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Representative seismic hazard map of Coimbatore, India

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A R T I C L E I N F O

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A B S T R A C T

The seismic hazard value of any region depends upon three important components such as probable earthquake location, maximum earthquake magnitude and the attenuation equation. This paper presents a representative way of estimating these three important components considering region specific seismotectonic features. Rupture Based Seismic Hazard Analysis (RBSHA) given by Anbazhagan et al. (2011) is used to determine the probable future earthquake locations. This approach is verified on the earthquake data of Bhuj region. The probable earthquake location for this region is identified considering earthquake data till the year 2000. These identified locations match well with the reported locations after 2000. The further Coimbatore City is selected as the study area to develop a representative seismic hazard map using RBSHA approach and to compare with deterministic seismic hazard analysis. Probable future earthquake zones for Coimbatore are located considering the rupture phenomenon as per energy release theory discussed by Anbazhagan et al. (2011). Rupture character of the region has been established by estimating the subsurface rupture length of each source and normalized with respect to the length of the source. Average rupture length of the source with respect to its total length is found to be similar for most of the sources in the region, which is called as the rupture character of the region. Maximum magnitudes of probable zones are estimated considering seismic sources close by and regional rupture character established. Representative GMPEs for the study area have been selected by carrying out efficacy test through an average log likelihood value (LLH) as ranking estimator and considering the Isoseismal map. New seismic hazard map of Coimbatore has been developed using the above regional representative parameters of probable earthquake locations, maximum earthquake magnitude and best suitable GMPEs. The new hazard map gives acceleration values at bedrock for maximum possible earthquakes. These results are compared with deterministic seismic hazard map and recently published probabilistic seismic hazard values.

1. Introduction

Seismic hazard analysis is the process of estimating the seismic hazard parameters such as peak ground acceleration (PGA), peak ground velocity (PGV), peak ground displacement (PGD) and spectral acceleration at different periods. These seismic hazard parameters are the essential components in any earthquake resistant design. Seismic hazards can be analyzed deterministically; as and when a particular earthquake scenario is assumed. The probabilistic approach is the other way of seismic hazard analysis, in which uncertainties in earthquake size, location and time of occurrence are explicitly considered and are combined at the end (Kramer, 1996). The probabilistic seismic hazard analysis provides not one, two, or three choices, but infinite choices for the user and decision-makers (Wang, 2005). Krinitzsky (2005) commented on the problems in the application of probabilistic methods and gave an deterministic alternative, which highlights that “A Deterministic Seismic Hazard Analysis (DSHA) uses geology and seismic history to identify earthquake sources and to interpret the strongest earthquake each source is capable of producing regardless of its exposure time, because that earthquake might happen tomorrow”. Also, DSHA practically accounts for all the inherent uncertainties explicitly (Panza et al., 2011). Presently used Probabilistic Seismic Hazard Analysis (PSHA) cannot fill the gap of knowledge in the physical process of an earthquake (Klügel, 2005a,b,c). Recently, scenario-based seismic hazard analysis was recommended by Klügel et al. (2006) over traditional PSHA, which accounts parameters appropriate for damage index of the structures. Earthquake data and the knowledge of various tectonic features are the two basic requirements for seismic hazard analysis of any region of interest. Even though the deterministic approach takes into account the worst scenario and probabilistic approach considers the recurrence relation and uncertainties involved to estimate hazard parameters, the estimated values weakly match with the actual earthquake hazard values (Tsang, 2011). Maximum earthquake magnitude and locations arrived in the deterministic hazard analysis do not match with the reported earthquake magnitudes and locations. Spectral acceleration reported during recent earthquakes are much more than spectral values estimated considering the probabilistic approach (Tsang, 2011). There are many

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recent examples where actual ground shaking during an earthquake was much higher than what were predicated by the hazard maps (Stein et al., 2011). This may be due to poor representation of probable earthquake location, regional seismic source characters and attenuation models. In order to overcome these issues, Rupture Based Seismic Hazard Analysis (RBSHA) method was proposed by Anbazhagan et al. (2012). In RBSHA, probable future earthquake locations are identified by eliminating the past ruptured sources and considering the seismic sources associated with the recent minor earthquakes. A summary of RBSHA method is given in the next section and more details about RBSHA can be found in Anbazhagan et al. (2012).

In the present study, validation of the probable future earthquake zones in the Bhuj region of Gujarat (India) and seismic hazard map of Coimbatore is attempted using RBSHA method. Probable future earthquake locations for study area are identified by considering recent minor earthquakes, associated seismic sources and eliminating ruptured sources during past earthquakes. The regional rupture characteristic is established by estimating the subsurface ruptured length (RLD) for past earthquakes using well established correlation between the magnitude and subsurface rupture length. The possible earthquake magnitudes for each probable earthquake zone are estimated by considering the regional rupture character and the length of seismogenic sources close to the probable earthquake zone. Further, best ground motion prediction equations (GMPEs) for a region is selected, instead of considering available two to three GMPEs randomly. Efficacy test has been carried out considering macro seismic intensity map in the region and information-theoretic approach proposed by Scherbaum et al. (2009). Hazard values at bedrock have been estimated considering probable earthquake zones, regional maximum earthquake magnitude and best suitable GMPEs. The conventional deterministic seismic hazard analysis (DSHA) has been carried out and PGAs are estimated. PGA values estimated in this study using RBSHA are compared with deterministic hazard results and existing probabilistic hazard results.

2. Methodology

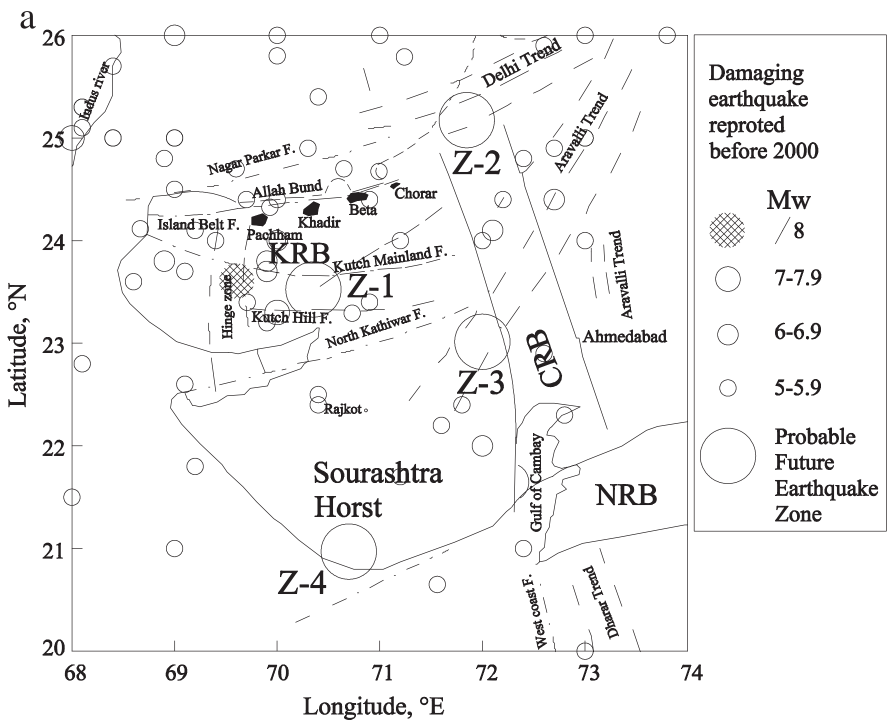
The study area of Coimbatore (India) is selected in this work to develop a representative seismic hazard map considering rupture based seismic hazard analysis. Anbazhagan et al. (2012) presented methodology for RBSHA without validating the identification of probable future earthquake locations. This study presents improved steps for RBSHA with validation of probable future earthquake locations identification for Bhuj region and preparation of representative seismic hazard map for Coimbatore area. A seismic study area in Coimbatore is identified by considering past Isoseismal map in the region. Seismotectonic map of Coimbatore is generated by merging regional earthquake data from Anbazhagan et al. (2012), Menon et al. (2010), Sreevalsa et al. (2012a) and seismic source details published by SEISAT (2000). All earthquakes are studied and delineated damaging earthquakes (MW > 5 for the study area) sources/area and minor earthquake sources/area. Probable future earthquake locations in the study area are identified by considering recent minor earthquakes, associated seismic sources and eliminating ruptured sources during past earthquakes. The regional rupture characteristics are established by estimating the subsurface ruptured length (RLD) for past earthquakes using well established correlation between the magnitude and subsurface rupture length. These RLD are normalized with respect to the total length of the source. The possible earthquake magnitudes for each probable earthquake zone are estimated by considering the regional rupture character and the length of seismogenic sources close to the probable earthquake zone. Further, an additional step is carried out in this paper for selecting appropriate GMPEs for estimating hazard values. Appropriate GMPEs are identified from multiple applicable GMPEs in the study area by carrying out efficacy test. Hazard values at bedrock are estimated considering probable earthquake zones, regional maximum earthquake magnitude and best suitable GMPEs. Coimbatore is divided into grids and peak ground acceleration (PGA) at the center of each grid has been estimated considering hypocentral distance, maximum possible earthquake and representative attenuation relations. Representative rock hazard map is computed by considering maximum of all PGA from probable future earthquake locations.

