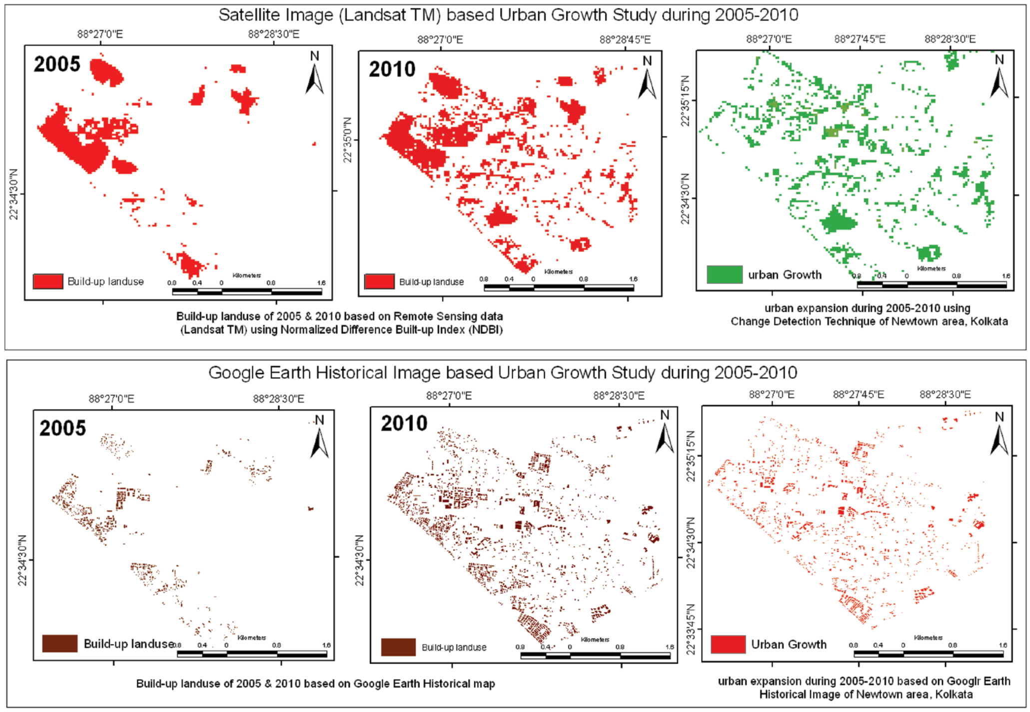


Figure 12.10 **Urban expansion during the period 2005-2010 based on both Landsat™ and Google Earth Imageries.**

The associated error matrix is given in Table 12.7. It has been observed that the optimal lifetime of structures in Kolkata is between 40-50 yrs. The urban expansion has been divided into seven clusters such as–younger than 5 yrs, 10 yrs, 20 yrs, 25 yrs, 30 yrs, 35 yrs and older than 35 yrs

Table 12.7 **Error matrix derived for building growth/age during 2005-2010 in New Town, Kolkata**

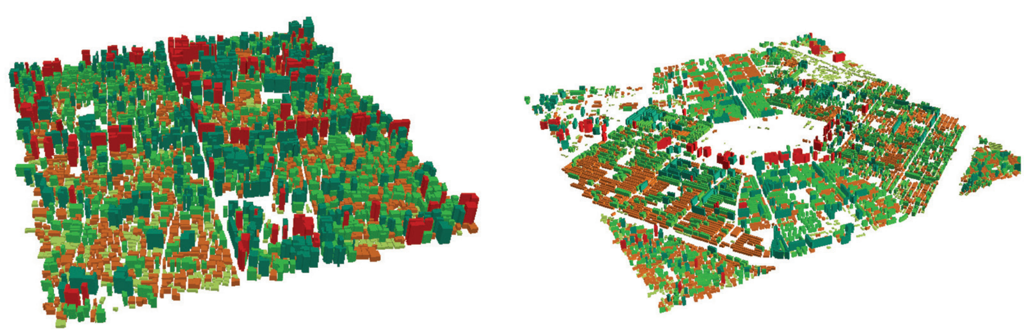
Urban Growth using Multi-temporal Landsat TM data (classified data)	Urban Expansion based on Google Earth Imageries (reference data)				User's Accuracy (%)
		High Expansion	Low Expansion	Total	
	High Expansion	678	69	747	90.7
	Low Expansion	93	281	374	75.1
	Total	771	350		

	Producer's Accuracy (%)	87.9	80.3		
	Overall Accuracy (%)				85.5
	Normalized Accuracy (%)				84.4
	Kappa value				0.67
	Kappa Variance				0.00056

as depicted in Figure 12.9. The older buildings (>35 yrs) have been adopted from the "Atlas of the City of Calcutta & its Environs" (Kundu and Aag, 1996). However, older buildings are likely to be vulnerable to severe damages and even subjected to total collapse under strong seismic excitations. There are many aged ill-conditioned, closely spaced structures in Kolkata which also seem to be highly vulnerable to seismic threat.

12.2.5 Site-Structure Quasi-resonance and Possibility of Damage

The response of a building to seismic shaking at its base depends on the design quality of construction. The most important factor is the height of the building. The type of shaking and the frequency of shaking depend on the structure as well as the site of its construction. The fundamental frequency of structures may range from about 2 Hz for a low structure up to about 4 stories and between 0.5-1 Hz for a tall building from 10-20 stories; thus the tall buildings tend to amplify the longer period motions compared to small buildings (Kramer, 1996). Each structure has a resonance frequency that is the characteristic of the building. Therefore, in developing the design strategy of a building, it is desirable to estimate the fundamental periods both of the building and the site on which it is to be constructed so that a comparison can be made to understand the possibility



(a) (b)

