13.3.1.1 Potential Earth Science Hazard

Potential Earth Science Hazard (PESH) includes ground motion and ground failure accompanying with liquefaction. The city of Kolkata is associated with Site classes D and E as depicted in Figure 13.32.

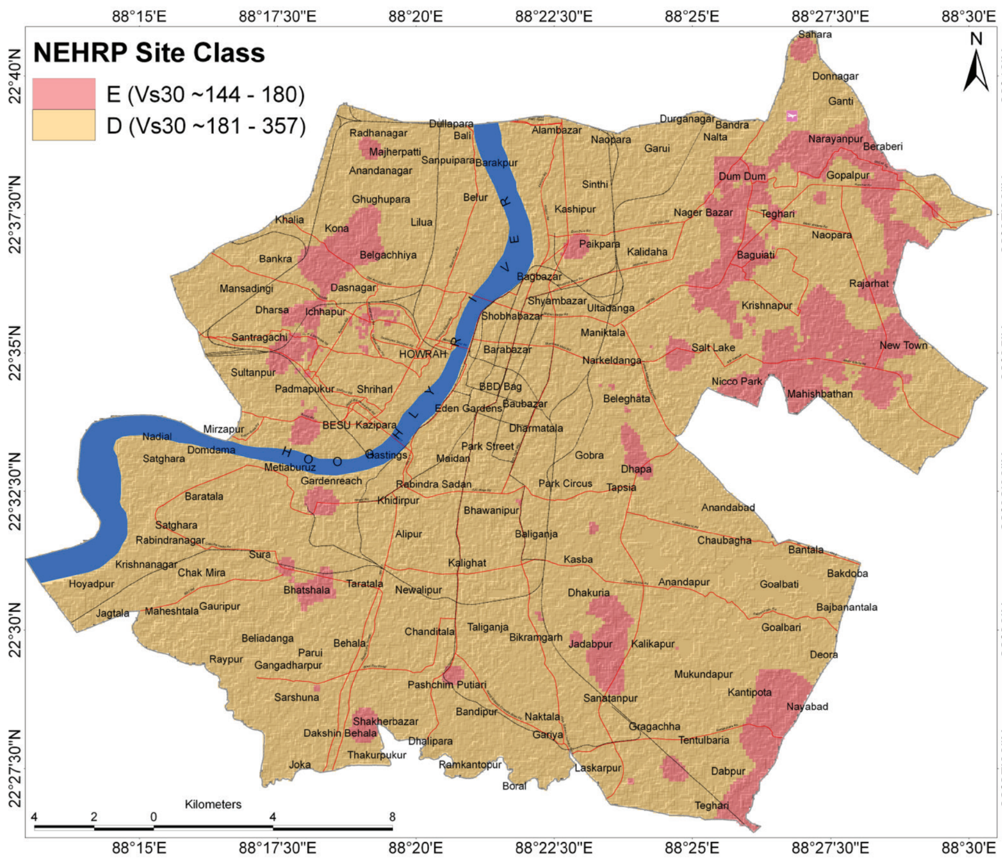

Figure 13.32 Site Class map of Kolkata.

Liquefaction is a secondary effect of an earthquake and is important for seismic risk appraisal. It induces damage to the building in terms of tilting or lateral displacement. For ground failure, Permanent Ground Deformation (PGD) has been estimated in HAZUS based on the provided Peak Ground Acceleration and Liquefaction Susceptible Index (LSI) in each census tract (FEMA, 2000). Poor foundation and building damage due to liquefaction are strongly related to each other. Piled, well reinforced, stiff concrete foundation will tend towards rigid body rotation, whereas the un-reinforced, adobe building possess high risk of liquefaction. Transportation disruption due to liquefaction generally comprises of minor damage and, therefore, easily repairable at relatively low cost. In some cases as in Costa Rica 1991 about 30% of the highway network was affected by liquefaction (Youd *et. al.,* 1993). Therefore, to compute a complete probabilistic damage and loss scenario for essential facilities and lifeline utilities of Kolkata, liquefaction susceptible class has been provided based on Liquefaction Potential Index (LPI) map depicted in Figure 13.33 with a complete discussion on this issue in Chapter 9.

