PROBABILISTIC SEISMIC HAZARD ASSESSMENT

A DISSERTATION

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(With specialization in Structure Dynamics)

By

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CANDIDATE’S DECLARATION

I, hereby, declare that the study, which is being presented in this dissertation titled **“PROBABILISTIC SEISMIC HAZARD ASSESSMENT”** for the partial fulfilment of the requirements for the award of the Degree of Master of Technology in Earthquake Engineering with specialization in Structural Dynamics submitted to the Department of Earthquake Engineering, Indian Institute of Technology Roorkee, is an authentic record of my own carried out under the supervision of **Dr. JOSODHIR DAS,**Associate Professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee, India.

The matter embodied in this dissertation has not been submitted by me for the award of any other degree or diploma.

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CERTIFICATE

This is to certify that the above statement made by the candidate is correct to the best of my knowledge.

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Finally, I have no adequate words to show my deep sense of gratitude for my beloved parents and especially my sister who has been constantly encouraging me all through. Their motivation and inspiration have made me to reach this position.

Place: IIT Roorkee (DHIRENDRA KUMAR)

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ABSTRACT

The seismic hazard assessment is concerned with the estimation of strong-motion parameters at a site for the purpose of seismic safety assessment. It involves estimation of the earthquake related phenomena such as ground shaking, fault rupture, ground failure or soil liquefaction at a site. For the reliable assessment of the seismic hazard at a site the level of ground shaking can be characterized by various types of ground motion parameters and estimated in terms of peak Ground Acceleration (PGA) and Spectral Acceleration (Sa).

In the present study Probabilistic Seismic Hazard Analysis (PSHA) has been carried out for the region of North-East India, which is one of the most seismically active region of India. For this purpose, the study area is divided into eight seismogenic source zones based on geology, tectonics and seismicity in and around the region of North-East India. And by using Gutenberg-Richter recurrence relationship, the seismic hazard parameters such as a, b and Magnitude of completeness, M_c has been completed for sources zones. Also, all seismic hazard parameters have been computed by combining all source zones into single source zone. An attenuation model proposed by boore et al (2014),Campbell (2014), Abrahamson,silva,kamai(2014), Idriss(2014)considering for 2%, 5%, 10% damping for the probability of exceedance in 50 years. Average PGA results The computed PGA and PSA values of the region are shown in the fallowing map by usingArcGIS10.According to Campbell (2014) attenuation models the estimated PGA values are higher in the source Zones-I, II and VIII. In source Zones-I and VII there exists Gangtok which are hard rocks but in source zone-II mainly Bangladesh have soil amplification.

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1 CHAPTER

INTRODUCTION

1.1 GENERAL

Earthquake is one of the disastrous phenomena which is experienced by mankind of the Earth. It is occurred due to the sudden release of strain energy which is stored inside of earth crust. And this energy propagates in the form of waves known as seismic waves. These waves hit a structure and cause the movement of structure in horizontal and vertical direction. A part of it also effect on artificial structures like roads, buildings, dams and bridges and also responsible for landslides, liquefaction, slope-instability. All these effects of earthquake result in loss of life and economic losses

The Indian subcontinent is seismically active region. Epicentre of earthquake shows non uniform characteristics of seismicity. Because of this India can be divided into four broad regions mainly Himalayan region, Andaman-Nicobar region peninsular India and Kutch region. Andaman-Nicobar and Himalayas are more active compared with others region . The Himalayas are the youngest mountain range and formed by collision between two plates that is Eurasian plate and Indian plate (Valdiya,2001). There is continuous penetration of plate to the Eurasia plate there is release of heavy stress, because of this seismicity is more active in this region in last twenty decades. The Himalayan region experiences numerous earthquakes of magnitude more than 8, among those Kanga earthquake, M=8.0 (1905), Shillong earthquake, M=8.7 (1897), and Assam earthquake M=8.5 (1950), Bihar-Nepal earthquake, M=8.3 (1934), Andaman-Nicobar region is also most seismically active, had been affected by many earthquakes which is more than 8 magnitude in the year between 1941-2004. Kutch region also seismically active which occurred two major Earthquake which are greater than magnitude 7.5 and moderate earthquake in last 200 years. Peninsular India is one of the oldest and seismicity but now it is somewhat stable land of Indian plate.

North-east India is situated in the north-east direction of India. This region suffers many natural disasters, such as landslides, earthquake, flash floods, cloud bursts, forest fires, avalanches, drought in the past. These disasters cause more trouble in the development of the region. Some area of the region is on the Himalayas which are more active in earthquakes on this basis of the damages by natural disasters the state can be called for unstable and disaster porn region according to the Indian standard (IS 1893:2002-part1) mainly area of seismic zone IV and V.

In the mountain region occurrence of earthquake leads to additional problems such as damming of rivers, landslides and different types of slope failure, so by knowing all these reasons there is importance in seismic hazard analysis for this particular region, which helps to reduce causalities and economic loss likely occur in this region.

1.2 SEISMIC HAZARD ASSESSMENT

It is used to assessment the strong ground motions parameters caused by earthquake. It gives information about the intensity of the earthquake and also expected further causing earthquake events. It provides the information on earthquake phenomenon at particular site. It gives the seismic severity in terms of probability that occurrence and causes damages to structure, economic, and loss of life. Based on the data available on seismicity, geology, tectonics, and attenuation characters of the area of all these are used to calculate the Ground motion parameters (level of shaking of ground due to particular earthquake). The estimated ground shaking is in terms of Peak ground acceleration (PGA), Spectral acceleration (Sa), and Peak ground velocity (PGV) these are considered as seismic design of the structure. For this two methods are followed. First approach is deterministic seismic hazard analysis (DSHA) and second one is Probabilistic seismic hazard analysis (PSHA).

Ground motion estimation by DSHA is mainly based on single large magnitude earthquake scenario and distance closest to the site but PSHA takes different types of Earthquake sources around the region which contribute ground motion at the site

1.3 OBJECTIVE OF THE STUDY

The purpose of the study is to estimate the PSHA of north-east India. The STEPS of the study include the following:

1. Identification and estimation of SHP of various seismogenic sources.
2. Assessment of seismic hazard in terms of (PSA) and (PGA) at different periods and results are presented in terms of zone maps for different models.
3. Comparison of the PSA and PGA value with the other reported studies carried out at a specific region.

1.4 ORGANISATION OF DISSERTATION

The work done is presented in the following chapters:

Chapter 1 Introduction of the seismicity of the north east area of india,

Chapter 2 Explains the complete methodology of doing PSHA which includes so many steps to fallow like homogenisation of earthquake catalogue, competition of earthquake data, difference between two methods DSHA and PSHA, assessment of SHP, maximum magnitude for every source of seismogenicsources and selecting the suitable attenuation model

Chapter 3 includes the details of study region, marking of seismogenic sources and also procedure to estimate SHP for given study region

Chapter 4 presents the results of a study region in terms of PGA and PSA at bed rock level, comparison and discussion of results

2 CHAPTER

SEISMIC HAZARD ASSESSMENT

2.1 INTRODUCTION

It is concerned with the assessment of seismic parameters at a place for the estimation of seismic safety assessment and earthquake resistant design(other ref, Gupta, 2002). It contains calculation of the earthquake related phenomena (e.g., ground shaking, fault rupture, soil liquefaction) at a place. Seismic risk is the measureable assessment in way of probability that incidence of these phenomena lead to damage to structures, damage of life & other economic losses. For reliable estimation of the seismic hazard at a region ,Ground shaking parameter can be measured by different types of GMP. The data of geology, tectonics, and seismicity with attenuation model are used to assess the design GMP of the site. The predicted SGA such as PGA and Spectral Acceleration(Sa) are considered for the seismicdesign of structures. Two approaches are opted for seismic hazard assessment, they are DSHA and PSHA. Ground motion assessed adopting DSHA is on a single large scenario earthquake whose magnitude and nearer distance to site are known whereas PSHA approach takes consideration of ground motions various range of earthquakes that can takes place due to various types of seismogenicsources recognized around the region (Kramer, 2003). In the last few years the practice of DSHA was dominant. However, nowadays PSHA is preferred as compared to DSHA because it is accomplished of dealing with uncertainties associated with different parameters that comes into seismic hazard analysis.

2.2 DIFFERENT TYPES OF SEISMIC HAZARD ANALYSIS

2.2.1 Deterministic Seismic Hazard Analysis (DSHA)

DSHA is mainly depends on worst case scenario earthquake which will produce sever damage at that site. This method uses discrete, single-valued models to arrive at one or more scenario earthquakes. This method is not well recognized in literature and hence it is adept differently in across the world.

In DSHA, maximum possible earthquake (also called as maximum credible earthquake or maximum considered earthquake (Reiter, 1990)) to different recognized seismogenic sources is assigned within an area of 300 km radius around the region of interest. The GMP of interest is calculated by using suitable attenuation model for that region. The DSHA is based mainly on the maximum possible earthquake shall occur very close to site.