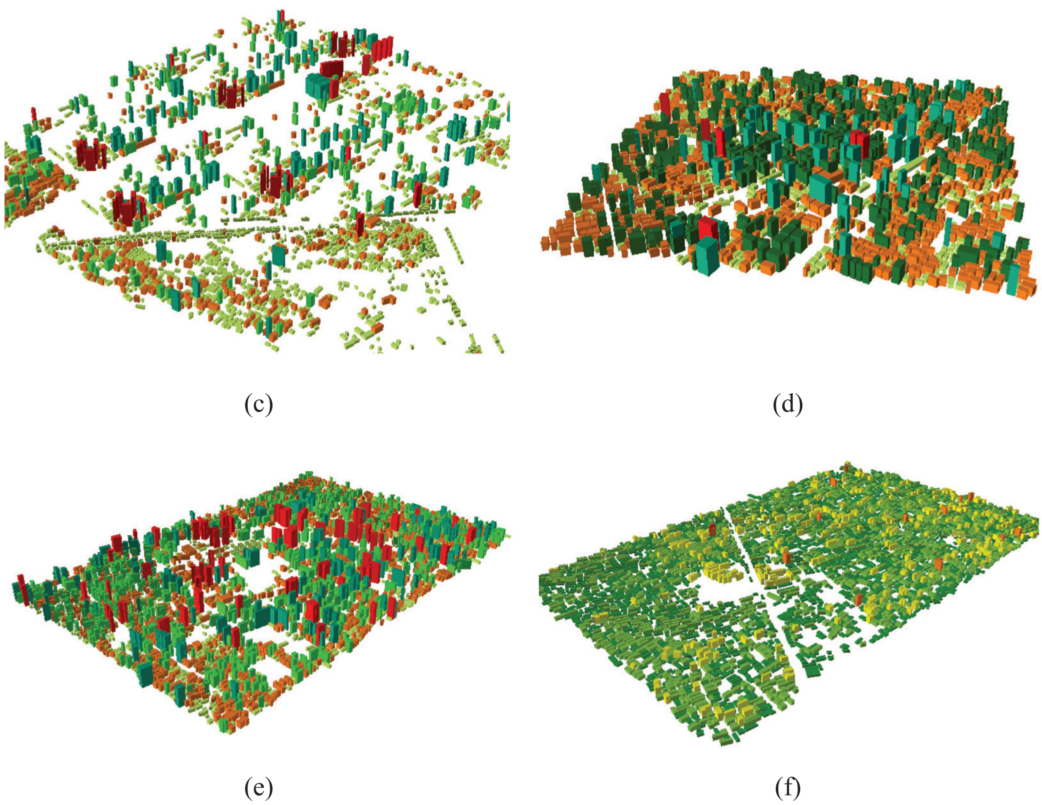


Figure 12.11 **3-D building footprint of (a) Central Kolkata, (b) Saltlake, (c) New Town, (d) South Kolkata, (e) Ballygunge, and (f) Howrah urban area.**

of quasi-resonance. In the present study, Google Earth has been used for visual identification of building height using 3-D aspect as depicted in Figure 12.11.

Google Earth image and about 1200 ground truth GCP have been used for visual identification of building height using 3-D aspect and its validation. In Figure 12.12 the building height map of Kolkata is presented. The accuracy statistics between the RVS derived 'reference' and the Google Earth derived 'classified' maps have been presented in Table 12.8.The building heights have been categorized into 5 classes: houses-1 floor, buildings-2 to 4 floors, tall buildings- 5 to 8 floors, multistoried buildings- 9 to 10 floors and skyscrapers >10 floors.

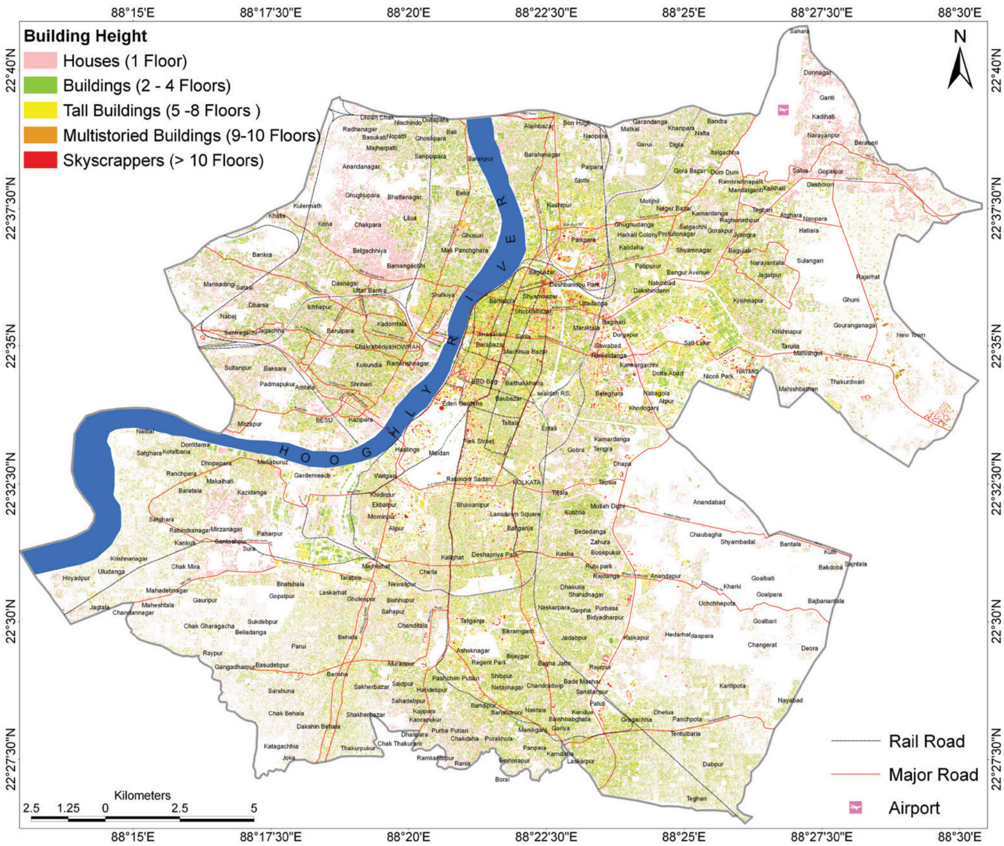


Figure 12.12 Building Height distribution map of Kolkata using Google Earth 2012 imagery.