3. Rupture based seismic hazard analysis

Most of the seismic hazard analyses/zonations are being carried out considering past earthquake location, size and rate of occurrence of earthquakes on the fault or in the region for future structure design. Moderate to major size earthquakes need sufficient energy to rupture the faults. The time required to build-up the required energy to create moderate to major earthquakes in the same location of previous earthquake is region specific. Therefore, the interval between two consecutive earthquakes in the same location is considerable, but it has not been fully accounted in the current hazard analysis and seismic zonation practices. In order to account for this, Anbazhagan et al. (2012) proposed Rupture Based Seismic Hazard Analysis (RBSHA). Based on the average return period of the damaging earthquakes (M_w >5 for the study area) in the region, the potential of past damaged earthquake locations for generating the future similar earthquakes can be worked out. The past earthquake location may be eliminated or considered for seismic hazard analysis depending on the life and the type of structures. Design of low to medium rise buildings and microzonation for urban planning and disaster management usually require hazard values for a period of next 50 or less years. The ruptured source in the last 50 to 100 years due to past damaging earthquakes may not rupture for the next 50 years for the region having a return period of 200 to 500 years (Jaiswal and Sinha, 2008). For example, Coimbatore had damaging earthquake during 1900, but there is no such damaging earthquake in the past 112 years in the same source/location. Ruptured sources need minimum period i.e. average return period or more to build energy to cause another rupture in the same location/source. In RBSHA method the possibility of occurrence of earthquake in the locations other than past damaging earthquake locations are accounted. The subsurface rupture length (RLD) of source which experienced past damaging earthquake was estimated considering Wells and Coppersmith (1994) correlation. A circle is drawn considering RLD as diameter and the epicenter as center, called as an influence circle for respective earthquake. In the absence of surface rupture signature and exact rupture area, influence circle shows ruptured region. The probable locations are identified by considering the minor earthquakes, potential seismic sources and by eliminating the damaging earthquake location (influence circle). These are called as the 'Probable Future Earthquake Zones' (PFEZ). Anbazhagan et al. (2012) showed the difference between hazard values from PFEZ and conventional deterministic hazard analysis. But the authors do not validate the identification of Probable Future Earthquake Zones. The first objective of this paper is the validation of probable earthquake zone by typical case study. The next objective is to develop a representative hazard map of the selected area by considering suitable maximum earthquake magnitude and ground motion prediction equations.

4. Validation of probable future earthquake zones

Bhuj in Gujarat, India is selected to check the Probable Future Earthquake Zones in the rupture based seismic hazard analysis. Bhuj has a complete record of historical and recent seismic activity with well defined seismic source details among intraplate regions. Bhuj is geographically in the center of Kutch district. Kutch is virtually an island, as it is surrounded by the Arabian sea in the west, the Gulf of Kutch in the south and southeast and Rann of Kutch in north and northeast. Though geographically it forms a part of peninsular India, the seismotectonic characteristics of Kutch region are somewhat different from the rest of the Peninsular India. Kutch Rift Basin (KRB) was developed during the Jurassic period (Gupta, 2006) and is characterized by highlands (uplifts) which are oriented generally along E–W and they tend to have escarpments facing the plains (Bodin et al., 2004). Major tectonic features in Kutch and adjoining areas modified after Gupta (2006) are shown in Fig. 1(a). The important E–W faults controlling the structural trend of the Kutch rift are the Nagar Parkar Fault forming the northern boundary of KRB, the Allah Bund Fault, the Island Belt Fault, the Kutch Mainland Fault, the Katrol Hill Fault and the North Kathiawar Fault forming the southern boundary of the KRB. These E–W trending master faults are displaced by NE–SW trending faults. In addition to this, KRB is restricted by NNW–SSE trending Cambay Rift Basin (CRB). Due to these typical geotectonic features of the Kutch basin and its spatial positioning relative to the Himalayan plate boundary, this area exhibits much higher level of seismicity compared to the rest of the peninsular India (Gupta, 2006). The



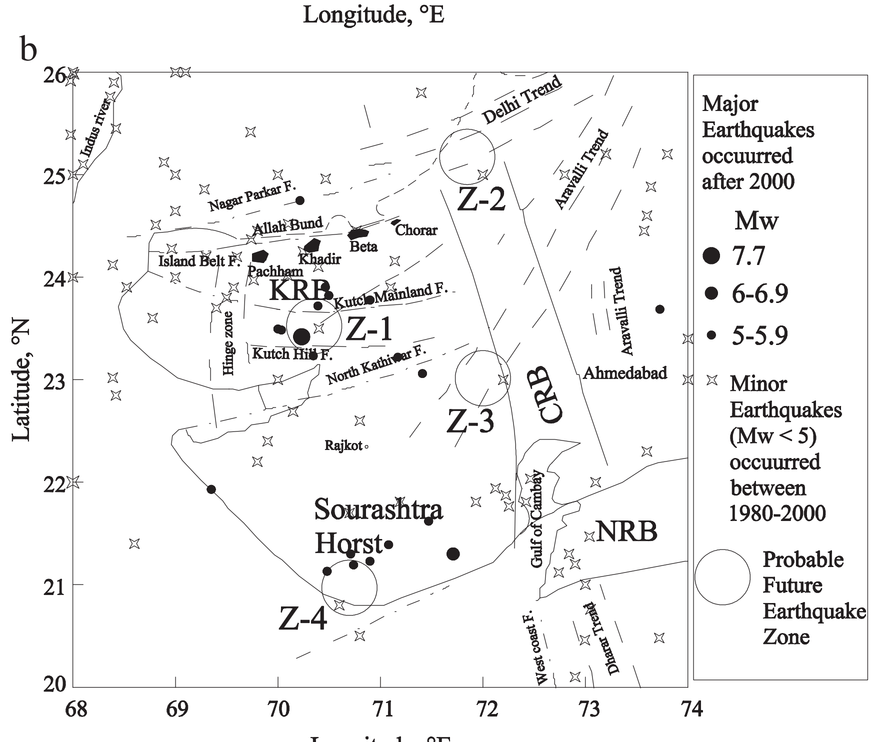


Fig. 1. (a) Seismotectonic of Bhuj region and reported past earthquake magnitude above 5 for period of 1800 to 2000. (b) Seismotectonic of Bhuj region and reported recent minor earthquake magnitude below 5 for period of 1980 to 2000 and Earthquakes reported above 5 after 2000.

three major earthquakes in the Kutch region are 1819 Allah Bund earthquake (M_w 7.8), 1956 Anjar earthquake (M_w 6.0) and 2001 Bhuj earthquake of (M_w 7.7).

4.1. Identification of PFEZs for Bhuj

In order to locate the probable future earthquake zones in Bhuj region, the earthquake data from the year 1800 to 2010 is considered. The data have been divided as two sets (a) data from 1800 to 2000 and (b) data set after 2001. The minor and major earthquakes in the region are delineated in both the data sets. The source which was ruptured by these damaging earthquakes may not create next earthquake within 100 years (less than the average return period of the region) due to insufficient time to for build strains. The probable earthquake zones are located by eliminating the locations of past earthquake with magnitude above 5 reported prior to 2000. These locations may not be ruptured sufficiently to release energy and had not caused any damaging earthquake in the past 200 years, hence these are identified as probable future earthquake zones. These probable future earthquake locations are shown in Fig. 1(a) along with past damaging earthquakes. Four zones are identified and these locations have not ruptured due to any damaging earthquake in the past 200 years. These zones are also satisfying the other two mandatory conditions given by Anbazhagan et al. (2012) which are; a) potential future earthquake zones must have minor earthquake events in the past 20 years and b) active seismic source should be within 10 km of radius. The minor earthquakes reported during 1980–2000 have been overlapped in Fig. 1(a) and shown in Fig. 1(b). It can be noticed that the identified four zones have experienced many minor earthquakes and are close to seismic sources. Further, damaging earthquakes reported in the region after 2001 have been plotted in Fig. 1(b). It is found that the location of Z-1 (Z indicates zone) identified in this study matches well with the epicenter of the devastating 2001 Bhuj earthquake with M_w of 7.7. Similarly, Z-4 has experienced many damaging earthquakes of $M_w > 5.0$. So, it can be highlighted that the probable future earthquake zones identified by Anbazhagan et al. (2012) are potential for near future earthquakes. A similar procedure is used to identify the probable future earthquake zones for Coimbatore City in order to estimate the representative seismic hazard values for seismic microzonation studies.

5. Study area of Coimbatore

Coimbatore is the second largest city of the state of Tamil Nadu, India. The city of Coimbatore is extended between latitude 10° 10′ N to 11° 30′ N and longitude 76° 40′ E to 77° 30′ E. It is situated in the west part of Tamil Nadu state, bordering the state of Kerala. Fig. 2 shows the map of Coimbatore City with important locations and its location in Indian subcontinent. The city is located at an elevation of 432 m above MSL (Mean Sea Level). Coimbatore has an area of 105.5 km^2 at city level and a population of over a million. The city is surrounded by the Western Ghats mountain range on the west and north, with reserved forests and the Nilgiri Biosphere Reserve on the northern side. The eastern side of the district, including the city is predominantly dry. The entire western and northern part of the district borders the Western Ghats with Nilgiri biosphere as well as Annamalai and Munnar ranges. A western pass to Kerala, popularly referred to as the Palghat Gap provides the western boundary to Coimbatore. The soil is predominantly black soil suitable for cotton cultivation with a frequent interlude of red loamy type soil. Coimbatore comes under Seismic Zone III as per IS 1893 (BIS, 2002), and has experienced an earthquake of moment magnitude (Mw) 6.3 in the past. This earthquake was reported on 8th February 1900 located at 10°48′ N, 76°48′ E.