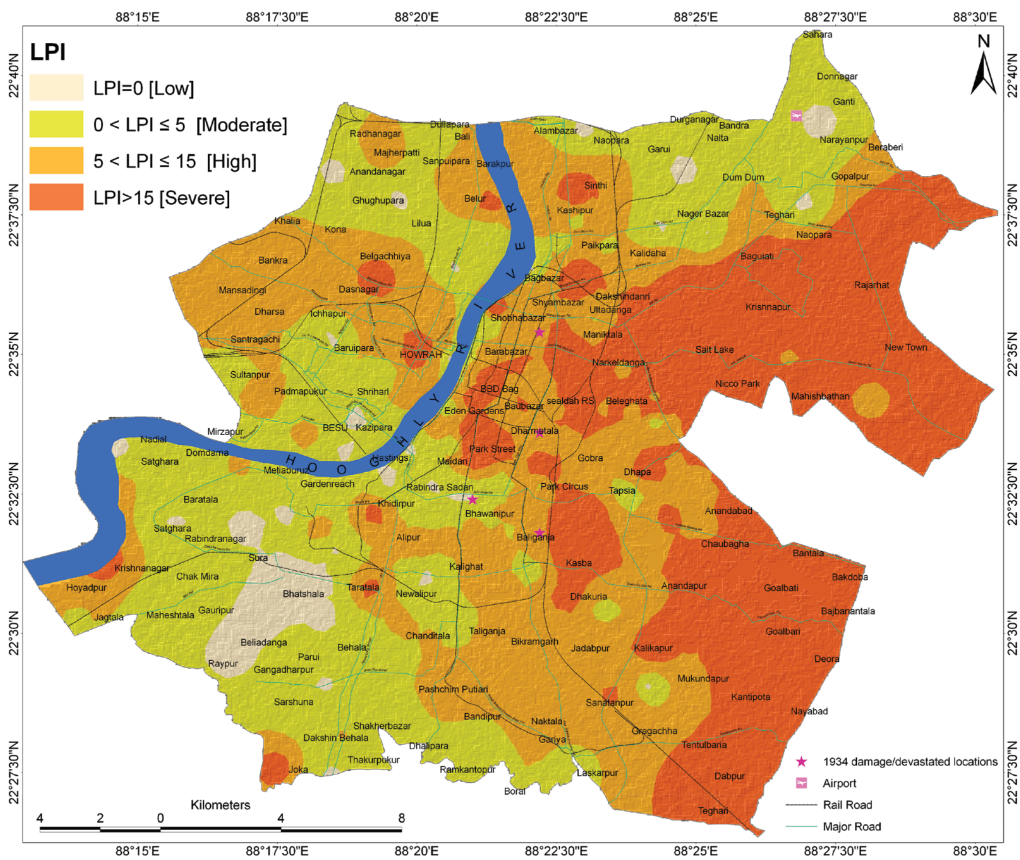

Figure 13.33 **Liquefaction Potential Index distribution map of Kolkata.**

13.3.1.2 Preparation of Essential Facilities' Module

Essential facilities *viz*. schools, hospitals, police stations, fire stations *etc*. provide services to the community and should remain functional even after a devastating earthquake so as to monitor rescue and relief operations for effective post-disaster management. To assess the vulnerability of these facilities a total of 1455 schools, 62 police stations, 17 fire stations and 1060 medical care facilities have been considered in the present investigation as shown in Figure 13.34.

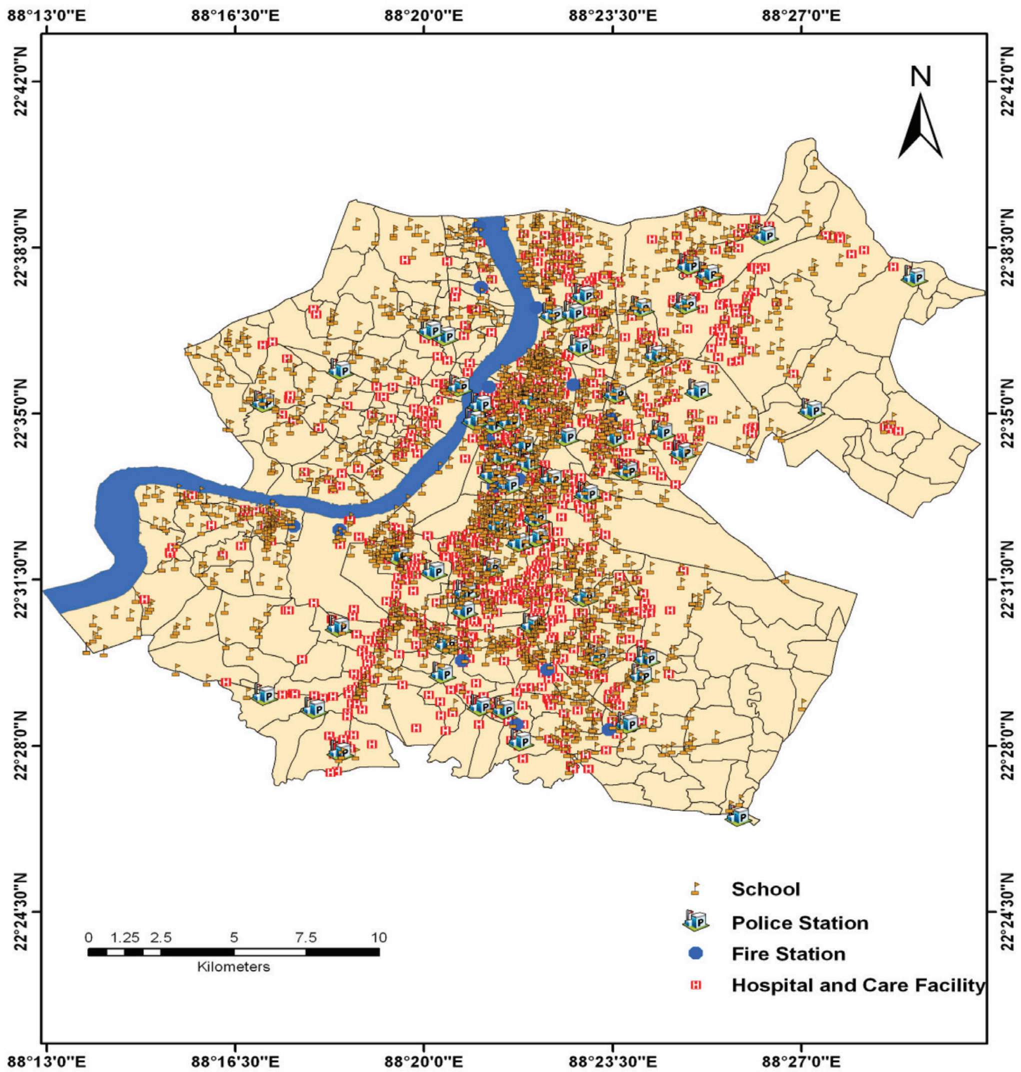

Figure 13.34 **Spatial distribution of essential facilities in the city of Kolkata.**

13.3.1.3 Preparation of Transportation Network Module

Transportation system is an important lifeline facility for disaster management and mitigation of any seismic prone region. For the present study, highway, bridge, railway, ferry and bus terminals have been considered for damage and loss estimation of the City using the HAZUS protocol. The transportation network of this busy City is quite complex and all modes of communication are available here. The spatial distribution of 15,024 km primary, secondary and tertiary road along with 232 bridges and flyover facilities are presented in Figure 13.35. Road network has been taken from Open Street Map (https://www.openstreetmap.org) and Google Earth satellite data and further classified according to OSM highway classification system in terms of their usage and importance.