A typical DSHA involves following four-steps as explained by Reiter (1990).

i) It involves identification and characterization earthquake sources which are capable of generating definite ground motion at the region. The separate sources can be modelled as point, line, area or volume depending upon the scattering of seismicity and its possible relationship with the seismic tectonics.
ii) The second step involves in selecting the governing earthquake which produce strongest level of shaking. This step also takes into account the selection of parameter that defines the source to site distance for each source zone associated with controlling earthquake. Generally, the minimum distance between the source and the site of interest is preferred.
iii) The third step consists of suitable ground motion attenuation model to determine of the earth quake effects. At different distances ground motion for an earthquake is estimated by choosing suitable ground motion attenuation model.
iv) Final step covers the calculation of hazard at the site in terms of PGV, response spectrum acceleration, or the other measure that effects of controlling earthquake.

2.2.2 Probabilistic Seismic Hazard Analysis

In DSHA model earthquake sources are discrete, single-valued events to estimate earthquake hazard, but in probabilistic analysis multiple events and models for the assessment of hazard are measured (Reiter 1990). In PSHA, the influence of all earthquakes that are capable of affecting the site in question are combined. PSHA allows combination of uncertainties related to location, size, variation of ground motion characteristics and rate of occurrence are considered (Kramer, 2003). The PSHA includes integration over all possible ground motions, earthquake sources and combined probability of exceedance is calculated by combining relative ground motions and rate of occurrence of different earthquakes.

The main limitation in DSHA is considering the single major scenario earthquake. But such earthquakes are not causing damages to all type of structures because of their wide range of frequency. The ground motion can be different for different combination of source distance and magnitudes around the region.

Several probabilistic approaches have been advanced and find applications in various fields of engineering. The first PSHA method was adopted by Cornell(1968) which was based on three specific assumptions. The magnitude was exponentially distributed ($\log N_m = \bar{a} - \bar{b}m$), seismicity is uniformly distributed in every seismogenic sources, and finally earthquake recurrence times should follow Poisson's process. Figure 2.2 explains the methodology of PSHA proposed by Cornell (1968) and contains following 4 steps:

i) Different types of seismogenic sources are characterised on the bases of available information on the geological, tectonic and seismicity (available from earthquake catalogues). Uniform probability distribution is assigned to every seismogenic sources in most cases. This indicates that earthquakes are equally and most likely to occur at any point with in same zone.

ii) This step involves in estimation of seismicity recurrence rate for each and every source zone. A reputation relationship, which states the average rate at which an earthquake of some magnitude will be exceeded the specific magnitude and it is used to characterise the seismicity of each and every source zones.

iii) The third step involves in selecting a ground motion prediction model for a region or each source zone is specified. Using this specified model, the ground motion created at the site by earthquakes occurring at different distances of different size in each source zone is determined. The uncertainties in the specified attenuation model are also considered in PSHA.

iv) Final step in PSHA is the evaluation of seismic hazard based on the combining effects of all earthquakes occurring at different locations which is caused due to different source zones of variable sizes at different probabilities of exceedance. A probability value is achieved showing that the ground motion parameter will be exceeded during a specific time period.

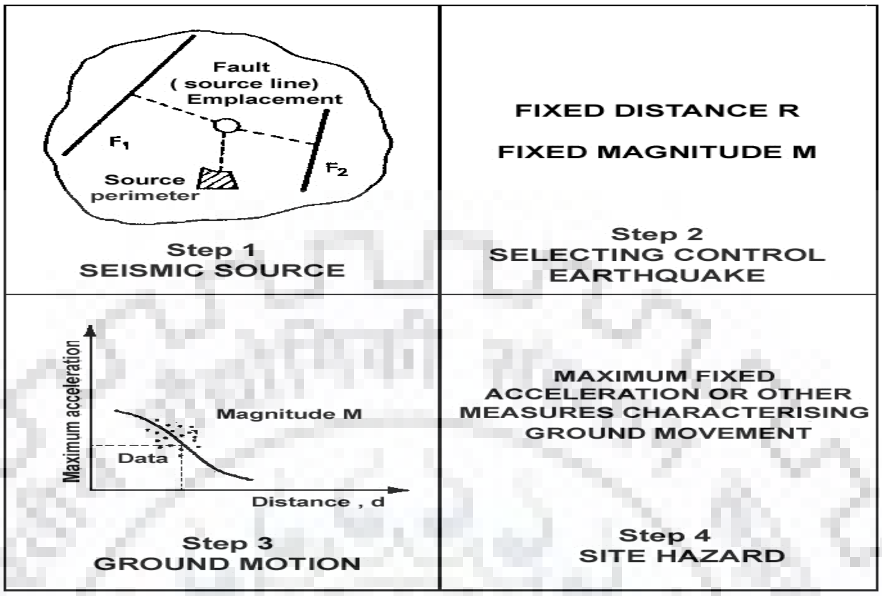


Figure 2.1Deterministic seismic hazard analysis methodology (Reiter et al. 1990)

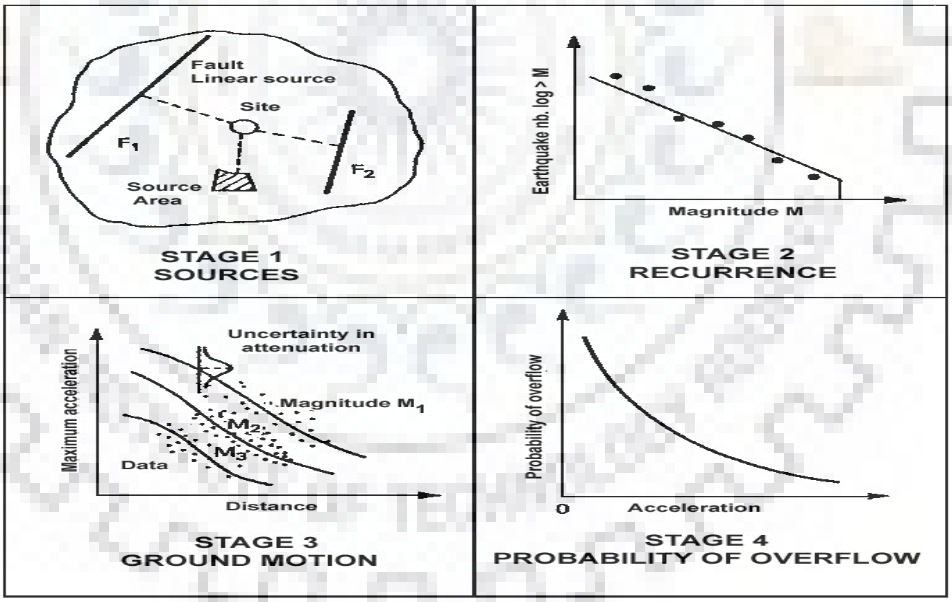
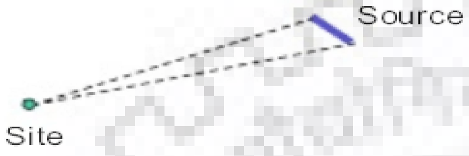


Figure 2.2Probabilistic seismic hazard analysis methodology (Reiteret al. 1990)

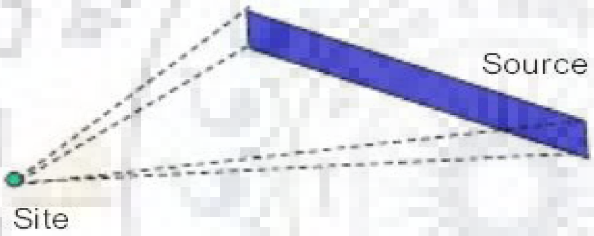
2.3 REQUIRED PARAMETERS TO ESTIMATE PSHA

2.3.1 Source to site distance

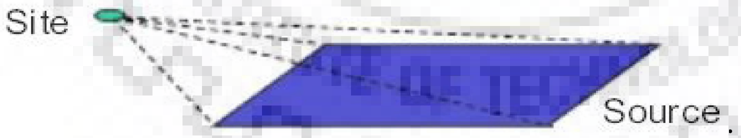
i) Earthquakes related to volcanic activity, generally emerge from the zones nearby volcanos and are small enough to characterise. So they are called as point sources.Point source is the constant distance between the source and the site.



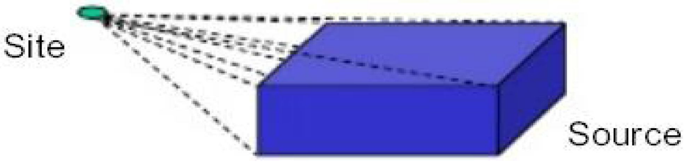
ii) Linear source in which parameters are causes for certain distances mainly Shallow and distant fault.



iii) Areal source which are associated with the certain two geometric parameter distances such as Constant depth crustal source. Defined fault planes, on which earthquakes can occur at variable locations, can be considered as 2-D geometry areal sources.



iv) Volume source: Areas where the earthquake process mainly seismogenic are unsuccessfully defined, or where wide-ranging faulting is able to preclude distinction between individual faults, this region is defined by specific polygon can be treated as three-dimensional volumetric sources.