6. Seismotectonics and probable future rupture zone

Identification and delineation of seismogenic sources is the most important step in any seismic hazard analysis (Gupta, 2006). Southern India, once considered as part of the stable continental region has recently experienced many small earthquakes and 11 earthquakes of magnitude more than 6 (Ramalingeswara Rao, 2000), indicating that its perceived seismicity is not correct. The seismicity of Peninsular India (PI) has a relatively high frequency of large earthquakes and low

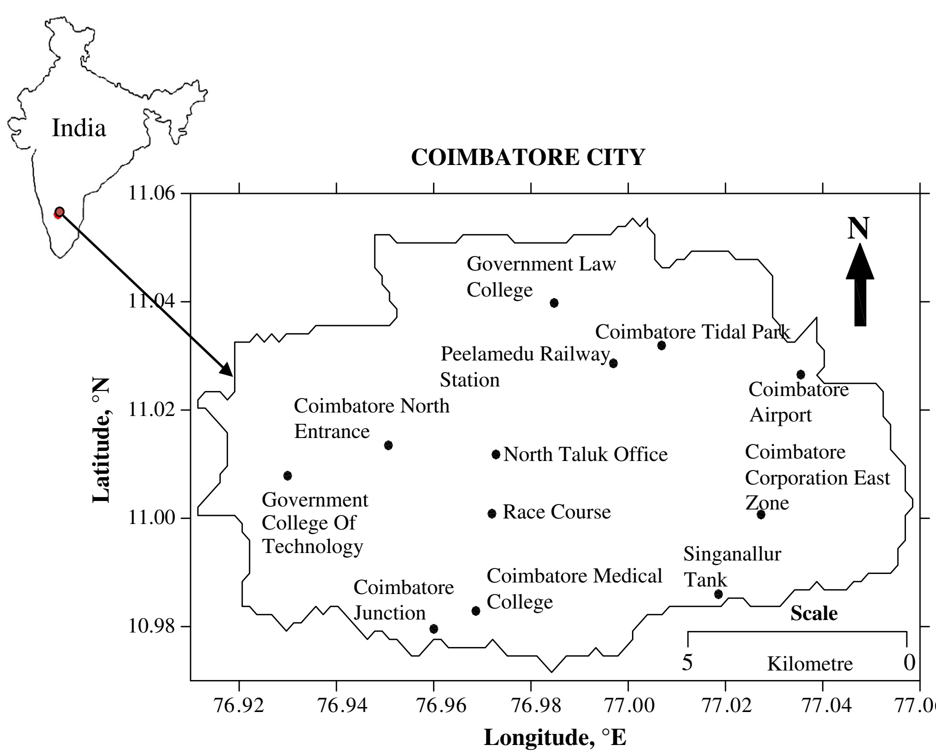


Fig. 2. Study of Coimbatore map and its locations and seismic study area boundary in India.

frequency of moderate earthquakes (Menon et al., 2010). Seismicity of south India is also observed and explained by Chandra (1977), Srinivasan and Sreenivas (1977), Valdiya (1998), Purnachandra Rao (1999), Ravi Kumar and Bhatia (1999). Ramalingeswara Rao (2000), Subrahmanya (1996, 2002), Ganesha Raj (2001), Parvez et al. (2003), Sridevi (2004), Ganesha Raj and Nijagunappa (2004), Singh et al. (2005, 2008), Sitharam et al. (2006), Sitharam and Anbazhagan (2007) and Anbazhagan et al. (2009, 2010a, 2013). For this study earthquake data compiled by Anbazhagan (2007), Menon et al. (2010), Sreevalsa et al. (2012a) and the seismic source details published by SEISAT (2000) have been merged together and seismotectonic map of Coimbatore has been generated as shown in Fig. 3. Fig. 3 also shows the past reported earthquakes of all magnitudes within 300 km radius from Coimbatore. Probable earthquake zones are identified by Anbazhagan et al. (2012) using the procedure discussed in the previous section. In the seismic study area (i.e. 300 km around the Coimbatore City), eight such zones were identified. There may be possibilities of occurrence of future damaging earthquakes in these zones. These eight probable future rupture zones are nomenclatured as Z-1 to Z-8 for further discussion and are also shown in Fig. 3. Summary of probable earthquake zones is presented in Table 1. The area around Coimbatore i.e. South India has experienced five minor tremors in 2011–2012 and which were felt widely by many villages and were also reported in local news, Indian Meteorological Department (IMD) and Amateur Seismic Centre (ASC). These five separate minor earthquakes were of Mw above 2 among which three events ranged from 3.0 to 4.0. Fig. 3 also shows these three earthquake locations, where it can be noticed that the two events were reported in northeastern part of seismic study area, where four probable zones are identified. Another event is located in south western part of seismic study area where three probable zones are identified. These minor earthquakes may be indicative of ongoing seismic activity of the region.

7. M_{max} estimation using regional rupture character

Maximum credible earthquake (MCE) of each source is important as this value is used to arrive at structural design seismic parameters. Maximum earthquake of each seismic source is usually calculated based on slip rate of fault and past seismic history. However, because of the low seismicity levels and lack of surface faulting in the intraplate study region, maximum magnitude is being estimated considering (1) addition of an incremental value to the largest reported earthquake magnitude, (2) extrapolation of magnitude recurrence relations and (3) maximum source dimension and magnitude estimation (Bollinger et al., 1992). In the absence of slip rate and considering low seismicity of the region, the maximum magnitude is estimated by the addition of an incremental value to the largest reported earthquake close to the source. This methodology is adopted by RaghuKanth and Iyengar (2006), Sitharam and Anbazhagan (2007), Anbazhagan et al. (2009, 2010b) for the study region of PI and have estimated maximum magnitude of each source by adding 0.5 units to past earthquake close to the source. This procedure is widely followed in India because of the absence of slip rate model and limited seismic database. Menon et al. (2010) estimated the maximum cutoff magnitude for each source by increasing 0.3 units of the maximum historical earthquake (MHE) close to the source zone for a part of south India. Recently RaghuKanth (2010 and 2011) estimated the seismic hazard parameters “b” values and maximum earthquake magnitude for India using maximum likelihood method by Kijko and Graham (1998). It can be noted here that maximum earthquake estimated depends on “b” values which in turn depends on the frequency magnitude distribution (FMD) of the region. Sreevalsa et al. (2012a) showed the variation of “b” values for the same region using different data sets. Fault rupture depends on source parameters such as density and shear wave velocity (SWV) of the crustal rock at rupture and other controlling parameters of asperities and barrier. These parameters are indirect representation of the shear strength of rock. In PI, these (density and SWV) source parameters are considered as uniform in many seismological models based on geology and deep geophysical data. If the rock is uniform in the region then the rupture characteristics will also be uniform which means that the average rupture dimension with respect to total dimension will also be similar. This can be used to define the rupture character of the region by considering regional average rupture dimensions. Anbazhagan et al. (2012) have established rupture character of the region by carrying out parametric study between subsurface rupture lengths and associated past earthquake magnitude for 18 faults which have caused earthquakes of M_w 5 and above. The total fault length was taken from seismotectonic map and RLD was calculated using Well and Coppersmith (1994) considering past earthquake magnitude. RLD values are divided by the total length of the fault and subsurface

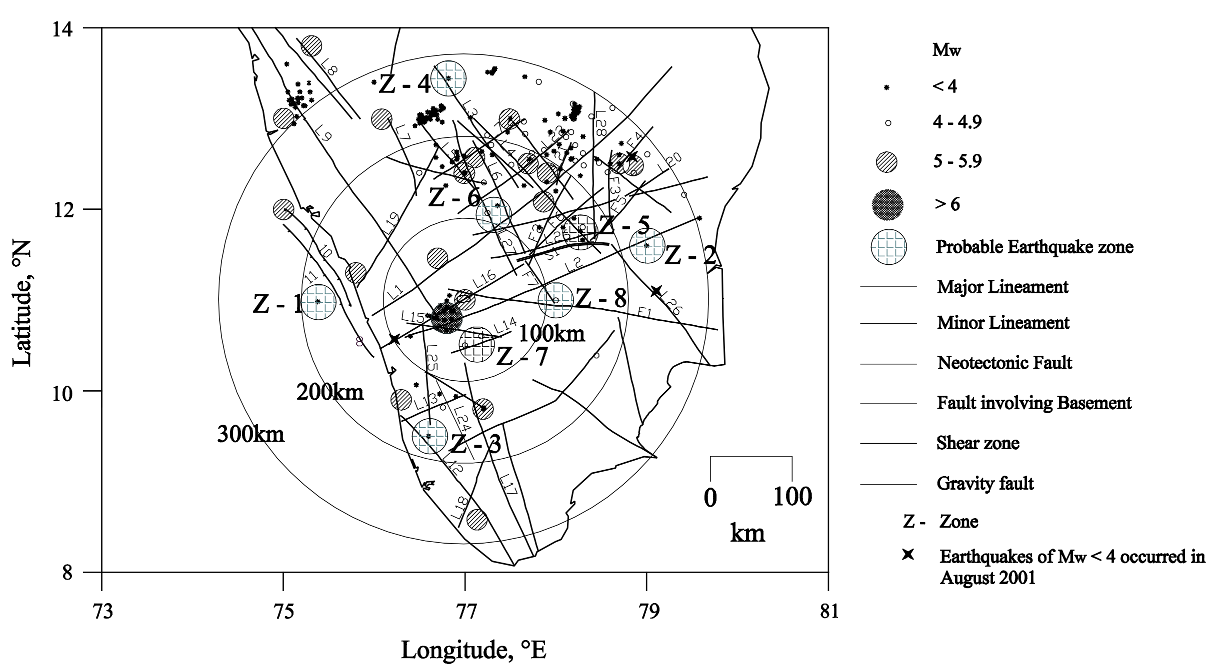


Fig. 3. Seismotectonic map of Coimbatore with probable future earthquake locations and three minor earthquakes reported in this region.