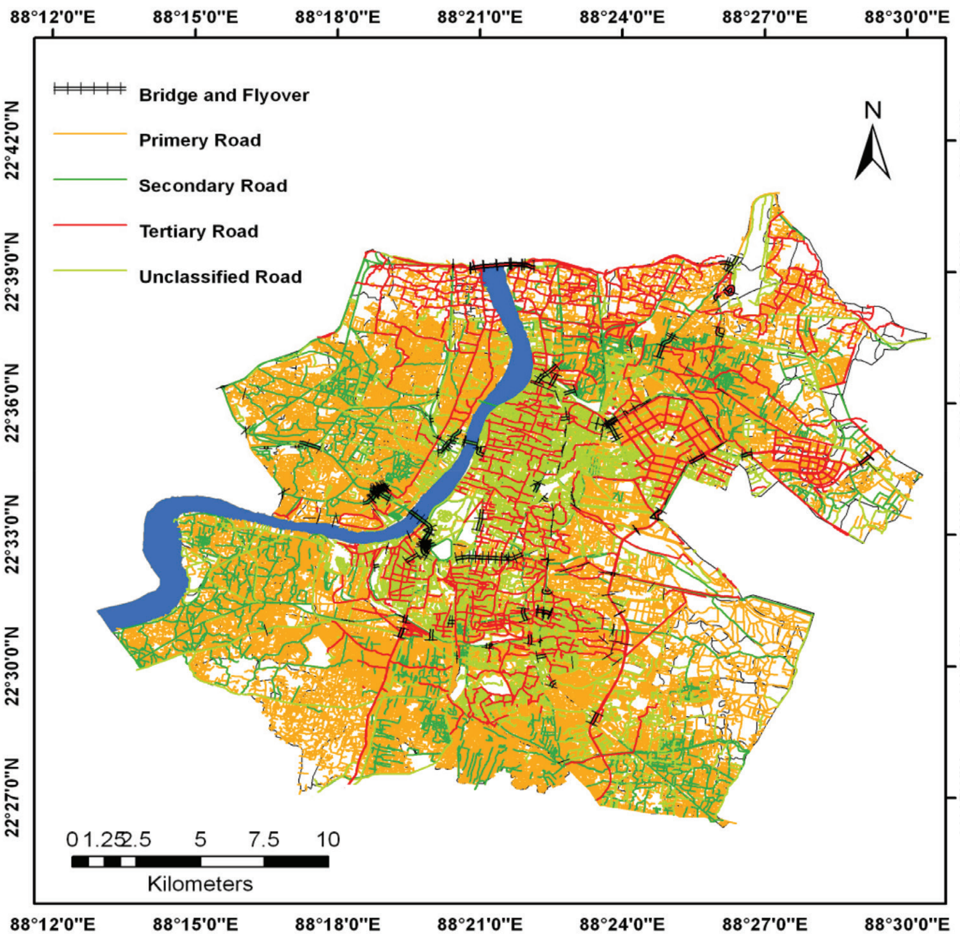

Figure 13.35 **Distribution of roads, bridges, and flyovers in Kolkata.**

The railway segments, 19 bus terminals and 31 ferry facilities of the City has also been considered in the HAZUS network modules as presented in Figure 13.36. These are very important and busy communications and, therefore, damage to these facilities will enhance the risk level of the City. The information of these facilities is taken from Google Earth satellite data and also during field survey and RVS.