Table 12.8 Error matrix derived for building height in Kolkata

Google Earth 3-D aspect based building height (classified data)	Rapid Visual Screening based building height (reference data)							User's Accuracy (%)
		Houses (1 Floor)	Buildings (2-4 Floors)	Tall (5-8 Floors)	Multistorie (9-10 Floors)	Skyscrapers (>10 Floors)	Total	
	Houses (1 Floor)	247	49	0	0	0	296	83.4
	Buildings (2-4 Floors)	55	298	27	0	0	380	78.4
	Tall Buildings (5-8 Floors)	0	29	195	19	0	243	80.2
	Multistoried Buildings (9-10 Floors)	0	0	10	128	24	162	79.0
	Skyscrapers (>10 Floors)	0	0	0	18	97	115	84.3
	Total	302	376	232	165	121		

Producer's Accuracy (%)	81.8	79.3	84.1	77.6	80.2		
Overall Accuracy (%)							80.6
Normalized Accuracy (%)							80.5
Kappa value							0.74
Kappa Variance							0.00022

Thereafter, the approximate fundamental natural period of vibration (T_a), in seconds, has been estimated by the empirical expression (BIS, 2002)

$$
\begin{aligned}
T_a &= 0.075h^{0.75} && \text{for RCC frame Building} \\
&= 0.085h^{0.75} && \text{for Steel frame Building} \\
&= \frac{0.09h}{\sqrt{d}} && \text{all other Buildings}
\end{aligned}
\tag{12.2}
$$

where, 'T_a' = Fundamental period of vibration in seconds, 'h' = Height of the Building in meters, 'd'= Base dimension of building at plinth level in 'meters' along the considered direction of the lateral force.

The site fundamental period has been estimated from both the microtemor H/V spectral ratio and the geotechnical analysis. The detailed site characterization of Kolkata has been discussed in Chapters 5 and 10. The H/V response curves obtained from the microtremor survey reflects the geology and soil properties of the test site. Ambient noise data acquired using SYSCOM MR2000 at 1200 locations in the City have been processed using VIEW2002 and GEOPSY software

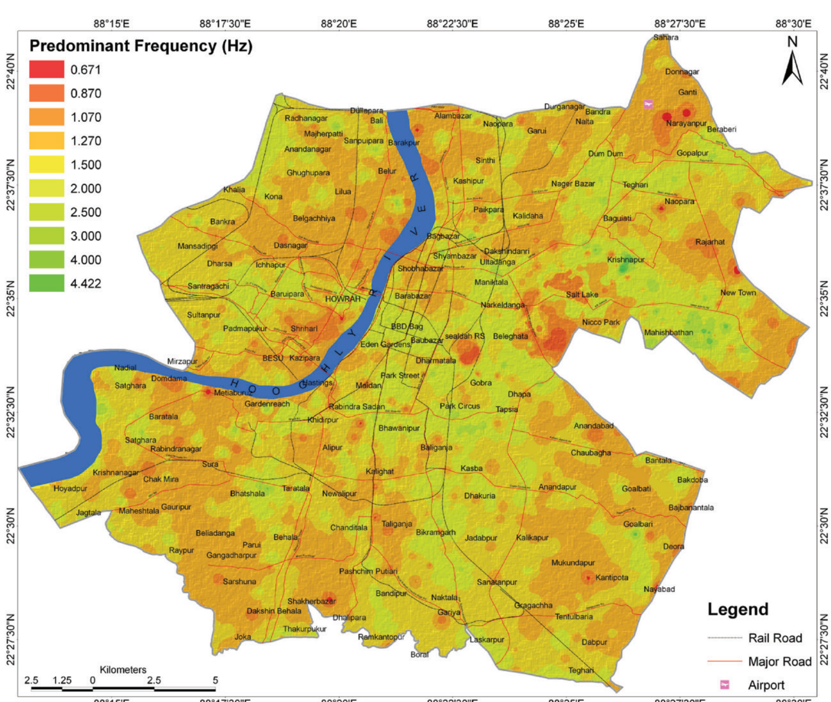


Figure 12.13 **Spatial distribution of Predominant Frequency in Kolkata as obtained from Ambient Noise Survey at 1200 locations and Geotechnical analysis at 654 locations.**

(www.geopsy.org). Apart from the Microtremor driven H/V spectral ratio, we have also performed site response analysis using geotechnical data at 654 locations through DEEPSOIL software to estimate the fundamental frequency of the site. The Predominant Frequency distribution map shown in Figure 12.13 is prepared on GIS platform exhibiting a variation between 0.67 Hz to 4.4 Hz.

The proximity of predominant frequency of the soil column and the natural frequency of life line facilities indicates higher vulnerability of the built-up environment owing to resonance effects (Nath and Thingbaijam, 2009). Normally, the natural period of vibration of any structure should not coincide with the predominant period of earthquake excitations, otherwise resonance may occur and even the strongest structure may collapse (BIS, 2002). Figure 12.14 represents the difference between the structure's natural period of vibration and the predominant period of the respective site indicating damage possibilities of existing structures/logistics due to the impact of an earthquake- the larger the difference the lesser is the possibility of destruction.