2.3.2 Regional Recurrence Relationship

The distribution of earthquake in past events will be recorded in a given time period, number of earthquake occurrence with different sizes. The basic assumption and understanding will be obtained from the past recurring events, by that there is a prediction of future event is possible in specified zone. For this purpose most and very important relationship for recurrence is given by Gutenberg-Richter relation (G-R relation).

The data of earthquake occurred in Southern California are collected over a period of many years Gutenberg and Richter developed G-R relation (1944). The data was arranged according to number of earthquakes that exceeded different magnitudes during a certain period of time.

The mean annual rate of exceedance, N_m of an earthquake of magnitude m; the number of exceedances of each magnitude is exponential of magnitude. The rate of occurrence of small earthquakes is mostly larger than that of the large earthquakes, N_m is more for small magnitude earthquakes compared with large earthquake. The reciprocal of annual rate of exceedance is the return period of an earthquake that exceeding particular magnitude. The G-R relation is the relation between annual rate of exceedance versus exponential of the earthquake magnitude are expressed as,

$$\log N_m = \bar{a} - \bar{b}m$$

where, N_m is the mean annual rate of exceedance of magnitude m, $\bar{a}$ is the log of the mean yearly number of zero magnitude earthquakes ($M \geq 0$) and depends on seismicity of the region at a particular zone, b the slope defines the relative large to small earthquakes.

The value of parameter of $\bar{a}$ increases with the increase of seismicity of the site, and increase in parameter $\bar{b}$ indicates the number of larger earthquakes decreases as compared to small and moderate earthquake.

The Gutenberg-Richter relation is also expressed as:

$$N_m = 10^{\bar{a} - \bar{b}m} = \exp(\bar{\alpha} - \beta m)$$

Where, $\bar{\alpha} = 2.303a$ and $\beta = 2.303b$.

The probability distribution of magnitude can be expressed as a function of Cumulative Distribution Function (CDF) or Probability Density Function (PDF).

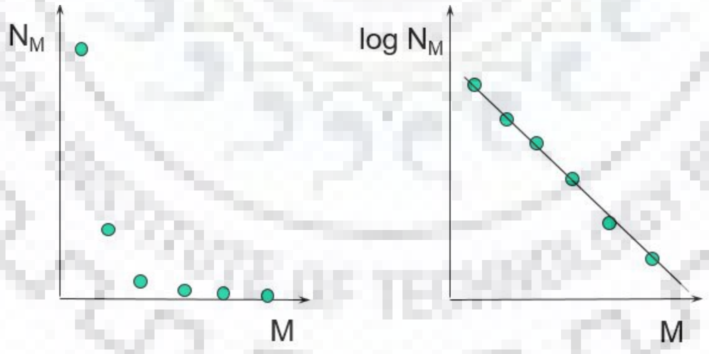
The expression for Cumulative Distribution Function (CDF)

$$C_M(m) = P[M < m] = 1 - e^{-\beta m}$$

The expression for Probability Density Function (PDF)

$$P_M(m) = \frac{d}{dm} F_M(m) = \beta e^{-\beta m}$$

The GR relation is applicable to all magnitude with in specific range. However, for engineering purposes it is common practice to neglect small magnitude earthquakes because they are less capable of causing significant damages.



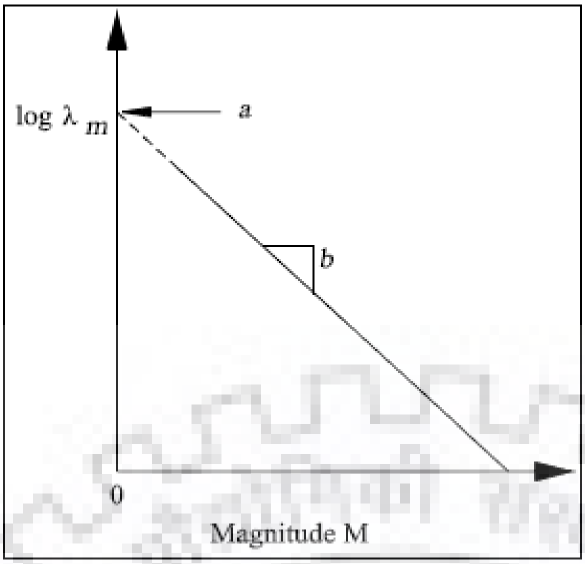


Figure 2.3 Shows the Gutenberg-Richter relation

Let all earthquakes with magnitudes smaller than m_0 are eliminated from the data. At the other end of magnitude scale, G-R relation predicts non-zero mean rates of exceedance for the magnitudes up to infinity rate of exceedance. Still, maximum magnitude m_{max} is related with all source zones. Thus the introduction of range i.e.m_0 and m_{max} to G-R relation called as Truncated Gutenberg-Richter relation (TGR). Besides TGR relation there is another recurrence relation called as Bounded Gutenberg-Richter relation (BGR). The BGR relation is very similar to that of TGR relation for magnitude near to$m_{min} = m_0$. The purpose of BGR relation is to avoid abrupt truncation or variation at$m = m_{max}$. For BGR relation, the mean annual rate of exceedance is given as,

$$N_m = N_0 \frac{e^{-\beta(m-m_0)} - e^{-\beta(m_{max}-m_0)}}{1 - e^{-\beta(m_{max}-m_0)}} \quad m_0 \le m \le m_{max}$$

The Cumulative Distribution Function (CDF) and Probability Density Function (PDF) for Gutenberg-Richter relation with upper and lower bound magnitudes are expressed as:

Cumulative Distribution Function (CDF)

$$C_M(m) = P[M < m | m_0 \leq m \leq m_{max}] = \frac{1 - e^{-\beta(m-m_0)}}{1 - e^{-\beta(m_{max}-m_0)}}$$

And, Probability Density Function (PDF)

$$P_M(m) = \frac{\beta e^{-\beta(m-m_0)}}{1 - e^{-\beta(m_{max}-m_0)}}$$

The comparison between the TGR and BGR recurrence relations is shown in Figure 2.4 (Sabetta, 2005).

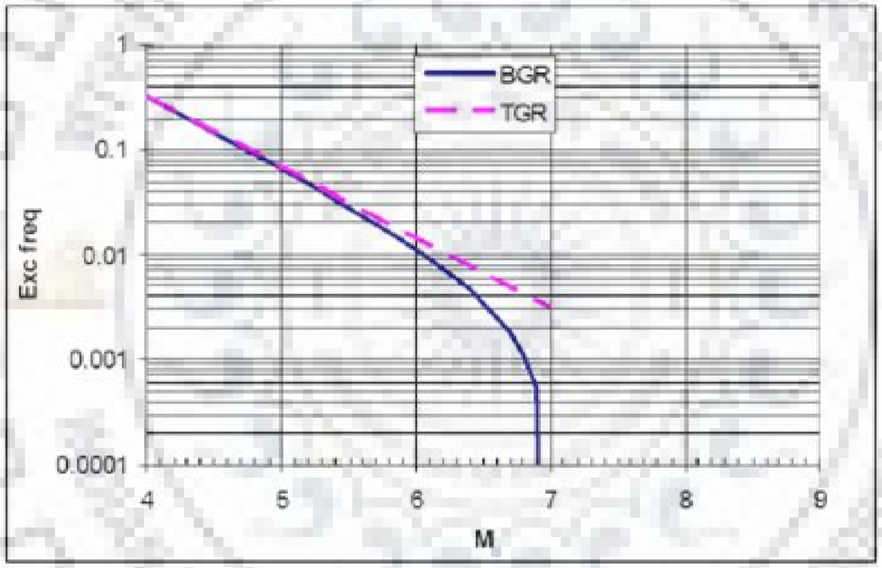


Figure 2.4 Shows Difference between the Truncated and Bounded G-R relations

2.3.3 Formulation of Poisson Model

The seismicity of PSHA based on the assumption of Poisson process. Poisson model is used to define the temporal distribution of earthquakes in the zone. It provides a simple framework to calculate probabilities of events that follow Poisson process---the Poisson model provides random variable relating the number of occurrences of an event during a given time interval or in a specified region. Poisson processes have these following properties:

i) The number of occurrence of a particular event is independent of other event in different time interval
ii) Probability of occurrence in a very short time period is proportional to length of that time period.
iii) Probability of greater than one existence in a very short time period interval is negligible.

From the above properties, Poisson process occur randomly, without memory of the size, time and location of any earlier event. Based on this process, the probability of a random variable$N$, indicates the number of occurrences of a particular event in a given time interval given by (Kramer, 2003)

$$P[N = n] = \frac{\mu^n e^{-\mu}}{n!}$$

Where, μ is the average number of occurrences of an event in same time interval.