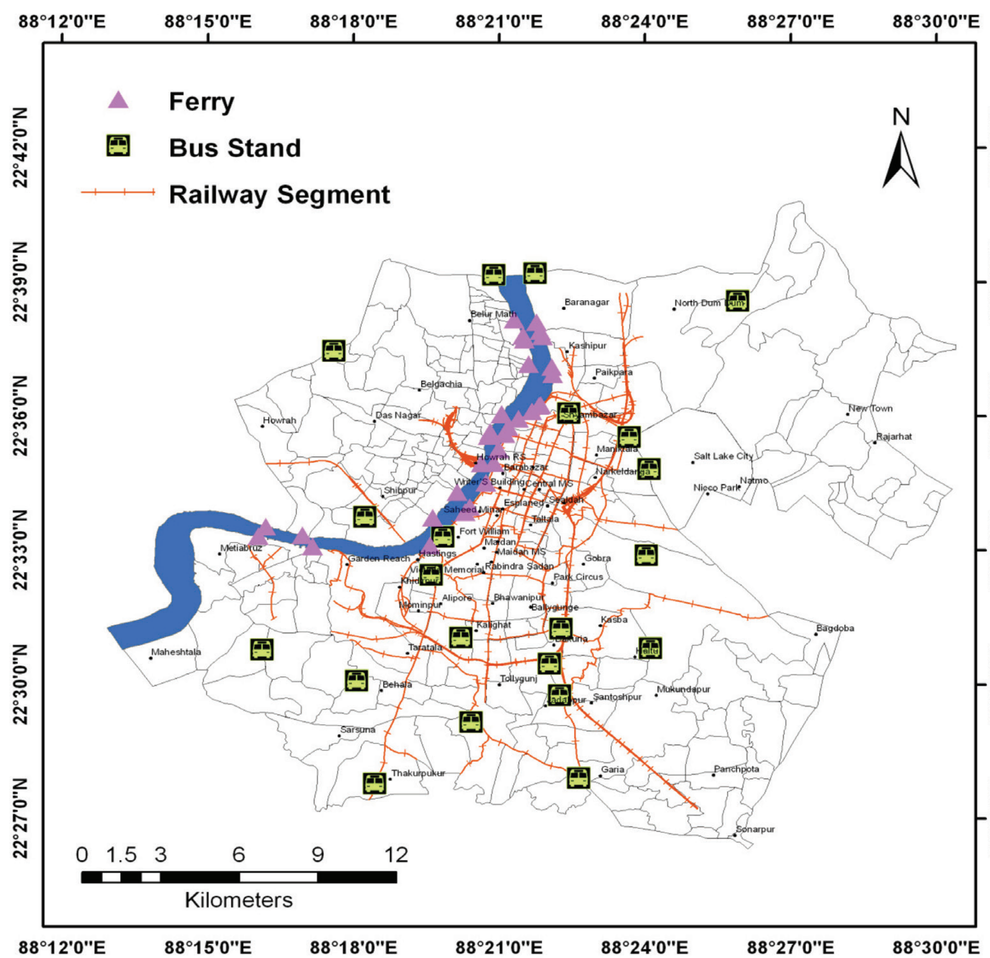

Figure 13.36 **Distribution of ferry, bus terminals and railway segments in Kolkata.**

13.3.1.4 Direct Damage Module

Output of the potential earth science hazard module and the data of the inventory module prepared in this study are used to estimate physical damage to essential facilities and transportation network of the City. The direct damage results are in the form of Damage Ratio (DR_i), which is the probability of each of the damage states (none, slight, moderate, extensive and complete) for each type of facility, or system component.

13.3.1.5 Direct Economic Loss Module

The direct economic loss module estimates direct economic consequences (repair and replacement costs) to repair the physical damage incurred to essential and lifeline system components. Direct economic loss estimates depend on probabilities of being in each damage state (ds_i), replacement value of the facilities and damage ratio (DR_i) as estimated by the direct damage module. Economic loss is evaluated by multiplying the Compounded Damage Ratio (DR_C) by the replacement value. Compounded Damage ratio can be computed by following the equation addressed by FEMA (2000)

$$DR_c = \sum_{i=2}^{5} DR_i * P\left[ds_i\right] \tag{13.7}$$

where, $P\left[ds_i\right]$ is the Probability of being in each damage state '*i*' which varies from 2 to 5, *i.e.* 'slight' to 'moderate' damage. No loss will be calculated for damage state 1 as it is 'none' damage state. The replacement value for essential facilities is already given in Table 13.2. So the replacement value for transportation network as provided by the local competent authority is presented in Table 13.4.

Table 13.4 Construction cost for Transportation network used in the module (source: KMDA)

Type of Facilities	Construction type	Rupees per km (Crores)
Road	Two lane Concrete road	7.0
	Two lane Bitumen road	8.0
Bridge	Two lane cable stayed bridge	160.0
	Four lane prestressed concrete bridge	90.0
	Two lane prestressed concrete bridge	50.0
	Two lane steel concrete bridge	80.0
	Four lane steel concrete bridge	155.0
Flyover	Two lane prestressed concrete flyover	45.0
Railway	-	12.0
Ferry	1.5 crore Rupees per station	
Bus terminal	1.0 crore Rupees per station	

13.3.2 Damage Estimate considering PGA distribution with 10% Probability of Exceedance in 50 years at the Surface Level

HAZUS evaluates a wide range of damage and losses resulting from devastating earthquakes to yield a basis for pre-disaster preparedness & post-disaster response planning and also to stimulate planning for mitigating the risk (Whitman *et al.*, 1997). It estimates the impacts to the functionality of the facilities, relative cost of the components and overall time to recover from the damage. Damage to the essential facilities has been estimated considering the surface consistent PGA distribution with 10% probability of exceedance in 50 years.

13.3.2.1 Damage to Essential Facilities'

a) Damage to Medical Care Facilities

Damage and loss estimation for hospital buildings after a seismic event has impacted a terrain is important for rescue and recovery operation. The map in Figure 13.37 depicts the distribution of emergency care facilities expected to face damage at different levels. Maximum number of buildings is expected to face 'slight' damage and remain functional even after the earthquake. But most of the facilities present in Central Kolkata, Saltlake and Rajarhat areas will face 'complete' damage according to the maximum probable hazard scenario of the City.

