Seismic Risk Assessment for Coimbatore Integrating Seismic Hazard and Land Use

E. Lalith Prakash, Sreevalsa Kolathayar(✉), and R. Ramkrishnan

Department of Civil Engineering, Amrita School of Engineering, Amrita Vishwa Vidyapeetham, Coimbatore, India
sreevalsakolathayar@gmail.com

Abstract. Indian cities are expanding not only in terms of built environment but also in population. Multi-story buildings are rising rapidly to accommodate the growing population, undesirably even in hazard prone areas. Such a scenario calls for a proper disaster risk reduction program and plan to control the inevitable damage to lives and properties. Earthquakes are destructive only if the factors that increase the damages prevail. Attention should be given to crowded cities with people and infrastructure vulnerable to hazard. This study presents the details of deterministic seismic hazard analysis (DSHA) done for Coimbatore city of the state of Tamil Nadu, India using the latest available information on seismicity of the region. The earthquake data was compiled from different agencies and homogenized in a unified moment magnitude scale to create an updated earthquake catalog. Seismotectonic map for the study area was prepared by superimposing the earthquake events on the seismogenic sources. DSHA was then performed by dividing the study area into grids of size 0.02º × 0.02º (approximately 2 km × 2 km) using a MATLAB code, considering three different attenuation relationships for the stable continental region. Land use (LU) map for the region was developed from LANDSAT 8 data using various GIS platforms. Hazard contour map prepared using ArcGIS, was then overlaid on the LU map to comprehend the seismic risk of the region. It was observed that, though the wards south-west of the city shows higher Peak Ground Acceleration (PGA) values, the wards north-east of the city have larger and denser built-up areas, increasing its vulnerability, in the event of an earthquake.

Keywords: Deterministic seismic hazard analysis · Peak ground acceleration
Land use · Remote sensing · Seismic risk

1 Introduction

1.1 General

Earthquakes have a devastating effect on human life and property when human activities interfere with the occurrence of such a natural phenomenon. Populated human settlements and congested built-up areas in earthquake prone regions amplify the risk to both human life and property. Identification of such risk prone regions will be of greater use for a comprehensive earthquake disaster mitigation plan. Presently, the seismic zone map available for India as per the Bureau of Indian Standards

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(IS1893-2002) broadly classifies India into four hazard zones based on past earthquake data. Previous studies indicate the limitations of the existing seismic zone map, as it projects unstructured regions of homogeneous hazard level as lumps of landmasses, lacking a scientific hazard assessment (Raghu Kanth and Iyengar 2006; Menon et al. 2010). In this study, a deterministic approach is adopted to analyze the seismic hazard for Coimbatore city. The deterministic hazard contour map thus generated was overlaid on a digitized ward wise map of Coimbatore city.

Indian cities follow a trend of rapid urbanization due to population concentration in urban centres and its suburbs, and also due to migration of rural population entailed by poverty. This rapid urbanization, also related to urban sprawl results in extremely high population intensity, which in turn leads to a gradual decline of urban services including disaster mitigation. An attempt is made here to identify and interpret the combined effect of seismic hazard and Land Use pattern for Coimbatore city.

1.2 Study Area of Coimbatore

The city of Coimbatore is located at the extreme west of the Indian state of Tamil Nadu (South India), spreading over an area of 105.5 sq. kms. As per the latest Census (2011), Coimbatore has a population of over a million (http://www.censusindia.gov.in/pca). Even though Coimbatore has experienced an earthquake of moment magnitude 6.3 in 1900 (the epicenter of the earthquake was located at 10°45′ North Latitude and at 76°45′ East Longitude), it was categorized in seismic zone Zero, in the first version of the IS 1893 (BIS 1962). Presently, Coimbatore city is categorized as Zone III as per the latest release of IS 1983 (BIS 2002), where Zone II corresponds to least hazard and Zone V corresponds to the highest hazard within the country. Coimbatore has not experienced major earthquakes after 1900. According to elastic rebound theory, the strain energy built up in the geologic faults for years are released during the event of earthquake; they are more likely to occur in regions where small or no seismic activity has been seen in recent past (Kramer 1996). Two earthquakes, each with a magnitude of around 5.0 on the Richter Scale, in Idukki and Coimbatore districts were observed in December 2000 and January 2001, respectively.