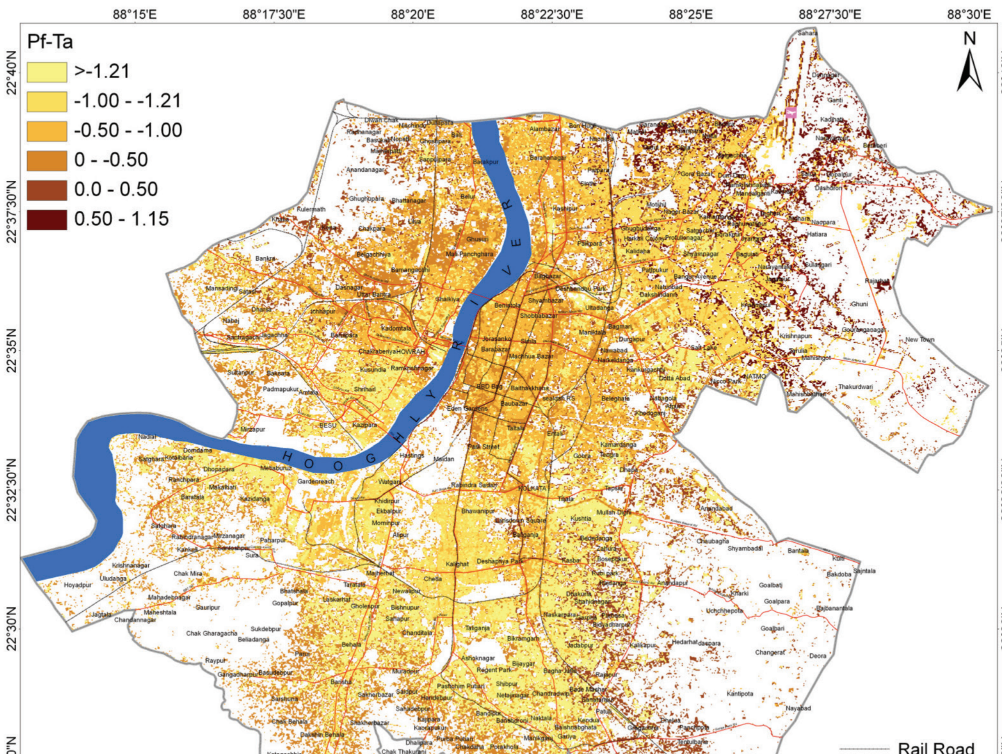


Figure 12.14 **The difference between the natural period of vibration of structure and the predominant period of the respective site indicating damage possibilities of existing structures/logistics.**

12.3 Multi-criteria Seismic Risk Assessment

Ishita and Khandaker (2010) performed seismic vulnerability assessment using AHP and GIS wherein various themes such as: building floors, building types, building age, resident population, population density, landuse/landcover *etc.* were used to evaluate seismic vulnerability. The steps usually followed in the vulnerability assessment are the identification of high risk areas by convolving Seismic Hazard Microzonation with vulnerability exposures in the GIS environment using AHP (Reveshty and Gharakhlou, 2009; Aghataher *et al*., 2008; Qunlin *et al*., 2013; Sarris *et al*., 2010). In the present study, the seismic hazard microzonation mapping is achieved through multi-criteria based decision support system formulated by Saaty (1980) as Analytical Hierarchal Process (AHP). The AHP method avails to investigate the consistency of judgments to determine the significance of relative weight of factors (Reveshty and Gharakhlou, 2009). To determine the degree of consistency in judgments a consistency ratio is also measured from the AHP matrix. In the present investigation AHP is used for the estimation of weights of various factors of vulnerability exposures for the computation of Risk Index (RI) in an attempt to generate a multi-criteria risk evolution protocol in both the socio-economic and structural perspectives. A combination of spatial/non-spatial exposures against earthquakes, the degree of vulnerability of each building element in terms of its typology, height and age, as also the socio-economic exposures have been measured.

Multi-criteria assessment of seismic hazard leading to seismic microzonation is the key factor to understanding the overall seismic risk of a region (Anbazhagan *et al*., 2010). The hazard themes pertaining to the study region materialized as thematic layers on the GIS platform are (i) Peak Ground Acceleration with 10% probability of exceedance in 50 years at surface, (ii) Liquefaction Potential Index, (iii) NEHRP Site Class, (iv) Sediment Class, (v) Geomorphology, (vi) Geology, and (vii) Ground Water Table fluctuation. The detailed seismic hazard microzonation attributes of Kolkata have been discussed in Chapter 11. In the present study ArcGIS 9.3 is used for the purpose of thematic mapping through vector layer generation and its spatial analysis.

12.3.1 Socio-economic Seismic Risk Assessment

The Socio-economic risk elements *i.e.* Population Density (PD) and Landuse/Landcover (LULC) are overlaid over the seismic hazard microzonation theme in GIS and integrated to demarcate the most vulnerable zones in view of socio-economic activities of the region. The Socio-Economic Risk Index (SERI) is calculated as

$$SERI = \left[SHM_w SHM_r + PD_w PD_r + LULC_w LULC_r \right] / \sum w \tag{12.3}$$

The ranks and weights for socio-economic vulnerability exposures over Seismic Hazard Microzonation are illustrated in Table 12.9. The concept of social vulnerability helps to identify those characteristics and experiences of individuals and communities that enable them to respond and to recover from earthquake hazards.

Table 12.9 **Normalized weights and ranks assigned to respective themes and the features of socio-economic risk attributes for thematic integration on GIS**

Themes	Weight	Attributes	Rating	Normalized Rating
Seismic Hazard Microzonation (SHM)	0.50	Low	1	0.0000
		Moderate	2	0.3333
		High	3	0.6666
		Severe	4	1.0000
Population Density (/km^2)	0.33	< 1,000	1	0.0000
		1,001-5,000	2	0.1111
		5,001-10,000	3	0.2222
		10,001-15,000	4	0.3333
		15,001-25,000	5	0.4444
		25,001-50,000	6	0.5556
		50,001-75,000	7	0.6667
		75,001-1,00,000	8	0.7778
		1,00,001-1,50,000	9	0.8889
		>1,50,000	10	1.0000
Landuse/Landcover	0.17	Water body, Pond, River, Canal	1	0.0000
		Open Space	2	0.1250
		Swampy Land	3	0.2500
		Dry Fallow Land	4	0.3750
		Vegetation	5	0.5000
		Plantation	6	0.6250
		Arable Land	7	0.7500
		Cultivated Land	8	0.8750
		Residential, Commercial and Industrial area	9	1.0000

The Socio-economic Seismic Risk map of Kolkata is depicted in Figure 12.15. Four broad divisions of Socio-economic Risk Index (SERI) have been identified with Risk Index (SERI) defined as 0.75<SERI≤1.0 indicating severe risk condition in BBD Bag, Saltlake, Kalidaha, Barabazar, Baguiati area, 0.50<SERI≤0.75 indicating high risk mostly in central Kolkata, 0.25<SERI≤0.50 moderate risk in most part of West and East Kolkata, while SERI<0.25 presents a completely risk free regime.