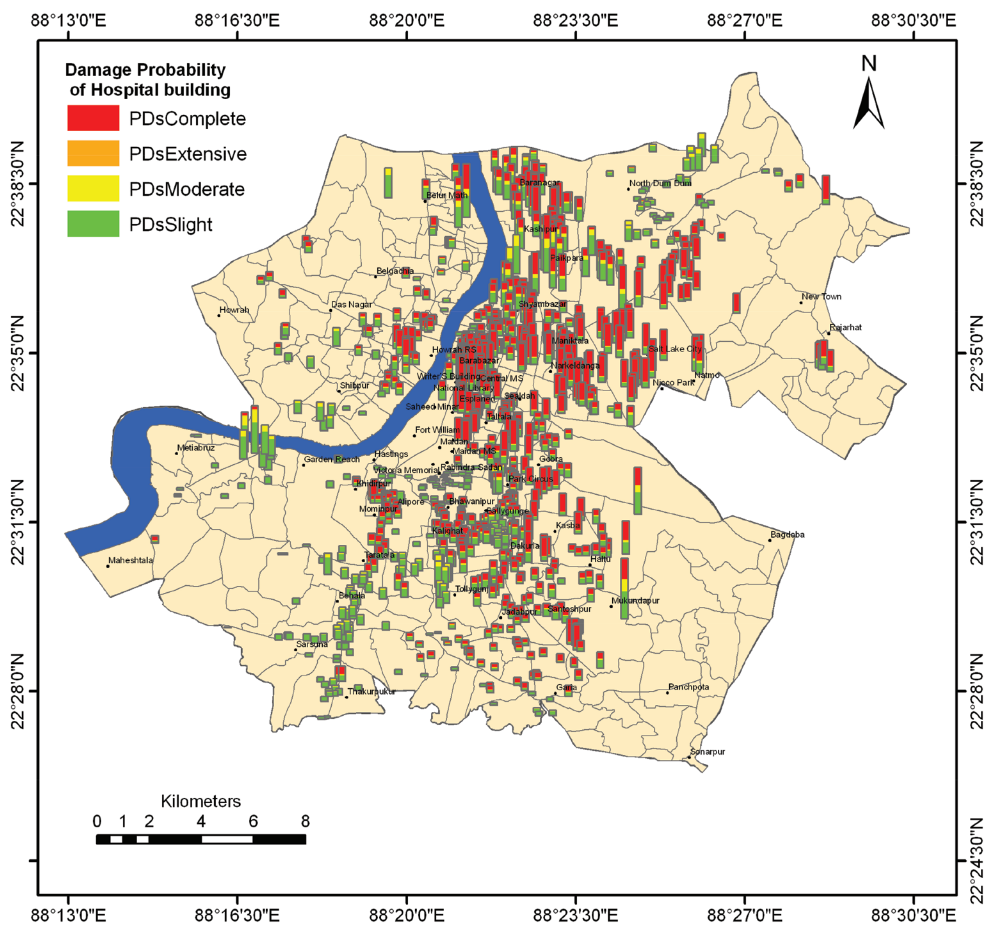

Figure 13.37 **Predicted percentage of hospital buildings expected to face 'slight', 'moderate', 'extensive', and 'complete' damage states.**

The probability of functionality of medical care facilities is also estimated through HAZUS due to the estimated probabilistic earthquake scenario at the surface for a return period of 475 years. It is observed that about 88% of the Hospitals and Medical care facilities will be available for the recovery of victims immediately after the earthquake as shown in Figure 13.38.

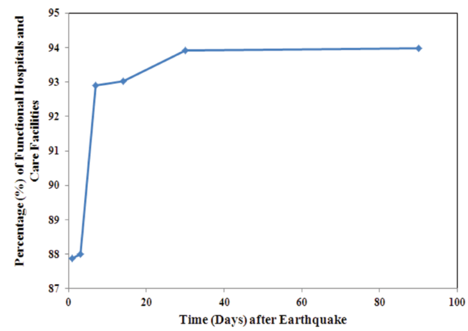

Figure 13.38 **Predicted Restoration Curve for Hospitals and Medical care facilities in Kolkata.**

b) Damage to Schools

Schools in many developing countries are not seismically designed to withstand strong ground shaking resulting from a large earthquake. As per HAZUS building inventory most of the school buildings are of URM type and hence is vulnerable to earthquake shaking. The distribution of damage to schools as estimated through HAZUS for a probabilistic surface consistent hazard scenario presented for Kolkata for a return period of 475 years is shown in Figure 13.39 for various damage states. It is observed that most of the school buildings are expected to face 'slight' damage, while in part of Central Kolkata, Saltlake and Rajarhat those will face 'complete' damage.

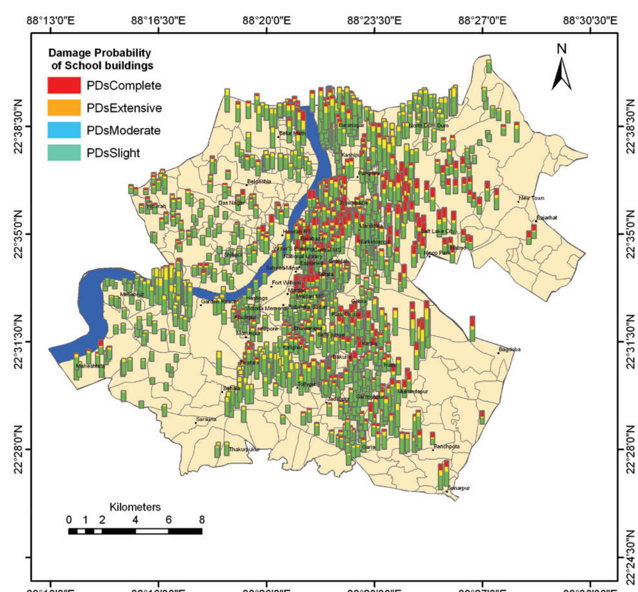

Figure 13.39 **Predicted damage for school buildings in the City.**

Using the HAZUS protocol the damage and loss associated with 1455 schools from the city of Kolkata have been estimated along with their restoration time which is essential for emergency response planning activities related to shelter and mass care, as well as for the continuity of governmental services. Out of 1455 schools, 953 schools will remain functional immediately after the earthquake impacted the region with a mean MCE of M_w 6.8 as indicated in Figure 13.40 which can be used for rescue operation purposes.