To describe the temporal distribution of earthquake recurrence to be used in PSHA, the Poisson probability is stated as

$$P[N = n] = \frac{(\lambda t)^n e^{-\lambda t}}{n!}$$

Where, t is the time period of interest and λ is average rate occurrence of an event. When event of interest is the exceedance of a precise earthquake magnitude, the Poisson model is united with few appropriate recurrence law to estimate the probability of at least one exceedance in a time period of t years by the expression,

$$P[N \geq 1] = 1 - e^{-\lambda_m t}$$

2.3.4 Seismic Hazard Curve

In a specified frame the probability of exceedance of a region for the selected ground motion is computed using seismic hazard curve. From all the individual source zone curves are combined to represents the aggregate hazard at a particular site. The probability of exceeding a particular parameter value,$y^*$of a ground motion parameter (like PGA, PGV, seismic hazard), Y is calculated for one particular earthquake at one particular source location and then integrated by the probability that the specific magnitude earthquake would occur at that specific site. The process is then repeated for all probable locations and magnitudes. The probability of exceedance is given as (Kramer, 2003):

$$P[Y > y^*] = \iint P[Y > y^*|m,r]\, P_M(m)\, f_R(r)\, dm\, dr$$

Where, $P[Y > y^*]$ is a predictive relationship of the region $f_R(r)$ and $P_M(m)$ are the probability density functions for distance and magnitude respectively.

If the site of interest is subjected to shaking from more than one site (say N_s sites), the total average exceedance rate for a particular region is given

$$\lambda_{y^*} = \sum_{i=1}^{N_s} \nu_i \iint P[Y > y^*|m,r]\, P_{Mi}(m)\, f_{Ri}(r)\, dm\, dr$$

The parameters showing in the above equations are complex and integrals cannot be estimated analytically for the estimate realistic PSHAs. To do so, magnitude is separated into different ranges and distance into number of segments to analyse distinctly.

2.3.5 De-aggregation

PSHA combines all the earthquake which occur near to site and away from the site with different magnitudes. The design of ground motion is not well defined whether it is more prominent due to closer smaller events or distant large happing events. The de-aggregation, introduced by McGuire and Shedlock (1981) interpret the relative contribution of events to the total overall estimated seismic hazard. De-aggregation consists varying parameters such as magnitude, m and distance, r. (McGuire (1995) defined the “beta earthquake” created on m-r with additional variable ε (epsilon) that denotes number of standard deviations from average ground motion predicted by a particular attenuation model. The design of “beta earthquake” mainly depends on seismic source/zone and it is related m-r-εto generate the target uniform hazard spectrum. De-aggregation is used to create time histories and predominant earthquake scenario in order to design detailed site effects analysis (McGuire, 1995).

2.3.6 Logic Tree Method

Logic tree is used to give the uncertainties related with all seismogenicsources. Using different PSHA models and parameters, the seismic hazard is calculated from the different parameters and their combinations which represents in a branches of logic tree. Logic trees PSHA analysis to take uncertainties and the GMP models used in assessing seismic hazard. Due to epistemic uncertainties a huge number of inputs sets with different weightage factor is associated to each set in PSHA. Logic tree is used in each step for which epistemic uncertainty is present in it, distinct branches are added to each choice and for every choice also, a normalised weight is given. The hazard designs are then done following all possible branches using through the logic tree producing hazard curve for every possibility (Bommer et al., 2005).

2.4 HOMOGENIZATION

A homogeneous and finishing seismicity catalogue is the most important requirements in PSHA. The various agencies give details about earthquakes that happened in the past. It contains the position of an earthquake in positions of latitude, longitude and depth; magnitude of earthquake (e.g. surface wave magnitude M_s, local magnitude M_L, moment magnitude M_w and body wave magnitude m_b) and time of happening in terms of year: month: day: hour: minute: second. This dataset is in the format of earthquake catalogues is obtainable from various agencies like ISC, IMD, USGS and ANSS. And also some global catalogues and some local catalogues is consideration by Oldham(1883) and Iyengar(1999) are also taken into consideration. Oldham (1883) has collected historical earthquakes up to 1869 obtained only in the place of occurrence and devastation caused by these earthquakes (i.e. intensity). Iyengar (1999) listed earthquake history of India in medieval times also that includes period from 1200 AD to 1800 AD. However, so many catalogue mentioned at present form are inadequate, inhomogeneous and not arranged in proper order for to allow detailed research and reliable inferences.

Hence, to take into consideration of variation in the size of the earthquakes measured with different magnitude scales. All scales must be converted into single magnitude scale mainly on the moment magnitude scale (M_{w}). To convert that data from one magnitude scale to another, different authors proposed various empirical relations by using regional earthquake data (e.g., Thingbaijam, 2008; Das et al, 2011) and global earthquake catalogue (e.g., Scordilis, 2006; Das et al, 2011).

Das et al (2011) used worldwide data for the period 1976 to May, 2007. In this data 3,48,423 events are recorded from ISC 2,38,525 events from USGS were considered for m_b magnitude. For M_sMagnitude scale 81,974 events from ISC and 16,019 events from USGS and 27,229 M_w earthquake magnitude events from GCMT has been considered. The following OSR relations can be dependably used for compiling homogeneous magnitude earthquake data.

The surface wave magnitudes calculated by ISC and NEIC are found to be similar, as both the databases uses the similar technique to determine M_s (Das et al, 2011)

Therefore,

For $M_{s,ISC} \approx M_{s,NEIC} \approx M_s$ to M_w

For M_s to M_w by OSR and ranges $3.0 \leq M_s \leq 6.1$, $h < 70$ km

$M_w = 0.67(\pm 0.00005)M_s + 2.12(\pm 0.0001)$

For M_s to M_w by OSR and ranges $6.2 \leq M_s \leq 8.4$, $h < 70$ km

$M_w = 1.06(\pm 0.0002)M_{s,} - 0.38(\pm 0.006)$

For M_s to M_w by OSR and ranges $3.3 \leq M_s \leq 7.2$, 70 km $\leq h \leq$ 643 km

$M_w = 0.67(\pm 0.0004)M_s + 2.33(\pm 0.01)$

For $m_{b,ISC}$ to M_w by OSR and ranges $2.9 \leq m_{b,ISC} \leq 6.5$,

$m_{b,ISC} = 0.65(\pm 0.003)M_w + 1.65(\pm 0.02)$

For USGS data,

For $m_{b,NEIC}$ to M_w by OSR and ranges $3.8 \leq m_{b,NEIC} \leq 6.5$,

$m_{b,NEIC} = 0.61(\pm 0.005)M_w + 1.94(\pm 0.02)$

2.5 DECLUSTERING OF EARTHQUAKE CATALOGUE

It involves removal of events represented by aftershocks and foreshocks from the earthquake catalogue. Studies conducted by Aki (1956) and Knopoff (1964) revealed that earthquake catalogues do not generally fit in a Poissonian distribution. This occurs because of presence of foreshocks and aftershocks in the earthquake database (Reiter 1990). Mainly moderate and large earthquake is followed by a collection of aftershocks and foreshocks where these occurrence is dependent on the magnitude of main shock. The foreshocks are most important in the prediction of future earthquakes but aftershocks define only source geometry and size of main shock. Since PSHA is created on the basic theory that seismicity follows Poisson process, it is most important to remove any non-Poissonian behaviour from earthquake data.

Dependant events can be removed by different techniques which consist of highly sophisticated algorithms or manual inspection. First-hand knowledge of the earthquake data on an event-by-event basis (Musson, 1999), was estimated After that to identify dependant events computational method is used mainly when earthquake catalogues are large. The most widely used de-clustering approach was introduced by Gardner and Knopoff(1974). They developed a procedure to identify shocks close in space and time to events in Southern California.

Using different fixed time-space window technique by Paul Reasenberg (1985) tried to discovery dependant events in the Central California. Uhrhammer (1986) modified Gardner and Knopoff method by changing a time and space window. Gardner and Knopoff (1974) provided an aftershock identification window in durations (days) and lengths (km). An approximation of the window sizes given by Gardner and Knopoff (1974) is exposed in the equation (Stiphout et al., 2012).

$$d = 10^{0.1238*M+0,983} \quad (km)$$

$$t = \begin{cases} 10^{0.032*M+2.7389}, & \text{if } M \geq 6.5 \\ 10^{0.5409*M-0.547}, & \text{else} \end{cases} \quad (days)$$

2.6 CATALOGUE COMPLETENESS

Completeness of earth quake catalogue means collecting of all earthquake data of all magnitude in a given time period. Completeness of earthquake data is an essential condition for seismic hazard assessment because they are used to determinate the values of a and b of Gutenberg-Richter relation. A mixture of instrumental and historic catalogue is considered to completeness. This method supports Poisson-distributed and determines in the interval of magnitude and completes the magnitude class and also time interval in which catalogue may be observed complete. By taking $n$years of time interval, it determines the average number of events in a year of each magnitude range.

Let $y_1, y_2, y_3, \ldots, y_n$ are the number of events in a year of magnitude range, then the mean rate for the y is given as

$$y = \frac{1}{n}\sum_{i=1}^{n} y_i$$

Where, $n$is Number of unit time interval,the variance is shown by

$$\sigma_x^2 = \frac{y}{T}$$

Where, T is Duration of the sample, if x remains constant then σ_x would vary as $1/\sqrt{T}$.