2 Methodology

2.1 Deterministic Seismic Hazard Analysis (DSHA)

An updated and homogenized earthquake data catalogue is the prime requirement for hazard estimation. Kolathayar et al. (2012) compiled a catalogue for the entire Indian subcontinent based on both historical and instrumental data. In the present study, the earthquake data catalogue for the study region was updated by including all the events till 2017 within a radius of 300 kms from political boundary of Coimbatore. All the earthquake events were homogenized in Moment Magnitude (M_w) scale using magnitude correlations specific to the Indian peninsular shield (Kolathayar et al. 2012). This earthquake data was declustered from aftershocks and foreshocks, rendering a Poisson distribution of earthquake events using the algorithm developed by Gardner and Knopoff (1974) modified by Uhrhammer (1986). Accurate Ground motion prediction equations (GMPE) for India are scarce due to lack of sufficient strong motion records in the region. For PGA estimation of the study region, the attenuation relationships developed by Raghu Kanth and Iyengar (2007), Atkinson and Boore (2006) and Campbel and Bozorginia (2003) were used. Raghu Kanth and Iyengar (2007) developed attenuation relations for Peninsular Indian region. Attenuation relations for Eastern North America (ENA) were developed by Campbell and Bozorgnia (2003) and Atkinson and Boore (2006). Similarities in the geological and tectonic settings of both the regions allows using the same equations for our study region. Cramer and Kumar (2003) studied the aftershocks of Bhuj earthquake and proved that the ground motion attenuation in Peninsular Indian shield and ENA are comparable. All three relationships were assigned equal weightage in a logic tree frame work for the estimation of PGA values.

DSHA was carried out using the earthquake sources and events data within a boundary of 300 kms from the outermost administrative boundaries of Coimbatore city in all four directions. The study area was divided into several grids of size $0.02^{\circ} \times 0.02^{\circ}$ (approximately 2 km $\times$ 2 km). Using the deterministic approach, the PGA values at the centre of each of these grids were estimated using a MATLAB code. All linear and point earthquake sources were considered for analysis. All earthquake events near the geologic faults in the area were considered and the event with maximum magnitude was taken as the governing event associated with that linear source. Controlling earthquake for the point of interest was then identified for all linear and point sources. PGA value at the central point of each grid corresponding to the controlling earthquake was then computed using the attenuation relationships as mentioned above, considering shortest source to site distance.

2.2 Land Use Mapping

Land Use map for the region was developed using open source GIS software platforms like QGIS and GRASS GIS, based on LANDSAT 8 remote sensing images of 30 m resolution (NIR, SWIR, visible); 100 m resolution (thermal); and 15 m resolution (panchromatic), obtained from USGS. The satellite images were geo-referenced, cropped and then extracted. Diverse patches in the landscape were identified on a False Colour Composite (FCC) generated from the georeferenced images (bands- green, red and NIR). Training polygons were selected on the FCC image by identifying and delineating various heterogeneous patches by overlaying it on a google earth satellite image. Pixels of deciduous and evergreen forest land, grasslands, farmlands, coconut, arecanut, mango and other plantations, built up areas including roads and highways, built structures, airports, waterbodies like rivers and lakes, and open areas were selected from different points on the FCC to form training polygons for LU mapping. Uniform distribution and accurate marking of these training polygons was ensured throughout the study area (Ramachandra et al. 2012). Built in Gaussian maximum likelihood algorithm was used to classify each pixel of the image, based on the training polygons previously selected on the FCC. Land Use was mapped based on six major categories like forest land, agricultural land, plantations, built up areas, water bodies and open areas.

2.3 Hazard Mapping and Overlaying

Seismic hazard contour map was developed using the PGA values corresponding to each grid points in QGIS. Land Use map generated was then overlaid on the hazard contour map to obtain a combined seismic risk map, which was then used to assess the risk pattern of the study area (Fig. 1).