Table 1
Details of probable future earthquake zones.

Zone	Zone location		Distance from Coimbatore (km)	Minor earthquake M_w (Max. of all)	Number of minor earthquakes within 10 km
	Latitude (°North)	Longitude (°East)			
Z-1	10.98	75.38	180	3.0	1
Z-2	11.60	79.01	230	2.5	1
Z-3	09.50	76.62	175	3.7	1
Z-4	13.44	76.82	270	2.1	1
Z-5	11.74	78.27	165	4.6	5
Z-6	11.94	77.32	110	4.7	2
Z-7	10.51	77.13	60	4.5	2
Z-8	11.00	78.00	110	4.9	1

rupture length is represented as a percentage of the total length of the fault. Anbazhagan et al. (2012) noticed that the estimated magnitude matches very well with the reported earthquake magnitude for a subsurface rupture length of 1.65% to 6.6% of total fault length. Fig. 4 shows the plot of subsurface rupture length in terms of percent of total length of fault versus total length of fault for 18 reported earthquakes in the study area. It can be noticed from Fig. 4 that the percentage of the total fault ruptured for shorter faults are more when compared to that of longer faults, showing a decreasing trend with an increase in the fault length. This indicates that most of the damaging earthquakes in the region follow some trend. Based on the observed trend, the curve is divided into two segments considering the average percentage of fault ruptured and total length of the fault. Segment-I consists of faults with total length up to 120 km and average RLD equal to 4.86% of total length of the fault. Segment-II consists of faults with a total length of 120 km to 450 km and average RLD equal to 2.15% of total length of the fault (see Figure 4). The rupture values of these two segments can be taken as an average rupture character of the region and the same can be considered to estimate design basis earthquake magnitude for the region. However, unusual rupture can cause large events where RLD is larger than the average regional rupture values. These are the maximum reported earthquakes in that region and are marked in Fig. 4. Subsurface rupture lengths of these two events are 4.72% and 5.41% of the total length of the fault. These values are close to the average RLD of segment I. Further, it can be noticed from Fig. 4 that more than 55% of the seismic sources in the segment I have average RLD of 4.86% of the total fault length. Therefore, a maximum possible earthquake magnitude in the region is associated with the upper value (segment I) of the average rupture character of the region i.e. 4.86%. This value is increased to account for the variance and the increased value is used to estimate the representative maximum earthquake of the source considering Wells and Coppersmith (1994) correlation. In this study, average regional rupture length value is increased from 4.86% to 6% of the total fault length and the same is used to estimate maximum possible earthquake magnitude for each seismic source close to probable seismic zones. Maximum possible earthquake magnitude for each zone estimated using the increased rupture character of the region is listed in Table 2. Maximum of the possible earthquake magnitudes for each source zone is considered as the Maximum Credible Earthquake (MCE) for the city of Coimbatore.

8. Ground-motion prediction equations

Suitable ground motion predictive equation/attenuation relation to calculate ground-motion in terms of PGA or spectral acceleration (SA) is a pre-requisite for seismic hazard analysis of the particular region. Most of the stable continents/regions in the world have poor strong-motion data and are not representative of the existing seismic hazard in the region (Menon et al., 2010). Coimbatore, South India has almost no strong motion records for moderate to large earthquakes. Therefore, there are no ground motion predictive equation/attenuation models developed considering the recorded earthquake data. For the area having poor seismic record, the synthetic ground motion model is an alternative. Regional synthetic ground model should include seismotectonic and geological settings (e.g., shallow crustal intraplate earthquakes) in the region. Modeling of strong motion helps to estimate future seismic hazard of the region and associated local site effects. Seismological model by Boore (1983 and 2003) is widely used in stable continent regions for generating the synthetic acceleration-time histories (Atkinson and Boore, 1995; Hwang and Huo, 1997; Sitharam and Anbazhagan, 2007) and attenuation relations.

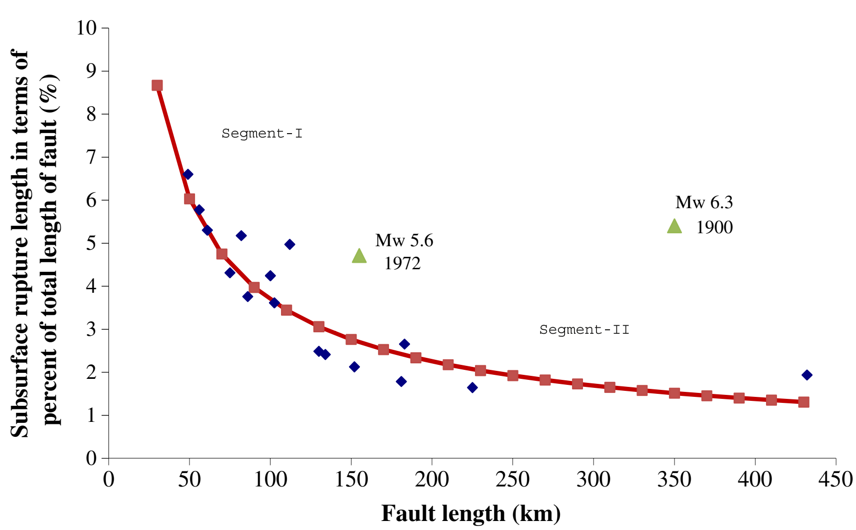


Fig. 4. Regional subsurface rupture length terms as percentage of total fault length correlated with total length of fault.

Table 2
Maximum possible earthquakes for various zones.

Zones	Associated source	Probable earthquake magnitude of each source considering the regional rupture character (M_w)	Maximum earthquake magnitude for each source zone (M_w)
Z 1	L11	5.8	5.8
Z 2	L2	6.4	6.4
	L26	5.9	
Z 3	L12	6	6
	L24	5.4	
	L25	5.5	
Z 4	L3	5.8	5.8
Z 5	S1	5.5	5.5
Z 6	L1	6.5	6.5
	L27	5.9	
	F6	5.5	
	L26	5.6	
	L28	5.7	
	F5	5.4	
Z 7	L14	5.2	5.5
	L15	5.5	
Z 8	F1	6.3	6.3
	F7	5	

There was no region specific ground motion predictive equation before 2004 for Peninsular India, in particular, South India. Now there are many attenuation equations to determine the PGA values for a given earthquake of known magnitude and hypocentral distance. Among all the GMPEs, the equations which are valid for the study area and their abbreviations are given in Table 3. The equations developed for Eastern North America (ENA) have also been considered in this study because of the similarity of regional tectonics of peninsular India with ENA (Bodin et al., 2004). The attenuation of strong motion in peninsular India (PI) is similar to that in the other intraplate regions of the world (Iyengar and Raghukanth, 2004). The nine GMPEs are considered in the study out of which two GMPEs were developed for peninsular India and other seven GMPEs were developed for other intraplate regions of the world. Summary of these nine GMPEs are given below.

Hwang and Huo (1997) developed the attenuation relations of peak ground acceleration (PGA) and spectral acceleration (SA) for rock and soil sites in the central and eastern United States using simulated bedrock ground motion considering 56 pairs of moment magnitude M_w and epicentral distance R. Toro et al. (1997) derived four sets of ground-motion attenuation equations for rock site condition in Central and eastern North America based on stochastic ground motion model. Toro (2002) further modified Toro et al. (1997) equation for larger magnitudes and short distances considering empirical modeling approach. Campbell (2003) proposed a hybrid empirical method that uses the ratio of stochastic or theoretical ground motion estimated to adjust empirical ground-motion relations developed for one region to use in other region. Tavakoli and Pezeshk (2005) utilized an alternative approach, where a stochastic model is used to derive modification factors from the ground motions in West North America (WNA) to the ground motions in ENA. Atkinson and Boore (2006) developed a GMPE for hard-rock and soil sites in ENA, including estimation of their aleatory uncertainty based on a stochastic finite-fault model. Iyengar and Raghukanth (2004) and Raghukanth and Iyengar (2007) statistically simulated ground motions in peninsular India using a well-known stochastic seismological model and regional seismotectonic parameters. Atkinson (2008) followed a reference empirical approach to develop GMPEs for ENA, which combines the ENA ground-motion database with the empirical prediction equations of Boore and Atkinson (2008) for the reference region of WNA. Finite fault stochastic seismological model was used by NDMA (2010) to develop strong motion attenuation relations for seven geological provinces of India with different stress drops and quality factors for each of these provinces. Atkinson and Boore (2011) compared the GMPEs for western North America (Boore and Atkinson, 2008) and eastern North America (Atkinson and Boore, 2006; Atkinson, 2008) to newly available ground-motion data and suggested revisions of both region GMPEs.

From the above discussion it can be noted that many equations developed for ENA is applicable to Coimbatore and also two region specific GMPEs were also developed by the same researchers for different research projects. Fig. 5 shows comparison of GMPEs given in Table 3 considering earthquake moment magnitude of 6 and up to a hypocentral distance of 300 km. From Fig. 5 it can be noticed that all GMPEs are following similar trends except CAM-03 and ATKB-11, where PGA values are suddenly reduced after a few kilometers. At a hypocentral distance of 10 km, lowest PGA is 0.262 g from ATK-08 GMPE and highest PGA is 1.913 g from TAPE-05 GMPE. Further the ratio between the maximum and minimum PGA values at every hypocentral distance has been estimated and shown in Fig. 6a. The maximum and minimum PGA values vary from 3.7 to 7.3. The lowest value of 3.7 is noticed at a hypocentral distance of 25 to 30 km for GMPEs of TAPE-05 by ATKB-06. The highest value of 7.3 is noticed at a hypocentral distance of 10 km for GMPEs of TAPE-05 by ATK-08 (see Figure 6a). This variation is not consistent with any particular GMPE. Eight GMPEs based PGA values give minimum or maximum PGA value for any particular hypocenter distance except GMPE by

Table 3
GMPEs applicable to Coimbatore with abbreviations, LLH values and ranks.