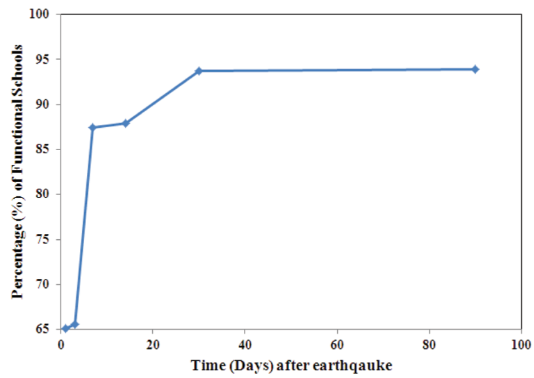

Figure 13.40 **Predicted Restoration Curve for schools in Kolkata.**

c) Damage to Fire Stations

As estimated through HAZUS, fire stations are expected to suffer moderate damage as shown in Figure 13.41. Out of 17 fire stations considered in Kolkata it is seen that most of the stations will suffer 'slight' damage, followed by 'moderate', 'extensive' and 'complete' damage. It should remain functional after any moderate to large earthquake triggers fire breakout from gas/oil pipeline damages, electric wire disruption *etc.*

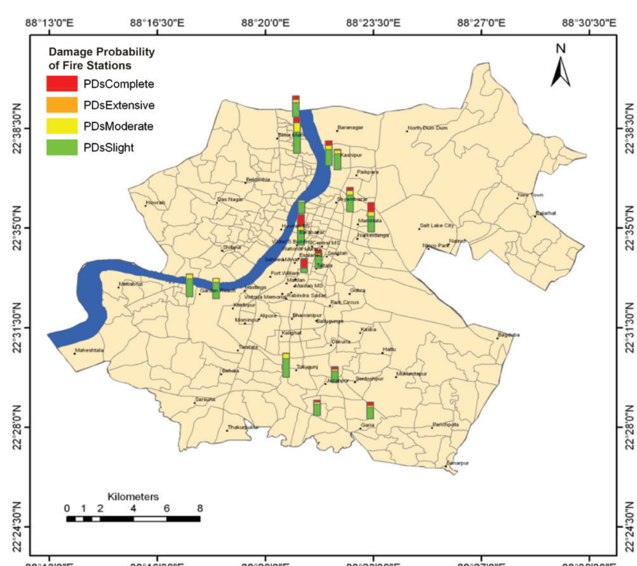

Figure 13.41 **Predicted damage for fire stations of the City.**

The restoration curve for fire stations is also provided in Figure 13.42 exhibiting the number of functional fire stations immediately after the earthquake impacted the City with a probabilistic scenario considered in this analysis. It indicates that 65% of the fire stations are expected to be available for mitigation of fire hazard prolonged by earthquakes.

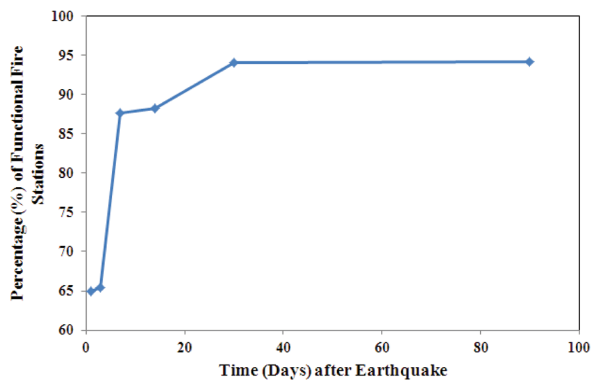

Figure 13.42 **Predicted Restoration Curve for fire stations of the city of Kolkata.**

d) Damage to Police Stations

To provide faster relief and rescue operation in the City police stations should be functional as these facilitates provides Law and Order control in the region under the most chaotic condition created at the aftermath of an earthquake inflicted disaster. The Damage Scenario generated using HAZUS indicate that this facility will face ‘slight’ to ‘moderate’ damage, while even ‘complete’ damage is expected in Central Kolkata, Saltlake, Santoshpur, New Town, and some parts of Howrah region as depicted in Figure 13.43.

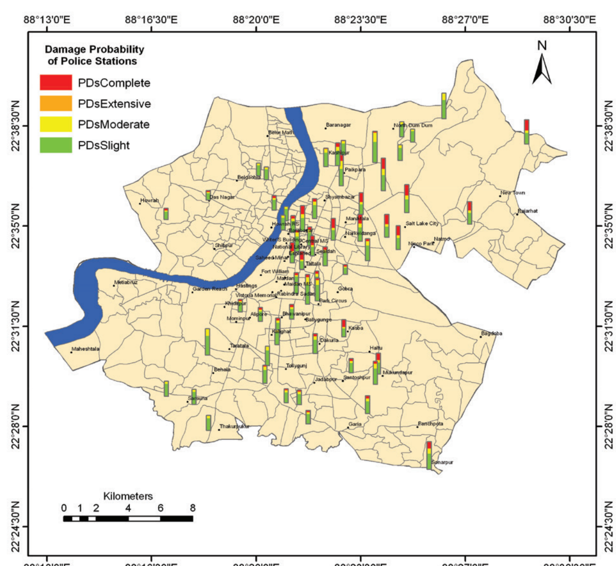

Figure 13.43 **Predicted damage for police stations of the City.**

The predicted restoration curve is also presented in Figure 13.44 that reveal that about 65% of the total police stations of the City will remain functional immediately after the earthquake impact to manage the rescue operations.