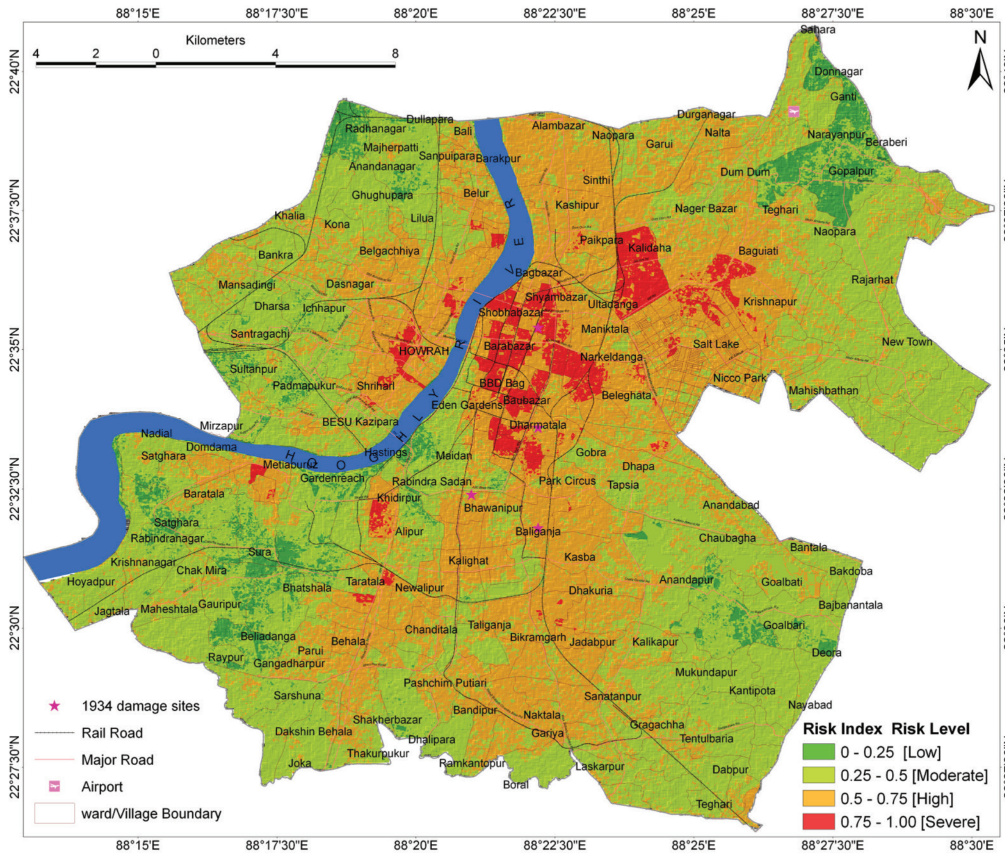
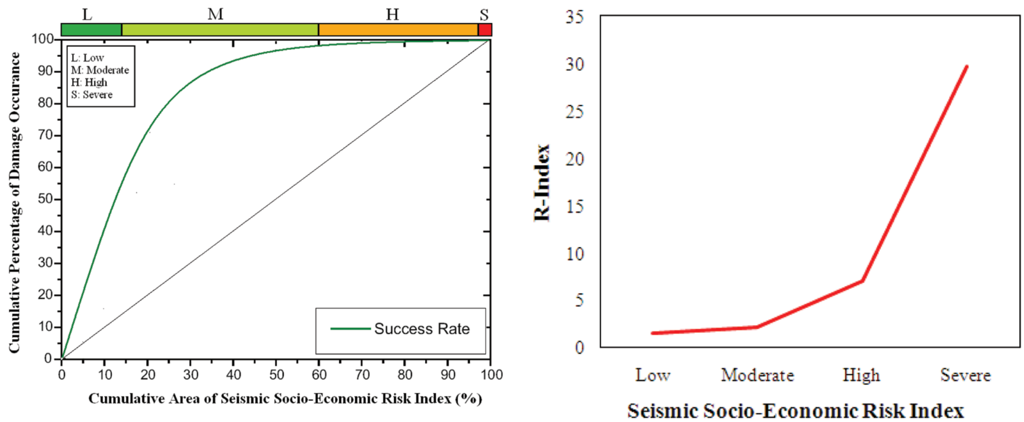


Figure 12.15 **Probabilistic Seismic Socio-Economic Risk Map of Kolkata. Four broad divisions have been identified with Risk Index (SERI) defined as: $0.75 < SERI \leq 1.0$ indicating severe risk condition in BBD Bag, Saltlake, Kalidaha, Barabazar, Baguiati area, $0.50 < SERI \leq 0.75$ indicating high risk mostly in central Kolkata, $0.25 < SERI \leq 0.50$ moderate risk in the most part of West and East Kolkata, while $SERI < 0.25$ presents a completely risk free regime. The damage distribution due to the 1934 Bihar-Nepal earthquake of M_w 8.1 (GSI, 1939) are identified in the High to Severe risk zone (marked by '★').**

Seismic Socio-Economic Risk Microzonation Map has been validated by the observed earthquake damage structures/sites corresponding to the risk levels using both the success rate curve and *R*-Index method as depicted in Figure 12.16(a & b). It is exhibited that the success rate curve and *R*-index increases with the level of socio-economic risk index. Thus it is concluded that the earthquake affected sites observed in these levels indicate consistency in socio-economic risk levels.



(a) (a)

Figure 12.16 **(a) Validation of Seismic Socio-Economic Risk map through success rate curve, and (b) Validation of Seismic Socio-Economic Risk map using R-index.**

12.3.2 Structural Seismic Risk Assessment

The structural risk elements namely Building Typology (BT), Building Height (BH) and Building Age/Growth (BA) have been integrated over the SHM depending on their contribution towards seismic vulnerability. The Structural Risk Index (SRI) due to the Structural Risk Exposures over the SHM are estimated as

$$SRI = \left[SHM_w SHM_r + BT_w BT_r + BH_w BH_r + BA_w BA_r\right] / \sum w \tag{12.4}$$

The ranks and weights for structural vulnerability exposures over Seismic Hazard Microzonation are illustrated in Table 12.10.