Sl. no.	Attenuation equation	Abbreviation of the equation	LLH value	Rank
1	Hwang and Huo (1997)	HAHO-97	2.4501	3
2	Toro (2002), extension of Toro et al. (1997)	TOR-02	2.4021	2
3	Campbell (2003)	CAM-03	2.6679	7
4	Tavakoli and Pezeshk (2005)	TAPE-05	2.6709	8
5	Atkinson and Boore (2006)	ATKB-06	2.3923	1
6	Raghukanth and Iyangar (2007)	RAIY-07	2.5755	6
7	Atkinson (2008), modification of Boore and Atkinson (2008)	ATK-08	2.5605	5
8	The National Disaster Management Authority, Govt. Of India, New Delhi (2010)	NDMA-10	2.5329	4
9	Atkinson and Boore (2011), modification of Boore and Atkinson (2008)	ATKB-11	2.6991	9

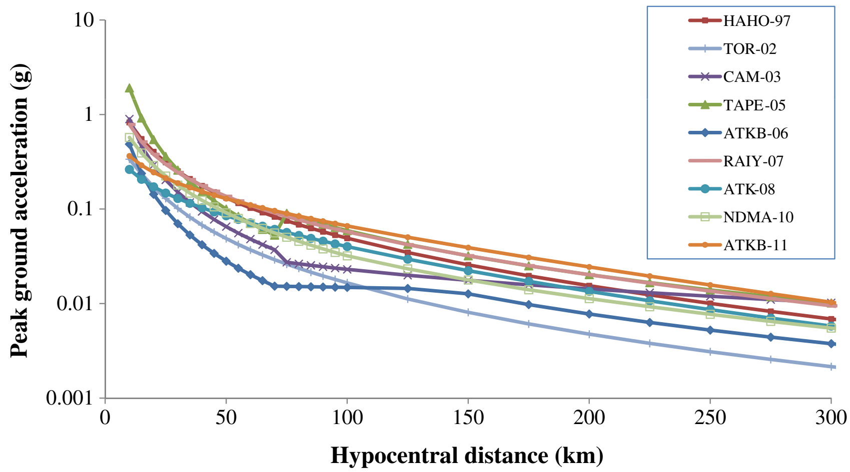


Fig. 5. Comparison of applicable ground motion prediction equations for Coimbatore region.

NDMA (2010). This equation predicting PGA values between maximum and minimum PGA values for all hypocenter distances. The position of NDMA (2010) GMPE with respect to maximum and minimum PGA from all GMPEs is shown in Fig. 6b. NDMA (2010) GMPE is recently developed for probabilistic seismic hazard mapping of India. The PGA values from NDMA (2010) GMPE is 1.4 to 3.4 times less than the maximum PGA values and 1.9 to 3.7 times more than the minimum PGA values obtained from other applicable GMPEs (see Figure 6a).

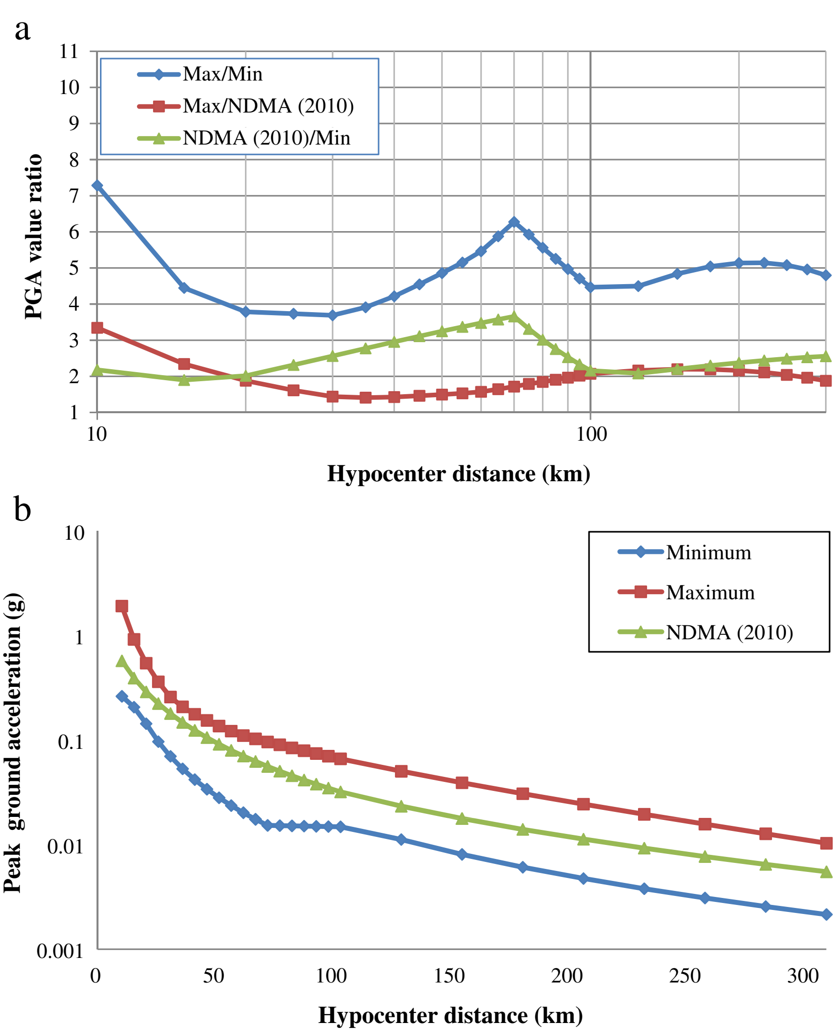


Fig. 6. Comparison of maximum and minimum PGA values from applicable GMPEs with regional GMPE developed for the preparation of probabilistic seismic hazard map of India. (a) Ratio of maximum and minimum PGA from applicable GMPEs and NDMA (2010) and (b) comparison of maximum and minimum PGA from applicable GMPEs and PGA from NDMA (2010).

The selection and ranking of appropriate GMPE for a study area often pose serious practical problems. Observed macroseismic intensity data can help to select suitable GMPEs in a systematic and comprehensive way.

9. Selection of GMPEs for the study area

Proper selection of GMPEs among the available GMPEs is significant in predicting the level of ground shaking and is a key element for any seismic hazard analysis (Bommer, et al., 2010). The GMPEs for a region must be capable of capturing the essence of ground motions i.e. earthquake source, path and site attributes at the same time. GMPE developments over the past four decades have shown rather consistency in the associated variability and epistemic uncertainty notwithstanding the increasing complexities (Douglas and Mohais, 2009; Strasser et al., 2009; Douglas, 2010; Nath and Thingbaijam, 2011). This necessitates the selection and ranking of GMPEs (Scherbaum et al., 2004, 2005; Bommer et al., 2005; Sabetta et al., 2005; Cotton et al., 2006; Hintersberger et al., 2007; Nath and Thingbaijam, 2011) and consequent usage of multiple GMPEs in a logic tree framework for the hazard analysis. In general, two to three GMPEs are selected to estimate the PGA for required earthquake magnitude and is compared with the observed PGA values. This method of random selection of two to three equations and comparison with observed values may not yield appropriate results, because of lack of systematic and comprehensive procedure. Therefore, in this study an attempt has been made to select the suitable GMPEs to calculate hazard values for Coimbatore.

Candidate GMPEs can be selected considering the criteria given by Bommer et al. (2010) and best GMPE is selected by carrying out efficacy tests proposed by Scherbaum et al. (2009, 2012). Efficacy test refers to a quantitative method to determine the suitability of GMPE for a particular region. The average sample log-likelihood (LLH) is one of the efficacy test that is used in the present study, Where, LLH is the measure of distance between the model and the data generating distribution. Therefore, a small LLH for a model indicates that it is close to the model that has generated the data (observed intensity in our case). Similarly, a large LLH for a model will indicate that it is less likely of being generated by the data (Delavaud et al., 2012). A ranking order for a suite of GMPE is decided based on LLH, the GMPE having the lowest LLH is ranked the highest and the one having highest LLH is ranked lower. The efficacy test makes use of average sample log-likelihood (LLH) for the ranking purpose. The method has been tested successfully by Delevaud et al. (2009) and applied to India by Nath and Thingbaijam (2011) and Anbazhagan et al. (2013). Nath and Thingbaijam (2011) gave suites of GMPEs for Himalayas, Northeast India and Peninsular India. However, the authors did not include recent GMPEs of NDMA-10 and ATKB-11. Hence for this study, efficacy test has been carried out by considering Macroseismic intensity map of 1900 Coimbatore earthquake and PGA-European Macroseismic Scale (EMS, Grünthal, 1998) relation at rock sites as is given by Nath and Thingbaijam (2011) for Indian crustal earthquakes.

The most damaging event in Coimbatore occurred on 8th February, 1900 with a magnitude of 6.3 (Tandon and Srivastava, 1974). A maximum intensity (EMS) value of VII was recorded in the region around the epicenter. The earthquake was felt throughout south India, south of 14° N, over an area of 25,000 km^2. The epicenter of the earthquake is 10.80° N of latitude and 76.80° E of longitude (Chandra, 1977). Macroseismic intensity map of 1900 Coimbatore earthquake is collected from SEISAT (2000). EMS intensity of IV to VII was reported due to this earthquake (see Figure 7) and similar earthquake may cause much higher intensities in unplanned engineering structures due to urban agglomeration in this region. The macroseismic intensity map was digitized and EMS values with distance were synthesized.