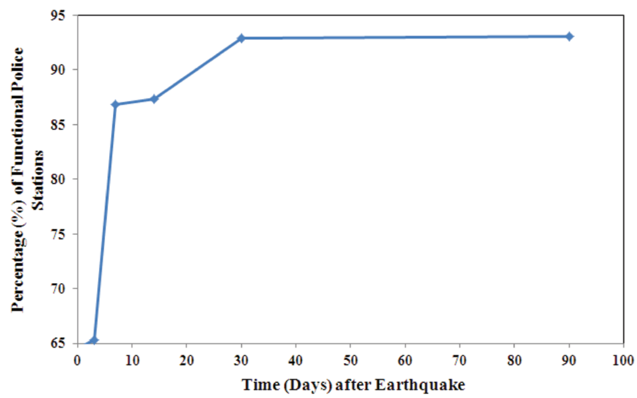

Figure 13.44 **Predicted Restoration Curve for police stations of the City.**

13.3.2.2 Transportation Network Damage

Probabilities of damage and losses were calculated for each bridge, highway segment, ferry, and bus terminals in the transportation module to establish the range of damage states from no damage to 'complete' damage. The probability of being at each damage state for each mode is important to estimate the overall loss projection.

a) Damage and Loss Estimation for Highway Segments, Bridges and Flyovers

Damage is estimated using HAZUS for highway segments and bridges in the City. The City is mostly dominated by moderate to high liquefaction induced ground failure which is directly related to the damage in the road segment. An estimation of total 15,024 km highway segment in Kolkata indicates that the entire segment is expected to damage moderately with a different damage ratio as depicted in Figure 13.45. Damage ratio will be high for Central Kolkata, Howrah, Saltlake and New Town areas. Damage to this facility will create more chaos in the society due to the disruption in the communication system. The estimated damage probability for highway, bridge and flyover in the City are expected to suffer 'slight' to 'extensive', while 'complete' damage is remotely expected for bridges under the present seismic hazard scenario.

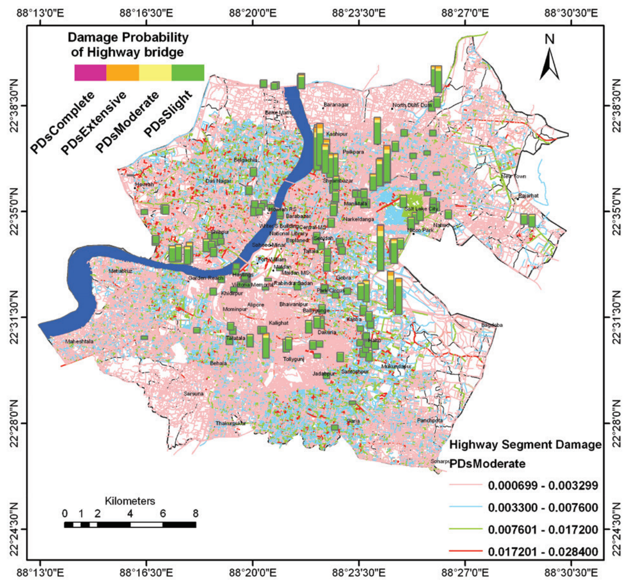

Figure 13.45 **Predicted damage to the highway segments and bridges of the city of Kolkata.**

The total economic loss is also interpreted for the respective damage states. It depends on the probability of being in a damage state, location and the cost of initiation of the project. Total estimated loss for highway segments and bridges damage is found to be about 73 billion Rupees as presented in Figure 13.46.

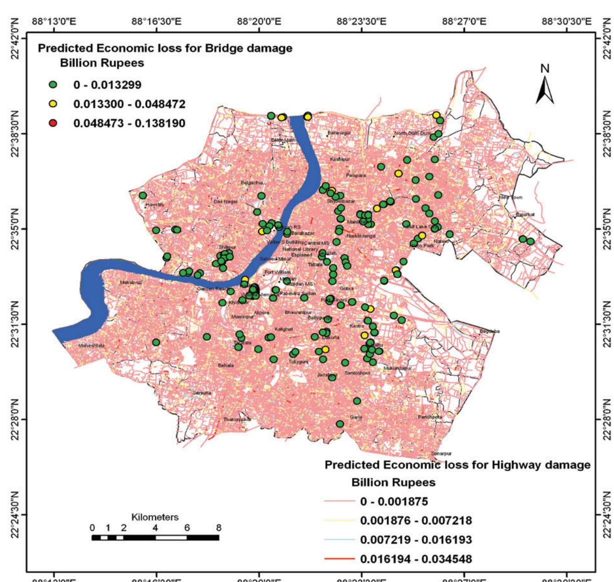

Figure 13.46 **Probable economic loss associated with highway and bridge facilities considering probabilistic hazard scenario of the City.**

b) Damage and Loss Estimation for Railway Segments, Bus Terminals and Ferry Facilities

The probabilities of damage to railway, bus terminals and ferry have also been estimated for Kolkata considering the surface consistent probabilistic seismic hazard condition. The probability of 'moderate' damage to railway segments and the distribution of damage states for bus terminals and ferry facilities have been depicted in the map of Figure 13.47. The study reveals that most of the ferry facilities and bus terminals are expected to suffer from 'slight' to 'moderate' damage. It also reveals that entire rail segments will face 'moderate' damage with a different damage ratio. Maximum damage ratio is associated with Central Kolkata, while Howrah and Sealdah railway segments are expected to face low damage ratio.