Table 12.10 **Normalized weights and ranks assigned to respective themes and the features of structural risk attributes for thematic integration on GIS**

Themes	Weight	Attributes	Rating	Normalized Rating
Seismic Hazard Microzonation (SHM)	0.40	Low	1	0.0000
		Moderate	2	0.3333
		High	3	0.6666
		Severe	4	1.0000

Themes	Weight	Attributes	Rating	Normalized Rating
Building Typology	0.30	A1-mud and unburnt Brick Wall	1	0.0000
		A2-stone wall	2	0.2500
		B-burnt bricks building	3	0.5000
		C1-i: concrete building	4	0.7500
		C1-ii: newly build concrete building	5	1.0000
Building Height	0.20	Houses (1 Floor)	1	0.0000
		Buildings (2-4 Floors)	2	0.2500
		Tall Buildings (5-8 Floors)	3	0.5000
		Multistoried Buildings (9-10 Floors)	4	0.7500
		Skyscrapers (>10 Floors)	5	1.0000
Building Age	0.10	Younger than 5 Yrs	1	0.0000
		10 Yrs	2	0.1667
		20 Yrs	3	0.3333
		25 Yrs	4	0.5000
		30 Yrs	5	0.6667
		35 Yrs	6	0.8333
		> Older than 35 Yrs	7	1.0000

To determine the most and least structural vulnerable areas, the SRI scores are mapped as <0.25 (low vulnerability) to ~1 (high vulnerability) as shown in Figure 12.17. Four broad divisions have been identified with Structural Risk Index (SRI) defined as 0.75<SRI≤1.0 indicating severe risk condition in Saltlake, Park Street, Kalidaha, Barabazar, Baguiati area, 0.50<SRI≤0.75 indicating high risk mostly in Behala, Dum Dum, Alipur, Jadavpur, Dhakuria region, 0.25<SRI≤0.50 moderate risk mostly in Bali, Kona, Kalighat and part of West Kolkata, while SRI<0.25 presents a completely risk free regime.

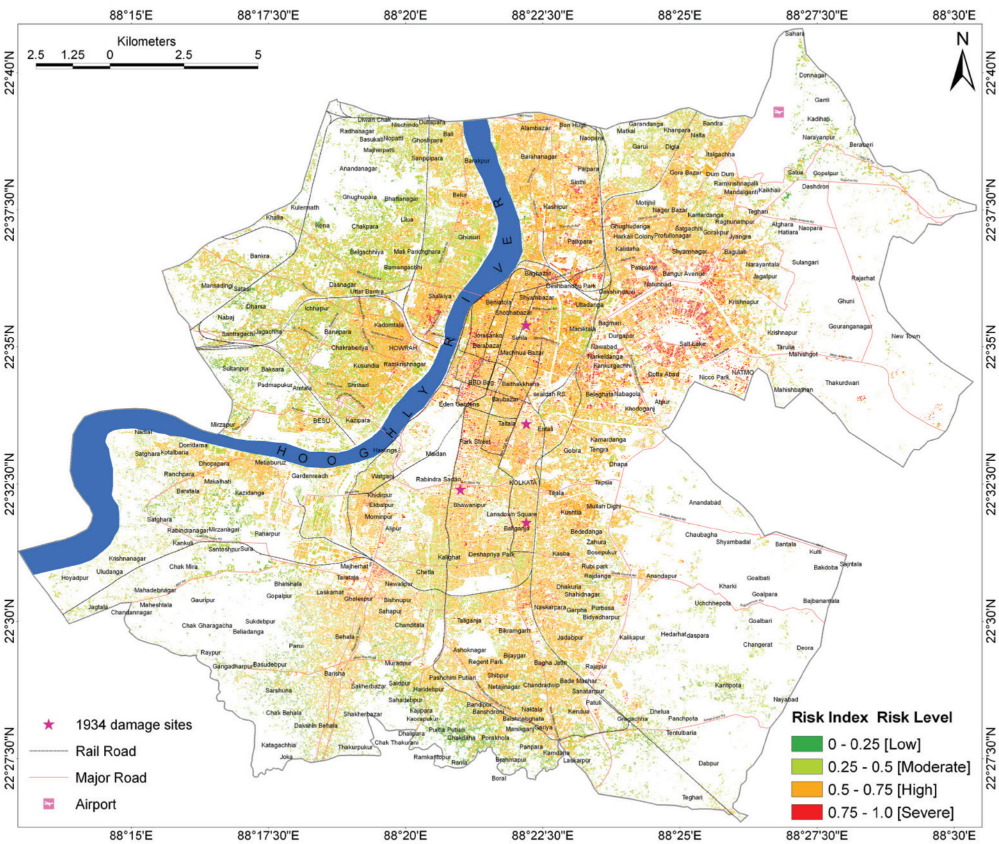


Figure 12.17 **Probabilistic Seismic Structural Risk Map of Kolkata. Four broad divisions have been identified with Risk Index (SRI) defined as: 0.75<SRI≤1.0 indicating severe risk condition in Saltlake, Park Street, Kalidaha, Barabazar, Baguiati area, 0.50<SRI≤0.75 indicating high risk mostly in Behala, Dum Dum, Alipur, Jadavpur, Dhakuria region, 0.25<SRI≤0.50 moderate risk mostly in Bali, Kona, Kalighat and part of West Kolkata, while SRI<0.25 presents a completely risk free regime. The damage distribution due to the 1934 Bihar-Nepal earthquake of M_w 8.1 (GSI, 1939) are identified in the High Risk zone (marked by '★').**

From the depiction of Figure 12.17, it is easier to identify the most vulnerable buildings and, therefore, the suggestion of preventive measures for those. In Kolkata, most of the structural vulnerability index range from 0.25 to 0.75 indicating moderate to high vulnerability level. Detailed analyses and ground truthing reveal that most of the buildings in the City are 1-4 storied where the resonance frequency of the soil column is between 1.0 - 2.0 Hz. It is observed that an index > 0.5 is of higher vulnerability level in terms of both height and severity of structural damage being constructed on swamps and artificially non-engineered fills. In central Kolkata most of the buildings exhibit high to severe structural vulnerability because of its age (80% >35 years) and unplanned construction. The damage distribution due to the Great 1934 Bihar-Nepal earthquake of M_w 8.1 are identified in the Severe to High Risk zones (marked by '★'). The detailed seismic vulnerability attributions are presented in Table 12.11. The present study will undoubtedly assist in the earthquake disaster mitigation planning for the city of Kolkata.