In order to quantify the suitability of GMPEs for Coimbatore, ranking estimator i.e., log likelihood (LLH) values are calculated for all the GMPEs, from which the ranking order of the set of GMPEs considered

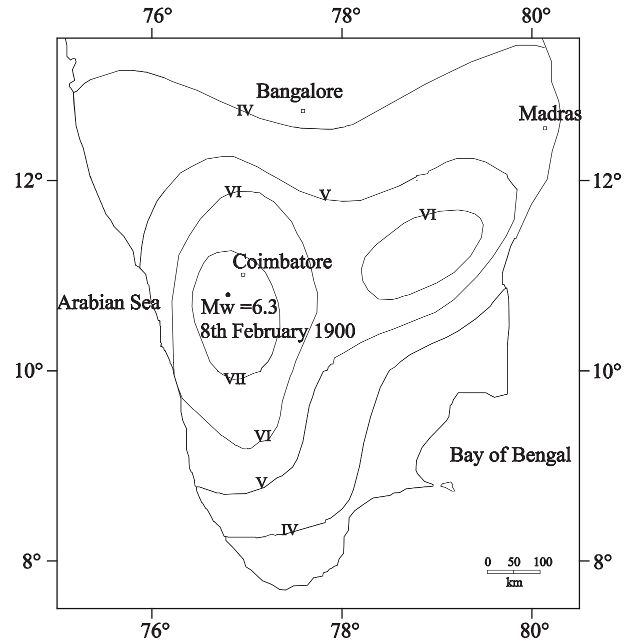


Fig. 7. Isoseismal map of Coimbatore 1900 earthquake with recent three minor earthquakes.
Modified after SEISAT, 2000.

is determined. Firstly, PGA was estimated for earthquake with M_w of 6.3 using all GMPEs and then it was converted to EMS using the relation between PGA and EMS by Nath and Thingbaijam (2011). Further, LLH for each GMPE was calculated using the equation given by Delevaud et al. (2009). The LLH values for all the nine equations, the ranking corresponding to LLH values and the order of GMPEs obtained in the study are given in Table 3. The best performances are attributed to the equations that are present in the first half of the ranking order (i.e., first to fifth equations, Delevaud et al., 2009). The first five GMPEs namely ATK-06, TOR-02, HAHO-97, NDMA-10 and ATKB-08 are the found best suited GMPEs for the Coimbatore. It can be noted here that ranking of the first two equations are similar to Nath and Thingbaijam (2011) ranking and GMPE by NDMA (2010) was not considered by Nath and Thingbaijam (2011). The LLH values estimated in this study are different from those obtained by Nath and Thingbaijam (2011). Nath and Thingbaijam (2011) estimated the LLH values considering the three major earthquakes in Peninsular India namely 2001 Bhuj, 1997 Jabalpur and 1970 Broach, but in this study Coimbatore earthquake of M_w 6.3 is considered. Ranking order arrived from this study is further used for the seismic hazard analysis. Seismic hazard values in terms of PGA for each source zone were calculated for Coimbatore using associated maximum possible earthquake magnitude and first five highly ranked GMPEs.

10. Hazard estimation for Coimbatore

In order to precisely map the seismic hazard values, Coimbatore City was divided into grid size of 0.01° × 0.01°. There are 160 grid points in total with approximate square size of 1.1 km × 1.1 km. Distances between the center of each grid point to each of the eight probable earthquake zones are estimated which is the epicenter distance. Anbazhagan et al. (2013) studied depth of the past earthquakes reported in PI and computed average minimum focal depth of moderate earthquakes as 10 km in the study region. In this study for the worst scenario, 10 km depth is considered as focal depth and epicenter distance estimated earlier are used together to estimate the hypocenter distance at the center of each grid point. Maximum possible earthquake magnitude for each probable earthquake zone given in Table 2 by considering the rupture character of the region. A maximum possible

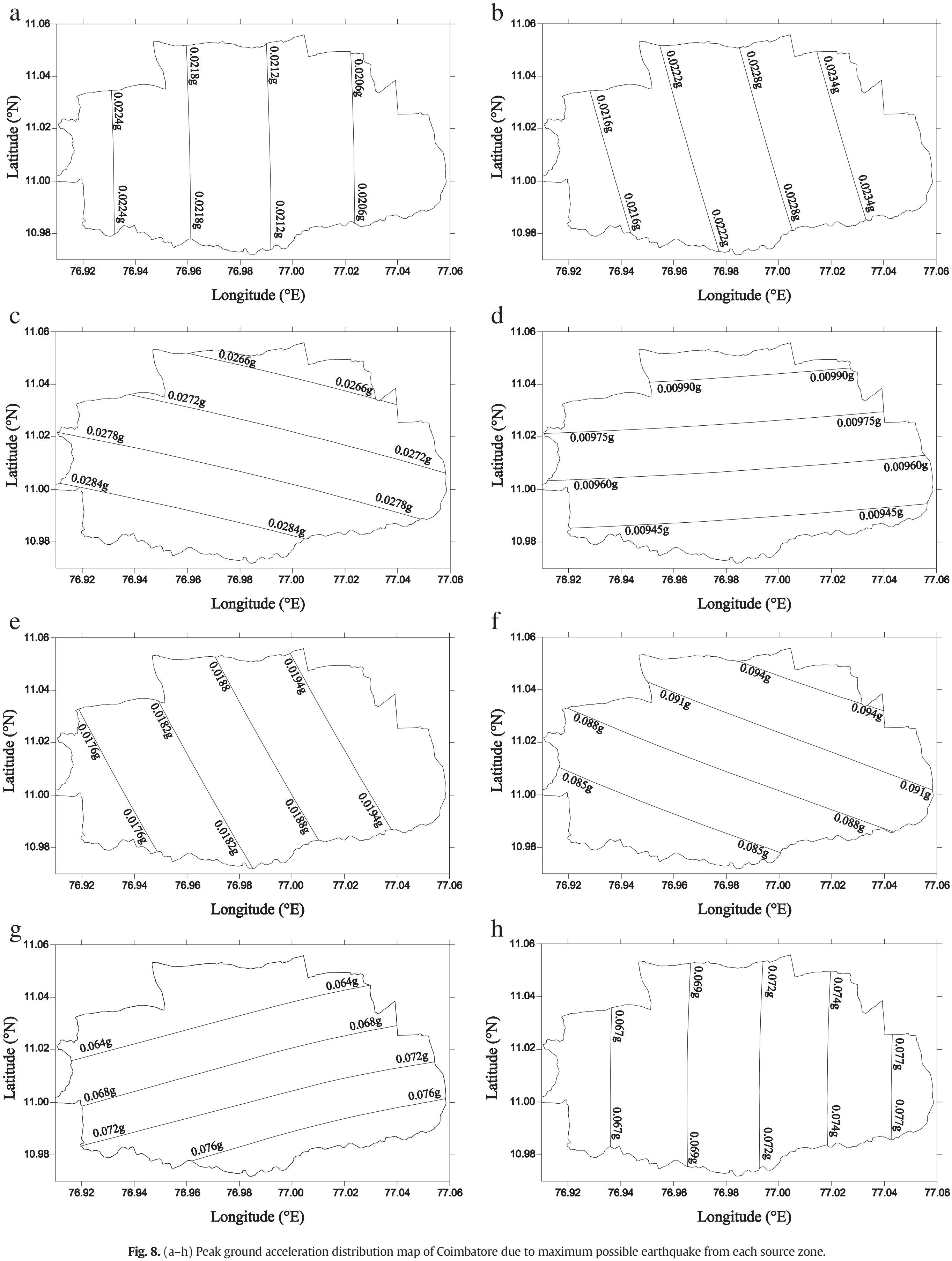


Fig. 8. (a–h) Peak ground acceleration distribution map of Coimbatore due to maximum possible earthquake from each source zone.