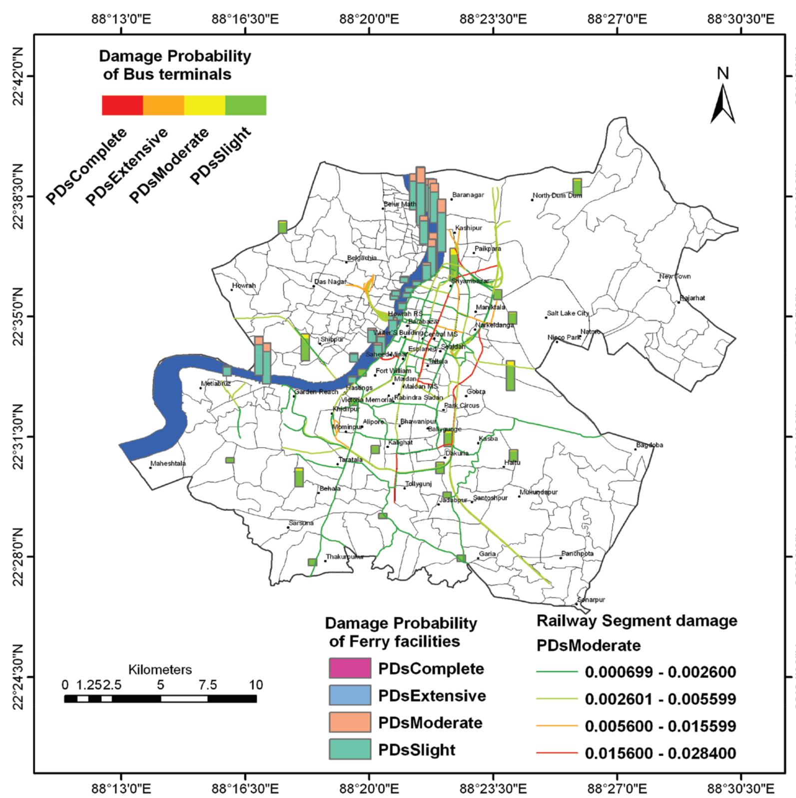

Figure 13.47 **Predicted damage distribution of the railway segments, bus terminals and ferry facilities of the city of Kolkata.**

The economic loss is also predicted for this particular damage scenario as shown in Figure 13.48 considering their construction cost and calculated damage ratio. Total estimated loss for damage to the railway segments, bus terminals and ferry facilities will be about 3 billion Rupees.

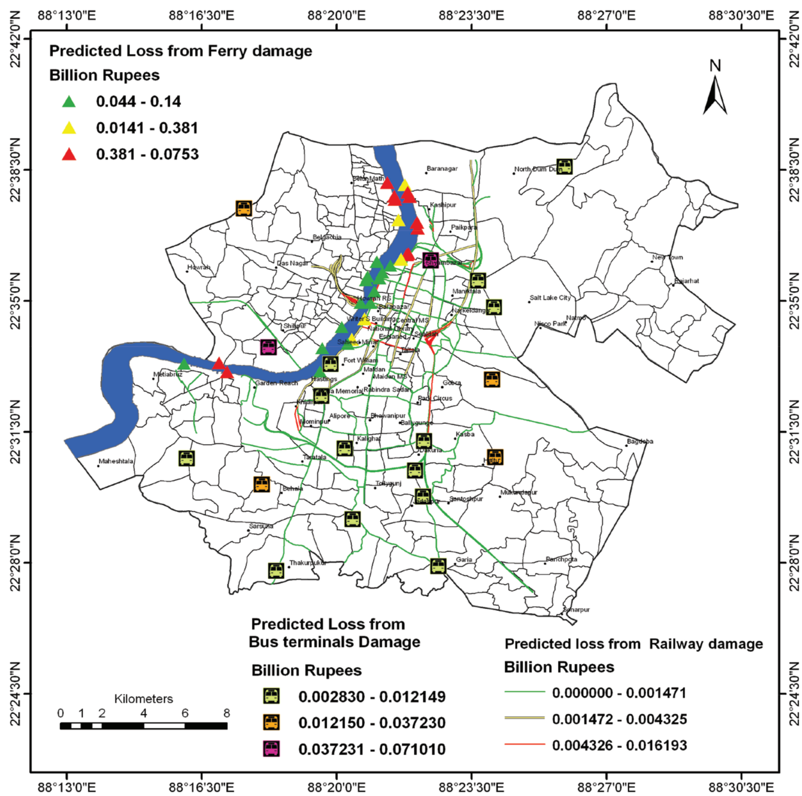

Figure 13.48 **Predicted economic loss associated with the railway segmnets, bus terminals and ferry facilities of the City.**

13.4 Concluding Remarks

The structural damage and its associated economic loss and casualty have been estimated for the maximum probable earthquake scenario of the city of Kolkata for a return period of 475 years with a view to possible disaster mitigation and management. The work presented here also deals with impact of seismic hazard on vulnerable exposures *viz.* schools, hospitals, police stations, fire stations, highway, railway and bridges of the City. These are essential facilities in the region and should remain functional even after the impact of an earthquake for rescue and relief operations. The damage and economic loss scenario of Kolkata can be used for land use planning and upgradation of seismic building codal provisions. The emergency response capabilities can be significantly improved to decrease casualties by rapid, selective and effective use of provided services. The architects and civil engineers may also use these information to assess the failure risk of the existing structures and thus design future earthquake resistant structures in Kolkata.