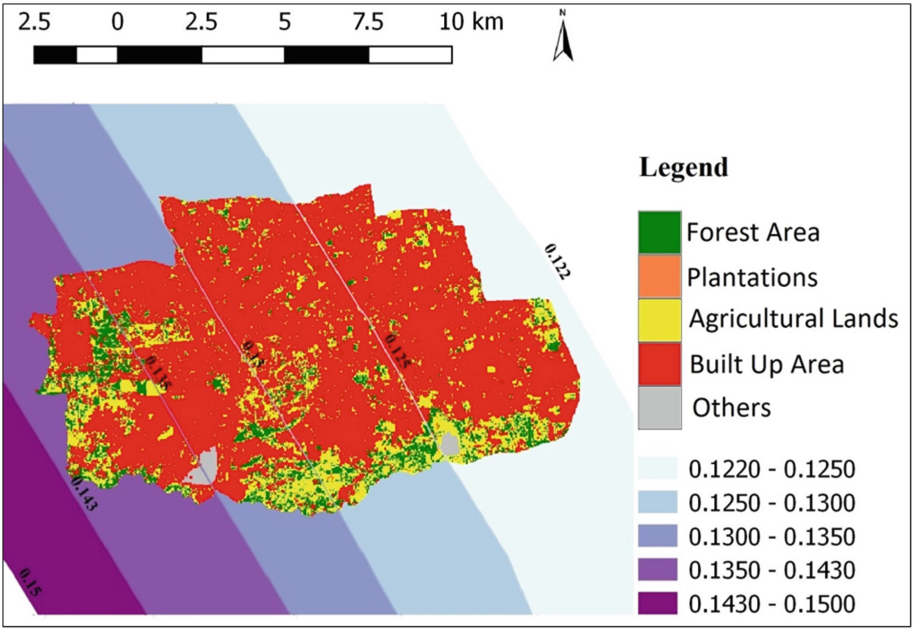

Fig. 1. Land-use map overlaid on hazard contour map for Coimbatore city (All PGA values are expressed in terms of 'g')

A ward wise administrative base layer for Coimbatore city was developed using ArcGIS. The same was overlain on the combined hazard-Land Use Seismic risk map so as to enable accurate risk assessment of each ward of the city. (Fig. 2).

The hazard values obtained for the area were classified as high, moderate and low, based on relative comparison of PGA values, as compared to a maximum PGA of 0.143 g and a minimum 0.122 g. By visual interpretation, the urban areas was classified as high, moderate and low based on the concentration of built up area in the LU map.

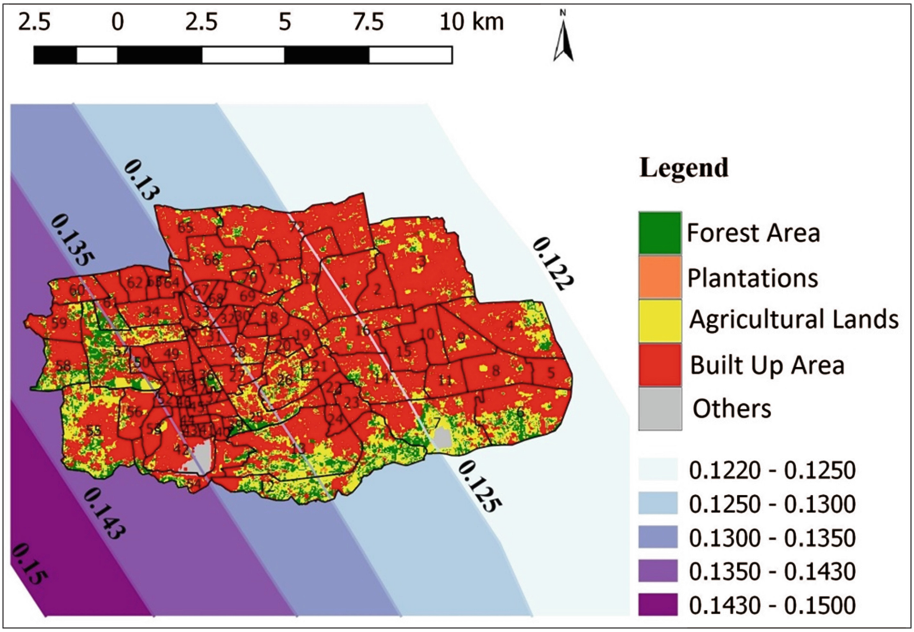

Fig. 2. Integrated ward wise seismic risk map (All values are expressed in terms of 'g')

3 Results and Discussions

3.1 Hazard and Land Use Map

Hazard contour mapping. Coimbatore falls within a PGA range of 0.122 g–0.143 g, with the southwestern zones of the city falling in the PGA range 0.135 g–0.143 g and northeastern zones in the range of 0.122 g–0.125 g (Fig. 1). The PGA distribution pattern was found to be in order with the ones estimated in previous similar studies (Anbazhagan et al. 2012), but with relatively lesser PGA values. The currently predicted PGA values for Coimbatore were found to be comparatively greater than the zone factors of 0.08 g specified in IS 1893 (BIS 2002).