earthquakes of 5.2 to 6.5 (M_W) are computed for the probable future earthquake zones and are used for seismic hazard analysis. These magnitude values are comparable with the M_{max} values estimated by Jaiswal and Sinha (2008), Raghukanth (2011) and Sitharam and Vipin (2011). It can be noted here that these authors used uniform M_{max} value throughout the seismic study area/south India irrespective of seismic source character. Seismic sources with small fault length and higher stiffness at focus may not be capable of producing high magnitude earthquakes. Maximum magnitude estimated in this study considering the regional rupture character and source length for each zone is more representative. The PGA at the center of each grid point due to maximum earthquake at each zone is estimated using the first five highly ranked GMPEs (see Table 3) obtained in the previous section. PGA distribution map of Coimbatore City due to earthquake at each of the eight probable earthquake zones are estimated and mapped. Fig. 8a–h shows the PGA distribution map of Coimbatore City at bedrock level due to the maximum possible earthquakes in zones 1–8 respectively. Fig. 8a shows estimated PGA from source zone 1 which is located about 180 km away from Coimbatore and having a maximum magnitude of 5.8. Maximum PGA of 0.023 g is noticed in the western part of the Coimbatore and it gradually decreases approaching 0.02 g at the eastern part. PGA values from source zone 2 are shown in Fig. 8b. Source zone 2 is located at the north-eastern side about 230 km away from Coimbatore City. This source zone may cause the maximum PGA value of 0.024 g at northeastern part and 0.021 g in the southwestern part of Coimbatore City corresponding to M_{max} of 6.4. Fig. 8c shows maximum PGA of 0.029 g in the southern part and lowest PGA of 0.028 g in the northern part of Coimbatore due to source zone 3 with a magnitude of M_W 6 and 175 km away from the city. Source zone 4 is located at 270 km from northern part of the city and gives PGA values of about 0.01 g (see Figure 8d) for the maximum magnitude of 5.8. Fig. 8e shows PGA due to source zone 5 located at 165 km northeast direction of the city and PGA values varies from 0.017 g to 0.021 g. PGA values from source zone 6 is shown in Fig. 8f; maximum value of about 0.1 g is noticed at the north east corner and minimum value of 0.085 g is noticed at the southwestern corner of the city. Source zone 6 consists of 6 sources and is capable of producing a maximum magnitude of M_W 6.5. Fig. 8g shows PGA values from source zone 7 located at 60 km southeast corner of the city. This source gives a PGA value of 0.081 g in the southeastern corner of city and 0.060 g in the northwestern corner of city due to maximum magnitude of 5.5. PGA values from source zone 8, located on the south side of the city are shown in Fig. 8h. It can be seen from Fig. 8h that the PGA vary from 0.08 g in the eastern side to 0.065 g at western side of the city. Source zones 8 and 6 are at equal distance from the city, however the maximum magnitude of source zone 8 is less than zone 6. Overall the maximum PGA values obtained from source zones 1 to 8 are 0.023 g, 0.024 g, 0.029 g, 0.0101 g, 0.021 g, 0.099 g, 0.081 g and 0.080 g respectively.

10.1. New seismic zoning map of Coimbatore City

Eight PGA distribution maps are generated considering earthquake at each of the eight probable future earthquake zones. For microzonation and estimation of earthquake effects, one final map is warranted. In order to develop a seismic zoning map at the micro level, PGA values from eight probable zones were compiled for all the grid points and maximum PGA value was selected for each grid point. Fig. 9 shows the maximum PGA map of Coimbatore City from eight probable locations. The maximum PGA value of about 0.1 g at northeastern part and minimum PGA of 0.084 in southwestern part of Coimbatore City are found. The PGA distribution pattern in Fig. 9 is predominantly similar to Fig. 8b, c and e. This map (Figure 9) is divided into five groups and is called as a 'New seismic zoning map of Coimbatore' for further studies. Southwestern part of the city is having relatively less PGA when compared to north-earthen part of the city. This study shows that expected maximum PGA value in the city is about 0.1 g at the rock level due to an earthquake around Coimbatore. Maximum PGA distribution (Figure 9) is further used to arrive spectral acceleration at 0.2 s and 1 s for the bedrock level design purpose. The normalized spectral shape was studied and presented by Anbazhagan et al. (2013) is used here, which shows that spectral acceleration is about 2.5 times and 0.66 times of PGA values for the period of 0.2 s and 1 s respectively. Spectral acceleration at center of each grid points was calculated for 0.2 s and 1 s and presented in Fig. 10a and b. Fig. 10a shows the maximum spectral acceleration of about 0.24 g in northeastern part and 0.21 g in the southwestern part of the city corresponding to 0.2 s. Similarly, Fig. 10b shows the maximum spectral acceleration of about

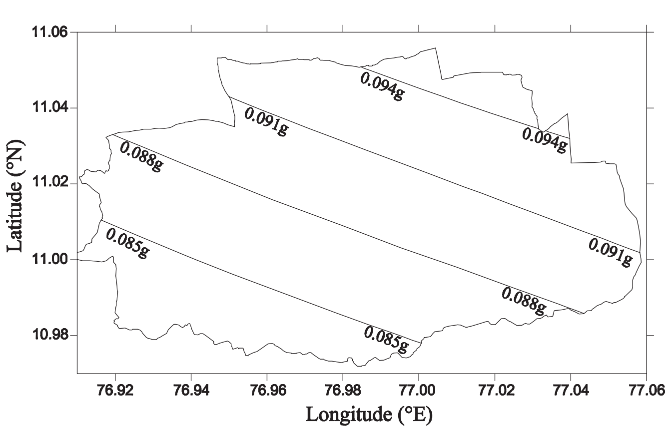


Fig. 9. New peak ground acceleration distribution map of Coimbatore from eight probable source zones.

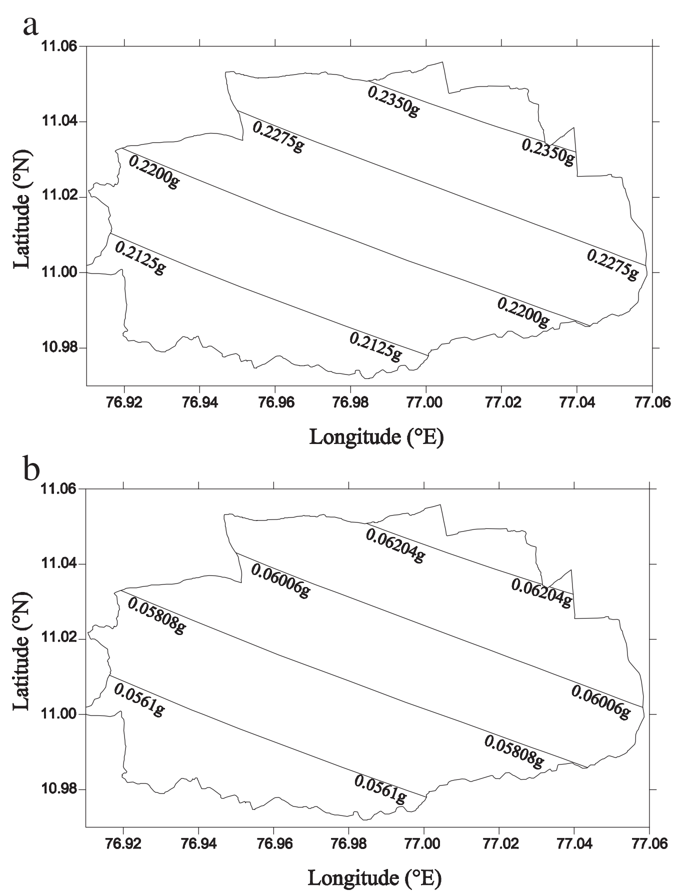


Fig. 10. a and b: Spectral acceleration distribution map of Coimbatore at (a) 0.2 s and at (b) 1 s considering normalized spectral ratio plot of south India.

0.062 g at north eastern part and 0.054 g at the southwestern part of the city for 1 s. PGA and spectral acceleration at northeastern part is more than south western part of the city. In order to compare hazard values from the proposed rupture based seismic hazard analysis, maximum PGA map obtained in this study is compared with the Deterministic Seismic Hazard Analysis (DSHA) result in the next section.

11. Deterministic seismic hazard analysis of Coimbatore

Seismic hazard analysis is usually carried out by considering possible earthquake sources within 100 km to 300 km radius around the study area and by determining Maximum Credible Earthquake (MCE) (Kramer, 1996). MCE of each seismic source is estimated by adding an incremental value of 0.5 units to past maximum reported earthquake in the region. Hence, the MCE of Coimbatore will become 6.8 (M_w). This magnitude is assigned to all the faults and the shortest epicenter distance at the center of each grid point from to these source is estimated. The minimum hypocentral distance from each grid center is estimated considering a focal depth of 10 km. The PGA for all grid points in Coimbatore are calculated and mapped considering the regional GMPEs by RAIY-07 and NDMA-10. Fig. 11a and b shows PGA distribution in Coimbatore City by DSHA approach using RAIY-07 and NDMA-10 GMPEs respectively. The maximum PGA value in Coimbatore using GMPE by RAIY-07 varies from 0.37 g to 0.57 g as shown in Fig. 11a. Fig. 11b shows the PGA variation from 0.40 g to 0.55 g for Coimbatore based on NDMA-10 GMPE. By comparing Fig. 11a and b, it can be noticed that RAIY-07 GMPE is found to predict hazard values slightly higher than PGA based on NDMA-10 GMPE, for the same magnitude and distance. The maximum PGA value of above 0.55 g

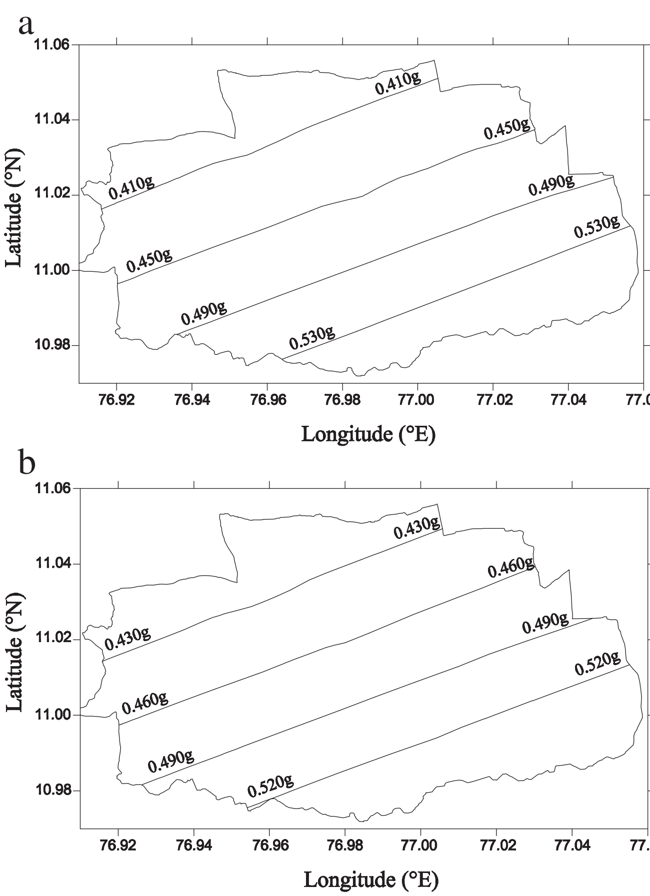


Fig. 11. a and b: Peak ground acceleration distribution map of Coimbatore as per deterministic hazard analysis using (a) RaghuKanth and Iyengar (2007) GMPE and (b) NDMA (2010) GMPE.

was observed in southeastern part of the city when conventional DSHA analysis is used. By comparing Fig. 9 by RBSHA and Fig. 11(a & b) by DSHA, it can notice that PGA values obtained from DSHA is 5 times higher than RBSHA based PGA values. Also the PGA distribution pattern from DSHA is completely different from RBSHA followed in this study. Considerable differences between the PGA values from two approaches may be attributed by the procedure used to arrive maximum magnitude, assigning maximum earthquake in the past maximum observed location and use of regional GMPEs.