2.7 MAGNITUDE OF COMPLETENESS (m_c)

Earthquake data are important in seismology. They provide a complete database useful for numerous studies related to seismicity, seismogenicand hazard analysis the main issue whether data is consistent, homogeneous and complete? Magnitude of completeness (m_c) is one of the important limitation that defines as lowest magnitude at which 100% of the events in a space-time window are noticed (Woessner et al., 2005). Various investigators tried to determine magnitude of completeness. These methods was given by Woessner et al., (2005) include: Maximum Curvature Method,$m_c$by b-value stability method and Entire Magnitude Method.

2.8 MAXIMUM MAGNITUDE (m_{max})

Maximum magnitude is an upper limit magnitude in a given seismic source zone or entire region. It is also called as maximum possible earthquake (Reiter, 1990; Kijko, 2004).This maximum magnitude is correctly estimated for a seismogeniczone that no one can expect larger event greater than this will occur in this zone. Thus the maximum magnitude is very useful in calculation of seismic hazard for important structures. As m_{max} represents maximum potential of strain released in the scenario of earthquake hence it plays important role in PSHA for a region. Various methods for calculating maximum magnitude are present. The knowledge of m_{max} is important and used in many engineering applications, till now there is no general accepted method for calculating the value of m_{max} which is reliable. Now-a-days, there are two approaches to estimate maximum magnitude: probabilistic and deterministic.

In deterministic analysis it is defined as a MCE(Reiter 1990). This method is mainly depending up on empirical relationships between magnitude and different tectonic and fault rupture such as rupture area, subsurface rupture length, and displacements. There are several researches that took place to find relationships between fault parameters and magnitude.

The relationships are different for different type of faults and different seismic areas (Wells and Coppersmith, 1994). Fault parameters use linear regression to calculate maximum earthquake. Relationships are worked out on world wide database of 421 historical earthquakes which includes continental interpolate, shallow focus or interpolate earthquakes (M>4.5).

Another procedure for deterministic is on historical seismicity data associated with the source zone. In this method m_{max} is obtained by the largest historical earthquake related with a particular source zone or fault structure or nearer to source is simply added by an increment. Generally, adding units 0.5-1.0 to the maximum magnitude are often added to get an estimate of new maximum magnitude (Gupta, 2002).

In probabilistic the value of m_{max} is estimated mainly on seismological history of the area that includes appropriate statistical estimation procedure and seismic event catalogues. Kijko and Sellevoll (2004) afford a procedure for calculation of maximum magnitude that is free from individual assumptions and earthquake catalogue of that region. In this process solution is generated from the past seismicity or assumptions of statistical model. This procedure is applicable where the nature of earthquake is not known but earthquake magnitude distribution is available. And also used where there is incomplete earthquake catalogue are available is limited. This method includes fallowing this.

i) Earthquakes magnitudes distribution fallow Gutenberg-Richter relation,
ii) The empirical magnitude distribution deviates moderately from Gutenberg-Richter relation,
iii) Where there is no specific form of magnitude distribution is assumed.

Solving above equation after that obtaining maximum earthquake magnitude is given as

$$m_{max} = m_{\max}^{\text{obsv}} + \int_{m_{\text{minm}}}^{m_{\text{maxm}}} [C_M(m)]^n \, dm$$

n = all earthquakes of magnitude $\geq m_{\text{min}}$,

m_{minm}= threshold of completeness or minimum magnitude,

$m_{\max}^{\text{obsv}}$= maximum observed magnitude,

$C_M(m)$= cumulative distribution function of magnitude (CDF).

It is Iterative method because here maximum magnitude is attained by iterative process. The non-parametric Gaussian(N-P-G) based estimator to calculate maximum magnitude and also no specific form of magnitude distribution is assumed.

$$m_{max} = m_{\max}^{\text{obsv}} + \int_{m_{\text{minm}}}^{m_{\text{maxm}}} \left[\frac{\sum_{i=1}^{n} \left[\emptyset\left(\frac{m - m_i}{h}\right) - \emptyset\left(\frac{m_{min} - m_i}{h}\right)\right]}{\sum_{i=1}^{n} \left[\emptyset\left(\frac{m_{max} - m_i}{h}\right) - \emptyset\left(\frac{m_{min} - m_i}{h}\right)\right]} \right]^n dm$$

Where, h is the smoothing factor.

Since, the above equation does not have any specification of the functional form of magnitude distribution, the estimator of m_{max} is non-parametric.

2.9 GROUND MOTION ATTENUATION RELATIONSHIP

This is the most important in SHA for the selection of proper ground motion attenuation relationship. Attenuation relationship more relayed to several factors such as source to site distance, magnitude, geological condition and fault parameters at the region. The accuracy is mainly depending on relationship of the data, function taken and used to deriving methodology. Because the main influence to estimation of strong ground motion so that it plays vital role in hazard estimation. Generally, some specific region attenuation relationships are used for estimation of ground motion, if there is no presence of global relations can be used with similar conditions. For example, for Himalayan region only a few attenuation relationships are available. But Himalaya was characterised on bases of shallow crustal earthquakes, hence equivalent attenuation relationship required for it. Based on shallow crustal earthquake many investors developed attenuation relationships considering worldwide database for which mainly includes Abrahamson and Silva(1997); Abrahamson and Litehiser(1989); Boore and Atkinson(1997); and predominantly for Himalaya, relationships developed by Jain et al 2000, Sharma, 1998, Sharma and Bungum 2004. But every attenuation relationship has its own merits and demerits. For mostly advanced Himalayan regional attenuation relationships predict PGA (peak ground acceleration). At present study we are interested in spectral attenuation relationship based on shallow crustal earthquakes considering database globally.

2.10 UNCERTAINTIES

The parameters which is included in the PSHA is incomplete and these parameters has different uncertainties.

i) Model related uncertainty or Epistemic: these are due to lack of knowledge. Uncertainties arising present are because of our scientific understanding is imperfect, to decrease uncertainties researchers gathering more and better earthquake data.

ii) Aleatory Uncertainties: These are integral under naturally observing process. These uncertainties come because of random nature of input parameters which is used to describe the seismicity and attenuation model. This cannot be minimized with more data or knowledge.

3 CHAPTER

DEMARCATION OF SEISMOGENIC SOURCES IN AND AROUND THE STUDY REGION

3.1 INTRODUCTION

In present study the region of North-east India includes seven states Assam, Manipur,Arunachal Pradesh, Meghalaya, Mizoram, Tripura and Nagaland and parts of Bangladesh and Myanmar lying between alatitude of 20°–30°N and longitude of 87°–98°E,. It is located at the junction of three plates: Indo-Burmese, India and Eurasian, so that it is uninterruptedly under stress field and experiencing crustal readjustments since last phase of the Himalayan origin in middle Pleistocene (Kumar et al.,1997). The manifestations of these crustal movements caused reappearances of some of the present tectonic features and formation of fresh cross-faults have taken place. As a result of these, this region has high seismicity. Two major great earthquakes, the Assam earthquake of 15 August 1950, and the Shillong earthquake of 12 June 1897 having a magnitude greater than 8.0, occurred in this region.

3.2 SEISMOGENICS, GEOLOGY AND SEISMICITY OF THE STUDY REGION

The NE-India is one of the complex tectonic and geological region. Because it is situated in tri-junction of three mountain belts: Mishmi Hills to the northeast, Himalayan range to north and Naga Patkai ranges to the east and southeast and Brahmaputra basin in the centre. Each and every segment is a complex geology and tectonic history.

The Himalayan mountain belt occupies the northern part. The altitude increases sharply from Brahmaputra plain at height of 100 m above mean sea level to the height of 7,089 m amalgamation with Tibetan plateau. It touches Mishmi hills through theTidding suture zone.