Land Use classification. Coimbatore city spans over a total area of 106.56 sq.kms where only 29.67 sq.kms of the land is covered by forests, plantations, agricultural lands, water bodies and open areas altogether, the remaining being built up and populated areas. About 72% of the city is built up land (Table 1) indicating the presence of urban settlements in the form of all types of commercial buildings, public buildings, residential buildings, industrial buildings and other city infrastructure. Southern and eastern parts of the city has lesser built up area, indicating lesser vulnerability and risk of the region in the event of an earthquake (Fig. 1).

Table 1. Coimbatore city land use classification for the year 2016.

Description	Square kilometre	Hectares	Percentage cover
Forest area	9.0621	906.21	8.51
Plantations	0.4149	41.49	0.39
Agricultural lands	19.1718	1917.18	17.99
Built up area	76.8789	7687.89	72.16
Open areas and water bodies	1.0179	101.79	0.95

3.2 Integrated Risk Mapping

The wards with higher PGA range and higher concentration of built up areas indicate a larger population under higher risk, whereas the wards with higher PGA range and lesser concentration of built up areas indicate lesser population under higher risk. Such wards are categorized as high-risk wards and moderate-risk wards respectively (Table 2). Similarly, wards with lower PGA range and lower concentration of built up areas are classified as low-risk wards.

Table 2. Risk categorization.

Hazard*	Built up area	Risk
Moderate	Low	
Low	Low	Low
Low	Moderate	
High	Low	
Moderate	Moderate	Moderate
Low	High	
High	High	
High	Moderate	High
Moderate	High	

*High – 0.13 g to 0.143, Moderate - 0.125 g to 0.13 g, Low-0.122 to 0.125.

Hence, 35 wards out of a total of 72 wards of the city have been categorized as high-risk wards, 2 wards as low-risk wards and the rest as moderate-risk wards. Areas such as Selvapuram, PN pudur, VOC nagar, Agricultural university, Selvapuram south, RS Puram, Ukkadam, town hall, Saibaba colony and Tatabad are the major areas under high-risk. Gandhipuram, Sanganur, Lakshmi mills, Racecourse, PN palayam and Uppilpalayam are the major areas under moderate-risk, and Nanjundapuram, Singanallur, Keelakarai and Karumbu kadai are the major areas falling under low-risk according to the integrated seismic risk map (Fig. 2).

4 Conclusion

In the present study, an updated earthquake catalog was created for Coimbatore and surrounding regions considering historical and instrumental seismic events dataset from various agencies like Bhabha Atomic Research Centre (BARC), India Meteorological Department (IMD), Indira Gandhi Centre for Atomic Research (IGCAR), Kalpakkam, National Geophysical Research Institute (NGRI) Hyderabad, International Seismological Center (ISC) data file, Harvard seismology and USGS/NEIC catalogue etc., which was then homogenized and declustered to remove foreshocks and aftershocks. A state of the art Deterministic seismic hazard analysis was carried out considering three attenuation relationships (Raghu Kanth and Iyengar 2007; Atkinson and Boore 2006; Campbel and Bozorginia 2004) to estimate the peak ground acceleration at grid points selected in the study region. Spatial variation of seismic hazard in the region was presented as contour map using GIS tools.

Land Use map was developed for the city using LANDSAT-2016 images using GIS software tools. An administrative map for the Coimbatore city showing ward-wise boundaries was also developed using GIS software. An integrated risk map was developed for the region by overlaying all three maps. The south-western wards were identified to have maximum seismic risk compared to other wards. Even though Eastern and North-eastern wards have higher built-up land use area, risks in these wards are found to moderate to low, as these wards have low hazard values when compared to western part of the city. The findings from this study will be useful for town planners and engineers as directions for future expansion and infrastructure development of the city. These findings will also aid in seismic retrofitting of existing buildings and increasing the seismic resilience of city residence by inducing the earthquake risk awareness into public consciousness.

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