12. Results and discussion

The probable earthquake locations for the seismic hazard analysis are assigned by considering the location of maximum past reported earthquake in the deterministic seismic hazard analysis. Many times future earthquake may not happen in the previous reported location/source, because sufficient time is required for the building up of energy to create another earthquake in the same location. In this study probable future earthquake locations are identified by eliminating past damaging earthquake location and considering future probable rupture possibilities. It was noticed that the normalized rupture length of fault follows a trend with total length of the fault and this was taken as a rupture character of the region. Maximum possible earthquake of each seismic source close to probable zones are estimated considering the rupture character of the region. The maximum estimated earthquakes in each zone is taken as the maximum credible earthquake of Coimbatore City. These values are comparable with the findings of NDMA (2010) and Raghukanth (2011). Proposed values are unique when compared to deterministic seismic hazard analysis and other previous studies because of new procedure adopted in arriving of seismic source location, M_{max} estimation and the selection of GMPE models. Many researchers have taken a single value for seismic hazard mapping, which are slightly higher than maximum earthquake magnitude calculated in this study. The seismic sources in different parts of the seismic study area may not be capable of rupturing equal amount and produce equal magnitude earthquake for the region. Hence, different maximum magnitudes are considered for different source zones in this study which are more representative of the source and rupture character the region. Suitable GMPEs for Coimbatore region is identified by carrying out the efficacy test considering the available GMPEs and the observed intensities from Isoseismal map. This study shows that ranking order of GMPEs for Coimbatore is different from the Nath and Thingbaijam (2011) study due to localized damage distribution. Nath and Thingbaijam (2011) did not consider the GMPE given by NDMA (2010) and used the earthquake damage reported in the northern part of Peninsular India. Ranking order of GMPEs given in this study is the regional representative as Isoseismal values in the region was used.

The seismic hazard values at Coimbatore were estimated considering representative probable location, maximum magnitude and GMPEs. The study area was divided into 1.1 km × 1.1 km grid size and PGA values at each grid was calculated for the maximum possible earthquake magnitudes at eight probable earthquake zones considering the first five GMPEs. The study shows that PGA obtained from each source zone i.e. Fig. 8a to h is different and depends on seismic sources, distance and maximum magnitude of the source zone. Fig. 8a to h shows the maximum PGA of 0.023 g, 0.024 g, 0.029 g, 0.0101 g, 0.021 g, 0.099 g, 0.081 g and 0.080 g for source zones 1 to 8 respectively. A new seismic hazard map of Coimbatore City is prepared by selecting maximum PGA among the eight maps. The new seismic zonation map is shown in Fig. 9 and has a PGA value of about 0.1 g at the bedrock level. Spectral acceleration for the PGA values given in Fig. 9 was shown in Fig. 10a for 0.2 s and Fig. 10b for 1 s. This study shows that spectral acceleration for 0.2 s is about 2.5 times and 1 s is about 0.66 times in comparison to PGA values. The PGA values for the study area are also arrived by adopting conventional DSHA way of incremented maximum magnitude,

Table 4
Peak ground acceleration (PGA) at rock level for Coimbatore from different studies and compared within this study.

Sl. no.	Study	PGA (g) from deterministic approach	PGA (g) for 10% probability of exceedance in 50 years
1	Khattri et al. (1984)		0.03
2	Bhatia et al.(1999)		0.075
3	IS 1893 (BIS, 2002)	0.08	
4	Pervez et al. (2003)	0.08	
5	Jaiswal and Sinha (2007)		0.05
6	Vipin et al. (2009)		0.13
7	Menon et al. (2010)		0.085
8	NDMA (2010)		0.04
9	Sitharam and Vipin (2011)		0.075
10	Nath and Thingbaijam (2012)		0.1
11	Sreevalsa et al. (2013)	0.175	
12	Anbazhagan et al. (2012)	0.128	
13	Sitharam and Kolathayar, 2013		0.1
14	*In this study*	*0.08 to 0.1*	

shortest distance and regional GMPEs. The PGA value variation from RAIY-07 GMPE is shown in Fig. 11a and from NDMA-10 GMPE is shown in Fig. 11b. The maximum PGA value is about 0.57 g from RAIY-07 GMPE and 0.55 g from NDMA-10 GMPE. This study shows that PGA values from RAIY-07 GMPE was valued slightly higher than NDMA-10 GMPE PGA values.

Seismic hazard values obtained from this study from probable zones are compared with previous studies. Indian seismic code, IS 1893 (BIS, 2002) has given design based peak ground acceleration of 0.08 g for Coimbatore which is slightly lower than the values proposed in this study. Zonation factors given in IS1893 (BIS, 2002) were developed considering past earthquake intensity and deterministic approach. Jaiswal and Sinha (2008) mapped PGA based on probabilistic approach, and shown a contour interval of PGA 0.05 g to 0.06 g for Coimbatore. These values are less than the rupture based approach values found in this study. Menon et al. (2010) found a PGA value of 0.086 g for Coimbatore for a return period of 475 years and 0.164 g for return period of 2475 years using logic tree in the probabilistic seismic hazard approach. Maximum PGA reported in this study is well within the PGA for the return period of 2475 years and more than 475 years return period PGA as given by Menon et al. (2010). NDMA (2010) published a probabilistic seismic hazard map of India for different return periods considering indigenous GMPE. PGA value given for Coimbatore by NDMA (2010) is much lesser than that obtained in the present study. NDMA (2010) used indigenous GMPE and this study used best suitable GMPEs based on efficacy test. Table 4 shows PGA estimated by different researchers for Coimbatore and in this study. It can be noted that PGA values given in most of previous DSHA except Sreevalsa et al. (2012b) and PSHA studies are less than PGA values given in this study and recent study's results are comparable. Sreevalsa et al. (2012b) results are similar to DSHA study carried out in the previous section. Seismic hazard values estimated in this study are more representative with respect probable location, maximum magnitude and GMPE selection. Deterministic and probabilistic are widely adopted methods to estimate hazard values at selected sites; in both methods more importance is given to past earthquake magnitude and location for predicting future hazard values. More importance is given to the maximum reported magnitude in the region irrespective of source and considers the worst scenario in DSHA. The probabilistic method evaluates future hazard considering state of knowledge and physical principles. But it is well understood that the deterministic method is a big advantage in comparison to the current probabilistic practice (Klügel, 2005b). The method used in this paper to arrive at the representative seismic hazard map of Coimbatore, India is similar to DSHA, but identification of probable source zones, estimation of maximum magnitude and selection of GMPEs are based on region specific seismotectonic details. The PGA and spectral values arrived from this study are based on present regional seismotectonic data and not based on uncertainty models. In this paper PGA and spectral acceleration are presented, however it is well-known that damage characteristic (intensities) correlates much better with peak ground velocity (PGV) (Klügel et al., 2006). Results obtained in this study may be updated when suitable attenuation relation/GMPE for velocity is found in the future.

13. Conclusions

In this paper, an attempt was made to locate future probable earthquake zones considering subsurface rupture phenomena and hazard values are estimated at the rock level considering RBSHA. In order to map the representative hazard map, Coimbatore City was selected as the study area. Coimbatore seismotectonic map showing past earthquakes and seismic sources was prepared. Earthquake data were divided into damaging earthquakes (M_w of 5 and above) and minor earthquakes (M_w less than 5). Ruptured seismic sources are delineated by drawing/rupture circles considering the subsurface length of damaging earthquakes. These locations are considered as probable locations for future earthquake for a period of 50 years, because the average return period of intraplate damaging earthquakes is about 200 to 500 years. Eight probable earthquake zones have been identified for near future earthquakes. Rupture character of the region was established at 6% of total length of seismic source. Maximum possible earthquake for each zone was computed by considering the regional rupture character and the length of seismic sources around each zone. The LLH was calculated considering the intensity values from the maximum reported earthquake of 6.3 (M_w) and the ranking order of GMPEs were decided based on LLH values. Peak ground acceleration at every grid point was estimated considering maximum possible earthquake with a focal depth of 10 km and the first five attenuation equations. Eight PGA maps were generated and the representative hazard map of Coimbatore was plotted by considering maximum PGA at each grid from these eight zones. Maps showing spectral acceleration for 0.2 s and 1 s was also presented. These maps can be used for further microzonation study and design of structures at rock level. PGA values computed from new approach are found to be more than that of previous studies in the region and are comparable with recent studies. PGA values obtained in the study were compared with the conventional deterministic approach. Deterministic approach is found to give higher PGA values when compared to this study.

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