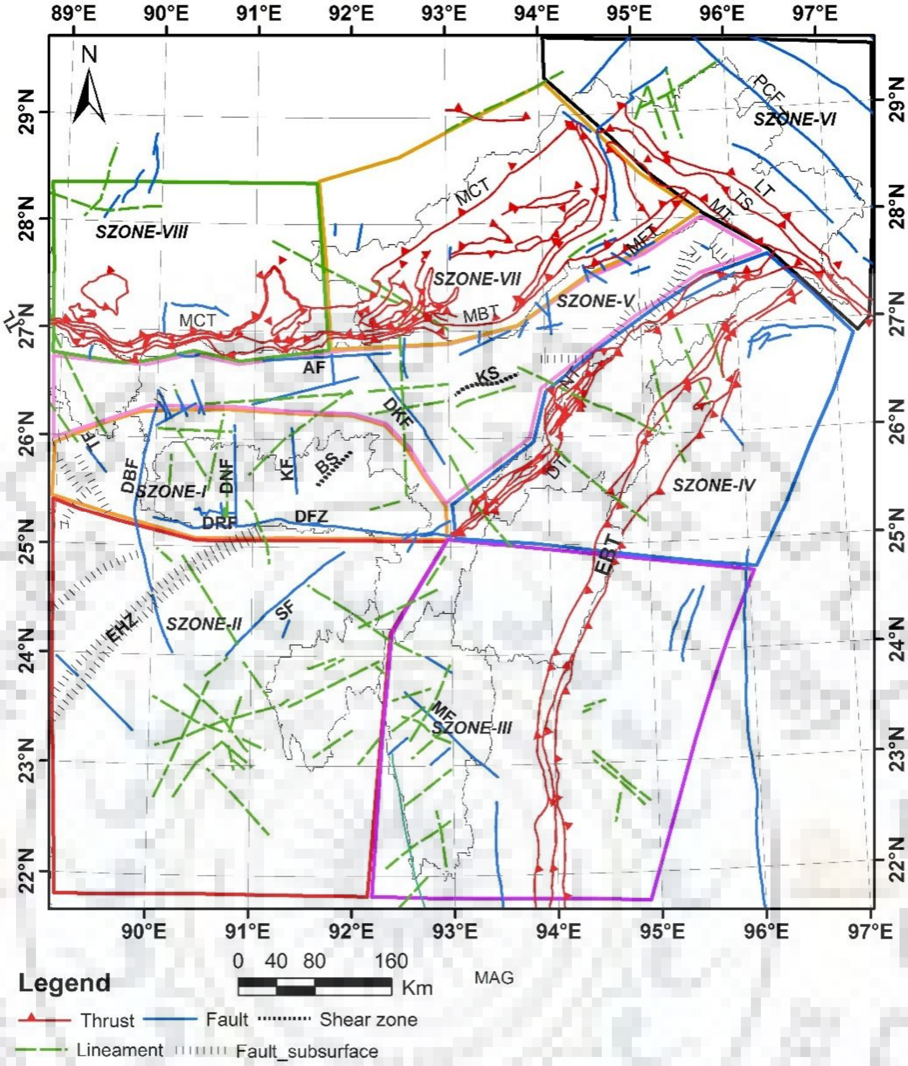


Figure 3.1Seismogenic source zones and tectonics of study area

MCT- Main Central Thrust, MBT-Main Boundary Thrust, MFT-Main Frontal Thrust, TL-Tista Lineament, TF-Tista Fault, AF-Atherkheit Fault, KS-Kalyani Shear, DKF-DhansiriKopili Fault, NT-Naga Thrust, DT-Disang Thrust, DFZ-Dauki Fault, BS-Barapani Shear, KF-Kulsi Fault, DNF-Dudhnoi Fault, DRF-Drapsi Reverse Fault, DBF-Dhubri Fault, EHZ-Eocene Hinge Zone, SF-Sylhet Fault, MF-Mat Fault, EBT-Eastern Boundary Fault.

The Himalaya mainly in Arunachal Pradesh is called as Arunachal Himalaya. This portion of the Himalaya as subdivided into four tectonic zones: Tethys or Tibetan Himalaya to North,Higher Himalayan Crystalline (HHC),Lesser Himalaya and Sub-Himalaya to the South. The north dipping Main Boundary Thrust (MBT), Main Central Thrust (MCT), and Main Frontal Thrust (MFT) are the main tectonic boundaries in this region, which delineates these tectonic zones.

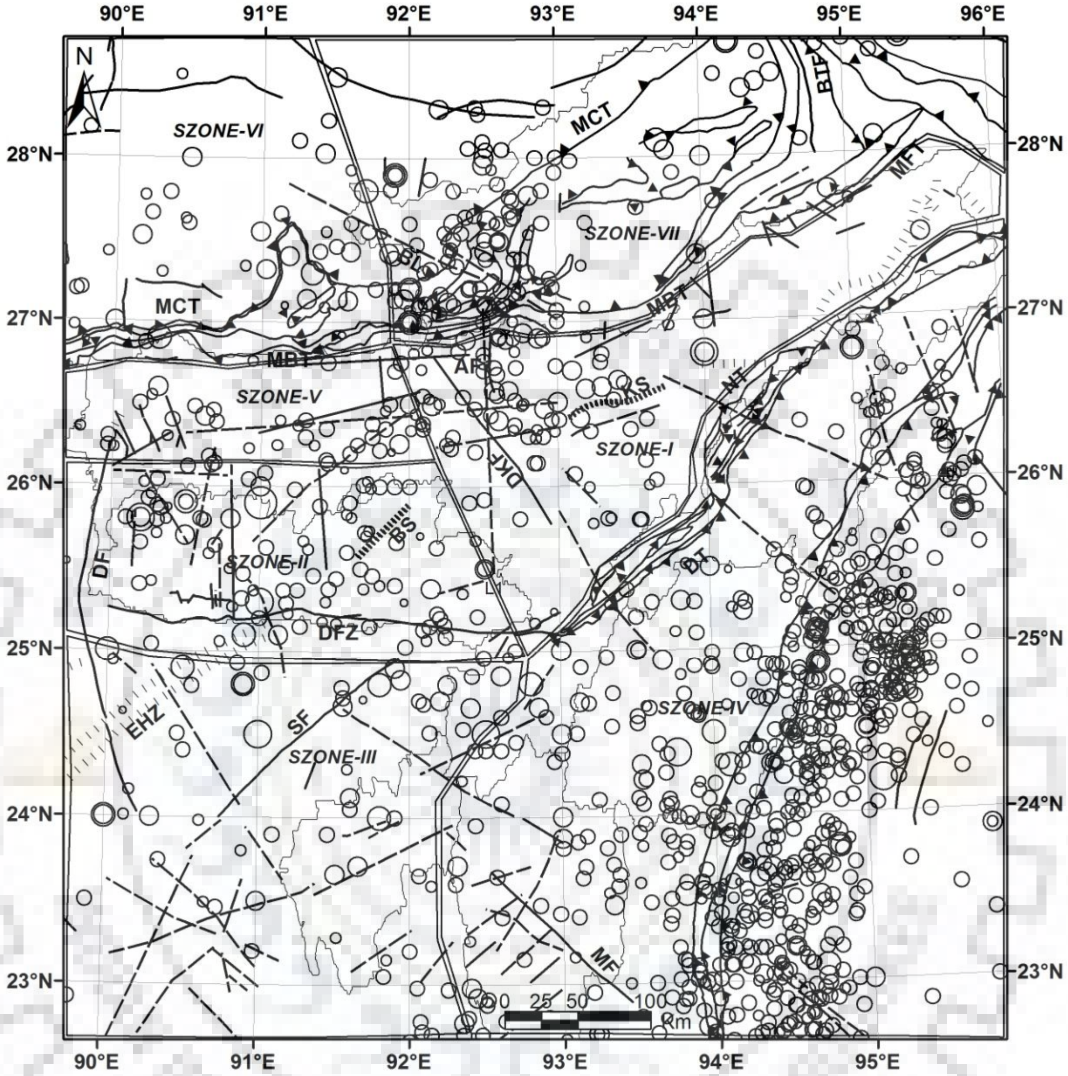


Figure 3.2Seismogenic source zones and seismogenic sources of the study area(NE India).

MCT- Main Central Thrust, MBT-Main Boundary Thrust, MFT-Main Frontal Thrust, TL-Tista Lineament, TF-Tista Fault, AF-Atherkheit Fault, KS-Kalyani Shear, DKF-DhansiriKopili Fault, NT-Naga Thrust, DT-Disang Thrust, DFZ-Dauki Fault, BS-Barapani Shear, KF-Kulsi Fault, DNF-Dudhnoi Fault, DRF-Drapsi Reverse Fault, DBF-Dhubri Fault, EHZ-Eocene Hinge Zone, SF-Sylhet Fault, MF-Mat Fault, EBT-Eastern Boundary Fault.

The Higher Himalayan region lies above the Lesser Himalaya through the MCT, the Less Himalaya are placed on the Sub-Himalaya along the MBT, and in turns it rides over Brahmaputra plain with the MFT (Thakur and Jain 1975; Nandy et al. 1980). The Mishmi Hills situated to the northeast contains of Lohit complex (Anon et al. 1974). It has NW-SE structural trends, abutted against the Himalaya and with Tidding Suture in southeast direction and in south beside the NE-SW trending Naga-Patkai ranges along with the Mishmi Thrust (Evans 1964). Somevital major thrust within the Mishmi hills is LohitThrust,which runs parallel direction to the Tidding suture. It defines tectonic contact between Mishmi formations and Tidding suture zone (Nandy 1976; Singh and Malhotra 1983). It also borders against the Mishmi Thrust to the south.In the southeast Naga-Patkaoiranges are present. This unitincludes of Tertiary succession of Assam (Mathur and Evans 1964).

The complex geological and tectonic status of the study area is the result of collision between the northward drifting of Indian plate and collision against theEurasian and Indo-Burmese plate.

3.3 SEISMOGENIC SOURCES

Source zone I: This zone consists of ShillongPlateau. In thisDauki fault is prominent fault.Which run about 450 km and it is considered as source of 1897 great earthquake. And this Dauki fault remained active during the formation of Shillong Plateau and trends along E-W direction. The average focal depth of earthquake of this zone is 35 km.this zone-1 consists 294 earthquake data available from the year 1835-2012.