Table 12.11 **Structural Risk Level with corresponding vulnerability exposures at selective locations in Kolkata**

Lat (°N)	Long (°E)	LM	SRI	P_F	LPI	I_{MM}	BH	BA	BT
22.4940	88.311	Behala	High	1.27	3.3	VII	Houses (1 Floor)	10 Yr	B-Burnt Bricks Building
22.5125	88.388	Rajdanga	Moderate	1.52	12.1	VII	Houses (1 Floor)	25 Yr	C1- i: Concrete Building
22.5971	88.367	Shyambazar	High	1.27	13.5	VII	Buildings (2-4 Floors)	35 Yr	C1- i: Concrete Building
22.6346	88.424	Dum Dum	High	1.27	5.7	VII	Buildings (2-4 Floors)	35 Yr	C1- i: Concrete Building
22.6468	88.344	Bali	Moderate	1.08	7.8	VII	Buildings (2-4 Floors)	Younger than 5 Yr	B-Burnt Bricks Building
22.6190	88.305	Kona	Moderate	1.27	9.3	VII	Buildings (2-4 Floors)	30 Yr	C1- i: Concrete Building
22.5037	88.252	Maheshtala	Low	1.27	6.6	VII	Houses (1 Floor)	35 Yr	C1- i: Concrete Building
22.5269	88.327	Alipur	High	1.08	10.1	VII	Tall Buildings (5-8 Floors)	10 Yr	C1- i: Concrete Building
22.5470	88.287	Metiaburuz	High	1.08	6.6	VII	Tall Buildings (5-8 Floors)	25 Yr	C1- i: Concrete Building
22.4556	88.422	Dabpur	Moderate	1.27	27.5	VII	Buildings (2-4 Floors)	25 Yr	B-Burnt Bricks Building
22.4938	88.379	Jadavpur	High	1.27	13.5	VII	Tall Buildings (5-8 Floors)	35 Yr	C1- i: Concrete Building
22.5182	88.342	Kalighat	Moderate	1.08	6.1	VII	Buildings (2-4 Floors)	Older than 35 Yr	A2-Stone Wall
22.4906	88.451	Deora	Low	1.27	21.2	VII	Buildings (2-4 Floors)	Younger than 5 Yr	B-Burnt Bricks Building

Lat (°N)	Long (°E)	LM	SRI	P_F	LPI	I_{MM}	BH	BA	BT
22.5092	88.379	Dhakuria	High	1.27	18.3	VII	Tall Buildings (5-8 Floors)	10 Yr	C1- ii: Newly Builtup Concrete B
22.4604	88.317	Thakurpukur	Low	1.27	4.3	VII	Houses (1 Floor)	20 Yr	C1- i: Concrete Building
22.5817	88.328	Howrah	High	1.27	14.0	VII	Houses (1 Floor)	Older than 35 Yr	C1- i: Concrete Building
22.5151	88.457	Bagdoba	Moderate	1.52	18.6	VII	Houses (1 Floor)	30 Yr	B-Burnt Bricks Building
22.6142	88.382	Paikpara	High	1.08	12.0	VII	Buildings (2-4 Floors)	Older than 35 Yr	C1- i: Concrete Building
22.5527	88.354	Park Street	Severe	1.52	15.3	VII	Multistoried Buildings (9-10 Floors)	20 Yr	C1- i: Concrete Building
22.5830	88.416	Saltlake	Severe	1.52	28.0	VII	Tall Buildings (5-8 Floors)	10 Yr	C1- ii: Newly Builtup Concrete B
22.5854	88.480	New Town	Moderate	1.27	26.5	VII	Buildings (2-4 Floors)	Younger than 5 Yr	C1- ii: Newly Builtup Concrete B
22.6030	88.468	Rajarhat	Moderate	0.88	34.2	VII	Buildings (2-4 Floors)	Younger than 5 Yr	C1- ii: Newly Builtup Concrete B

LM: major land marks; SRI: structural risk index; P_F: predominant frequency; LPI: liquefaction potential index; I_{MM}: predicted MM Intensity; BH: building height; BA: building age (Yr.); BT: building type as per BMTPC.

Seismic Structural Risk Microzonation Map has been validated by the observed earthquake damage structures/sites corresponding to the risk levels using both the success rate curve and *R*-Index method as depicted in Figure 12.18 (a & b). It is exhibited that the success rate curve and *R*-index increases with the level of structural risk index. Thus it is concluded that the earthquake affected sites observed in these levels indicate consistent risk level.

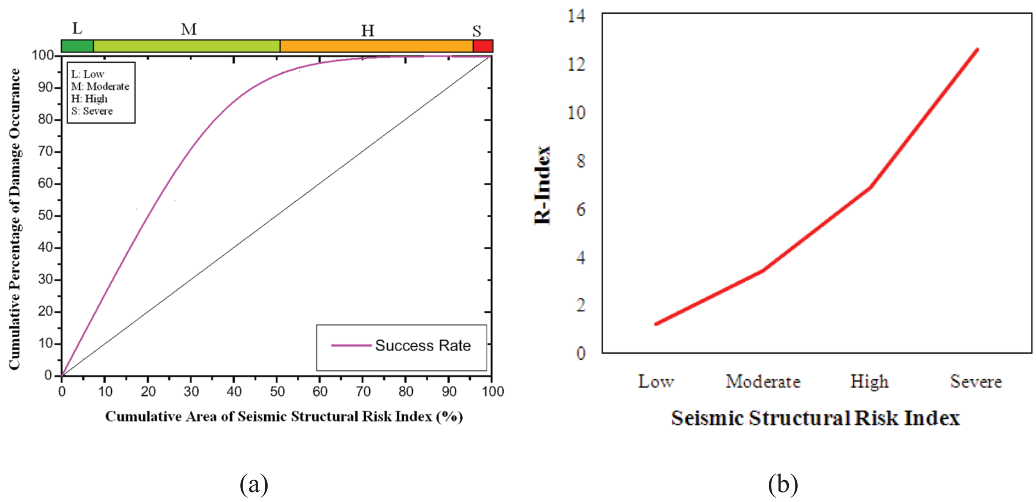


Figure 12.18 **(a) Validation of Seismic Structural Risk map through success rate curve, and (b) Validation of Seismic Structural Risk map using R-index.**