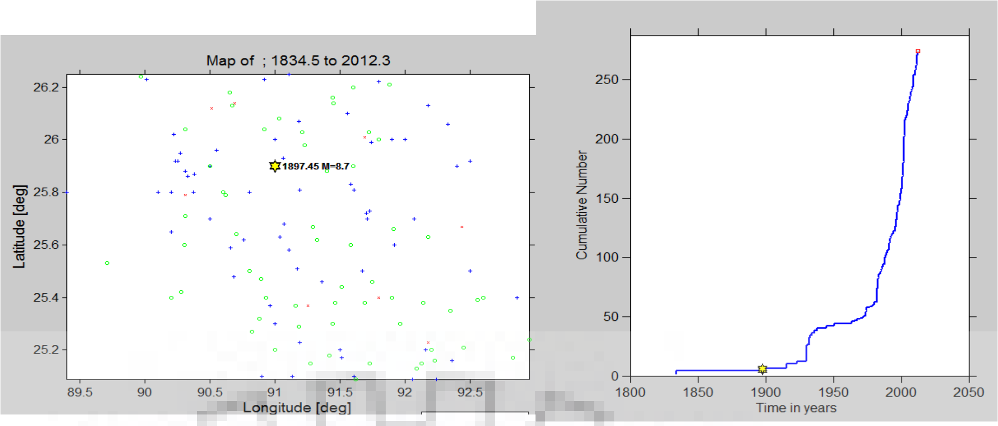


Figure 3.3 Catalogue data of source zone-I

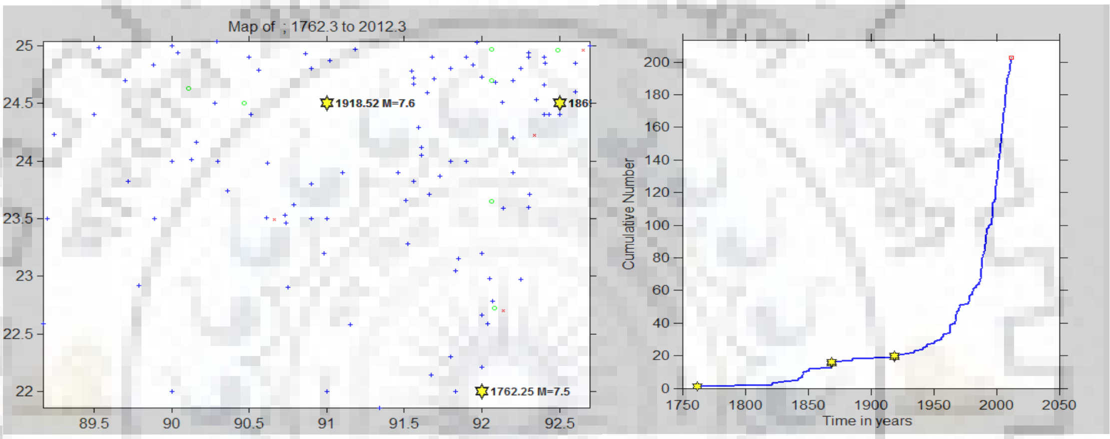


Figure 3.4 Catalogue data of source zone-II

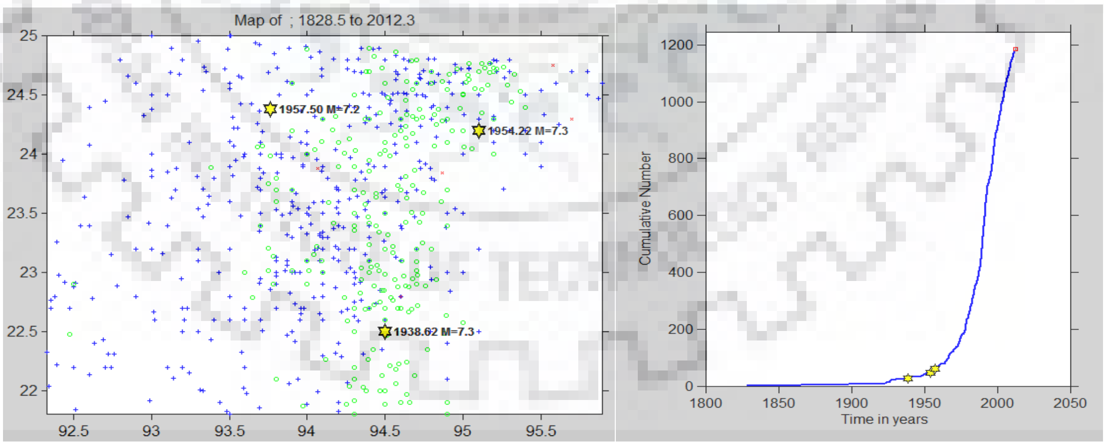


Figure 3.5Catalogue data of source zone-III

Source zone-II: This zone consists of Tripura and some parts of the Bangladesh. In this zone Sylhet fault is the important seismic features. Most import earthquake in this region is 1918 with magnitude of 7.6 and in this area the average focal depth of earthquake is 35km.A total number of events in this zone is 208.

Source zone III: This zone consists of Mizoram, Assam, and Manipur and part of Myanmar. This zone consists of folded belt and is represented by anticlinal ridges and synclinal valleys of Surmas and Tipams and having N-S trending strike faults. The average earthquake focal depth is 75 km. Total events 1187 during 1828-2012 with highest magnitude of 7.3.

Source zone IV: This zone consists of northern Indo-Burman fold belt. Thrusts dip towards southeast. This region has low seismic activity compared to others. The average earthquake focal depth of this region is 70 km. The total number of events are 433 during 1906-2012 with maximum magnitude 7.5.

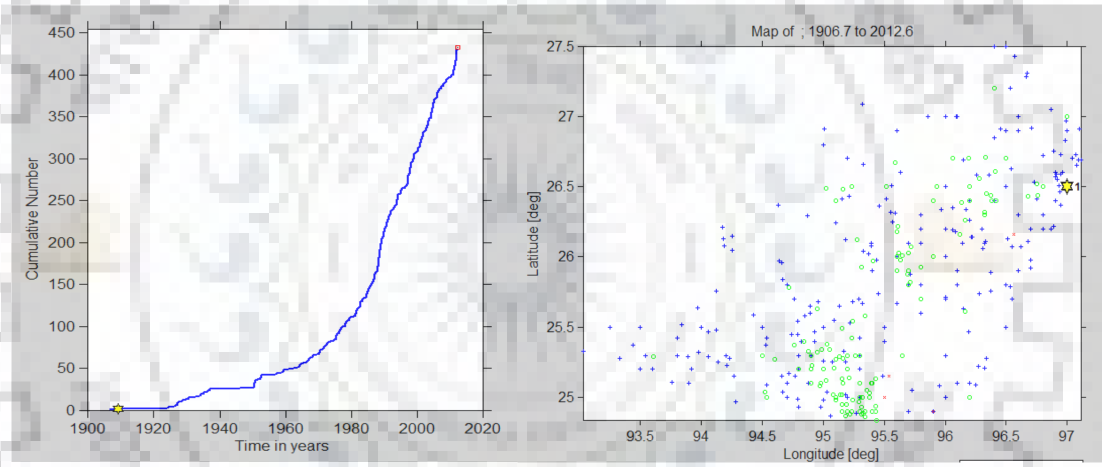


Figure 3.6 Catalogue data of source zone-IV

Source zone-V: This zone consists of complete Brahamaputra basin which is soft soil. Atherkeit and Dhansiri-Kopili faultsare the prominent tectonic features of this zone. The total number of events in this region is 248 during 1846-2012 with the maximum magnitude of 7.2.

Source zone-VI: This zone is called as Mishmi Massif. It contains Mishmi Thrust, Lohit Thurst, Po-Chu fault and and a few lineament. The averageearthquake focal depth is 42 km. The total number of events are 145 during 1930-2012 with a maximum magnitude of 8.5.