In the present study, we have also calculated the design horizontal seismic coefficient (A_h) for the existing structures by the following expression

$$A_h = Z_F I S_a / 2Rg \tag{12.5}$$

where, Z_F = Zone factor (taken from chapter 8), I = Importance factor, depending upon the functional use of the structures, R = Response reduction factor, depending on the perceived seismic damage performance of the structure and S_a/g = Average response acceleration coefficient for rock or soil sites (taken from chapter 8). BIS (2002) specified the values of 'I' and 'R' for all kinds of buildings.

The sample seismic coefficient (A_h) distribution to be used for Kolkata for all kinds of structures with the predominant period of 1.0 sec is depicted in Figure 12.19. Depending upon the value of seismic Coefficient (A_h) the category of building has been defined by BIS (2002) as given in Table 12.12. From Figure 12.19 it is evident that the City may be suitable for 'A' and 'B' type of structures only. However 'C' type of structures may also be built in the northeast part of the City.

Table 12.12 **Classification of Building Categories based on A_h (BIS, 2002)**

Range of A_h	Building Category	Description
< 0.05	A	Building in field-stone, rural structures, unburnt-brick houses, clay houses
0.05 to 0.06	B	Ordinary brick buildings, buildings of large block and prefabricated type, half timbered structures, buildings in natural hewn stone

Range of A_h	Building Category	Description
0.06 to 0.08	C	Reinforced buildings, well built wooden structures
0.08 to 0.12	D	Other type not covered in A,B,C
> 0.12	E	

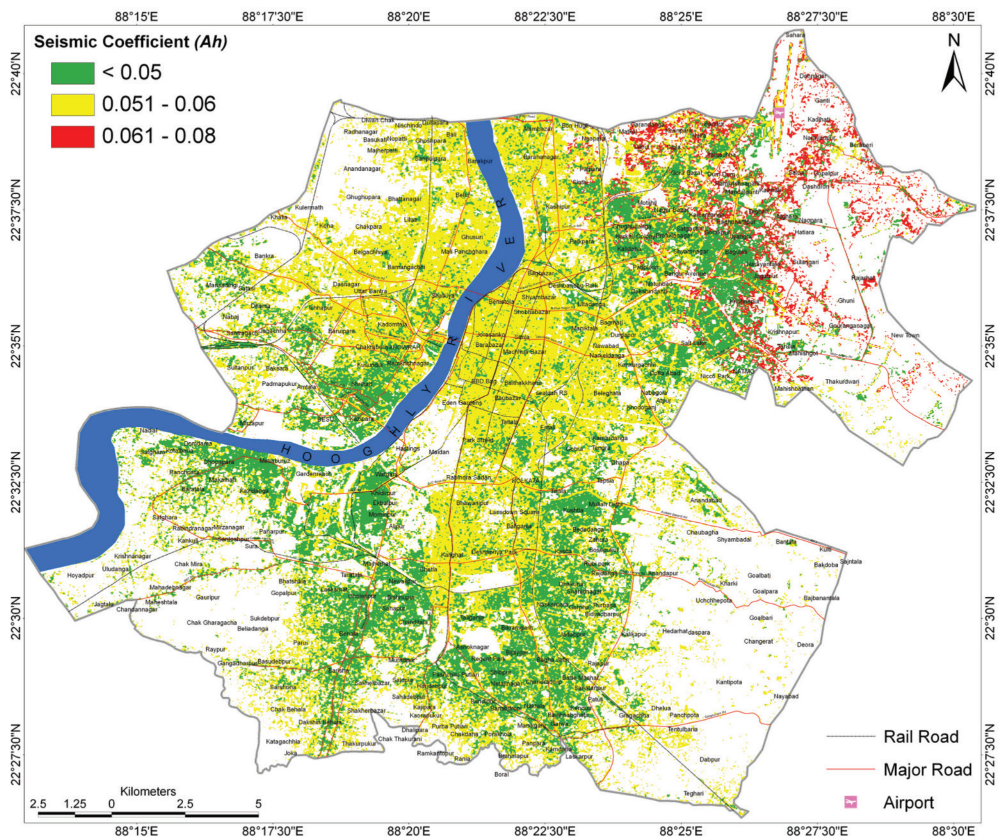


Figure 12.19 **Spatial distribution of horizontal Seismic Coefficient (A_h) to be used for Kolkata for structures with 1.0 sec predominant period.**

12.4 Concluding Remarks

Seismic Vulnerability and Risk has emerged as an important issue in high risk urban centers across the globe and is considered an integral part of earthquake induced disaster mitigation practices. The adopted seismic risk framework is a multi-dimensional concept based on seismic hazard which include Seismological, Geological, Geotechnical & Geophysical database and the Vulnerability exposures *viz.* population density, landuse/landcover, building typology, building height & building age judiciously integrated on Geographical Information System to identify those characteristics of buildings/socio-economic conditions which are responsible for earthquake disaster into a catastrophe.

In Kolkata about 40% buildings fall under the high risk zone in and an around the central part of the City which is the oldest part of the Metropolitan whereas about 5-7% buildings are in the severe risk zone, most of which are located in the artificial non engineered filled-up regions. Both the socio-economic and structural risk maps will contribute towards mitigation efforts against earthquake disaster of the City. Thus the knowledge of risk in the City based on existing urban built-up environment will immensely benefit the disaster mitigation and management endeavors put in place for the city of Kolkata.