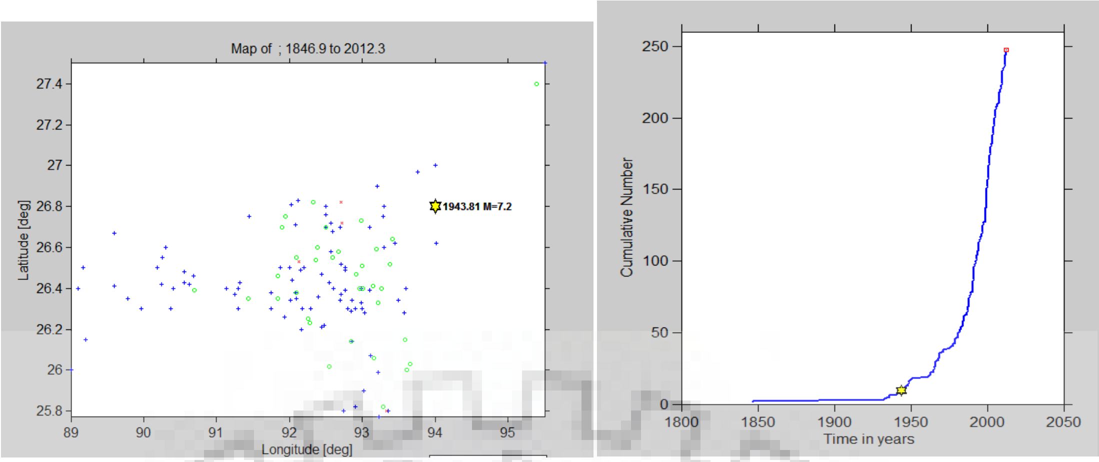


Figure 3.7catalogue data of source zone V

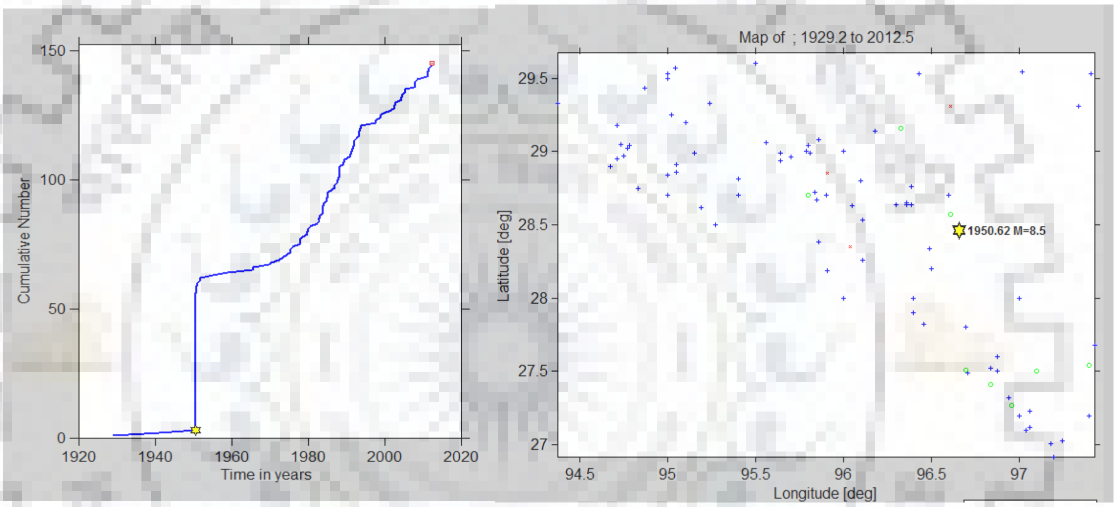


Figure 3.8Catalogue data of source zone-VI

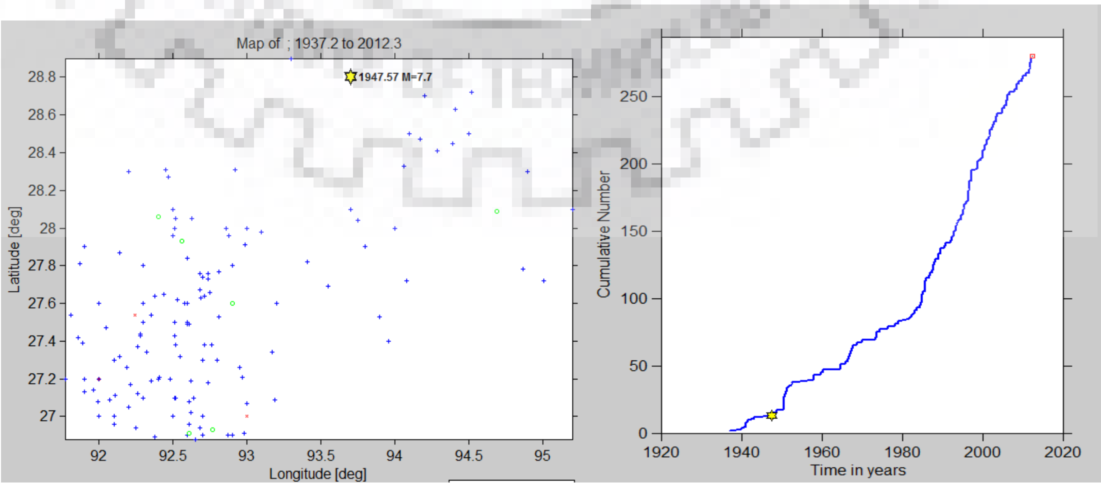


Figure 3.9Catalogue data of source zone-VII

Seismic zone-VII: This zone consists of Himalayan mountain belt which is having NE-SW trending structures and tectonics and consists of MCT, MBT and MFT thrusts. The total earthquake events are 202 occurred during 1937-2012 with a maximum magnitude of 7.7 and average focal dept is 42 km.

Seismic zone-VIII: This zone is also comprised of Himalayan mountain belt. The main tectonic features of this zone are MCT and MBT and the sturctures are oriented in E-W direction. The main seismicityof this region is due to these two thrust. The earthquake average focal depth of this zone is 39 km. The total number of events are 114 during 1938-2012 with a maximum magnitude of 6.5.

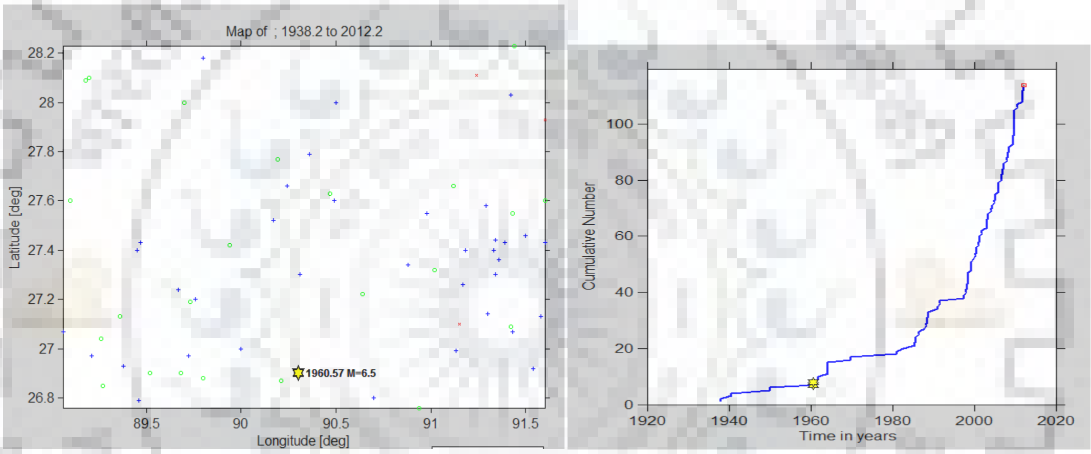


Figure 3.10Catalogue data of source zone-VIII

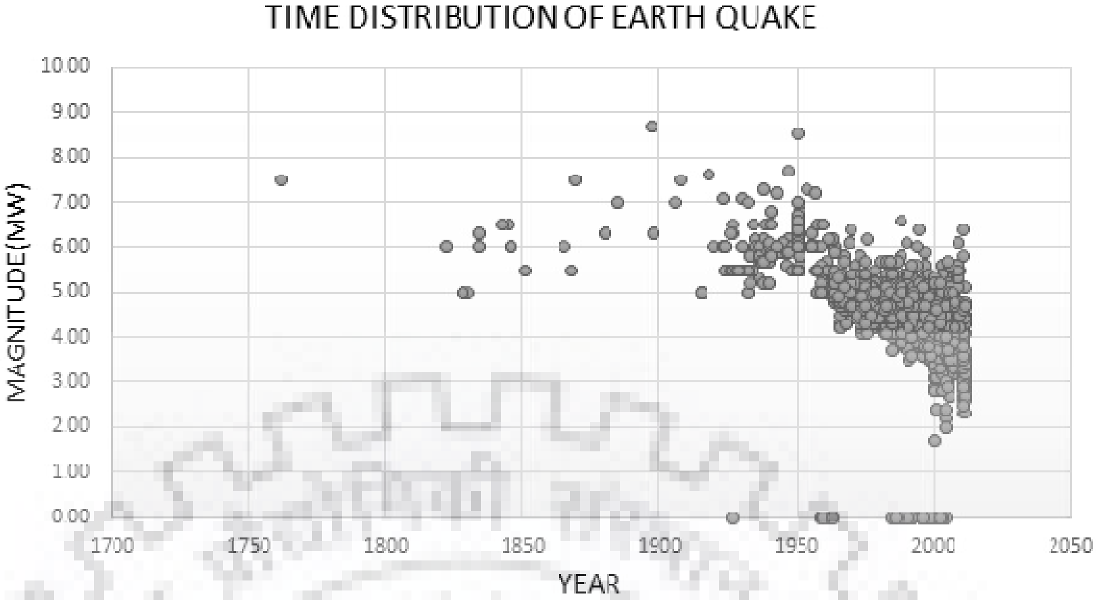


Figure 3.11Time Distribution of earthquake

3.4 CATALOGUE COMPLETENESS

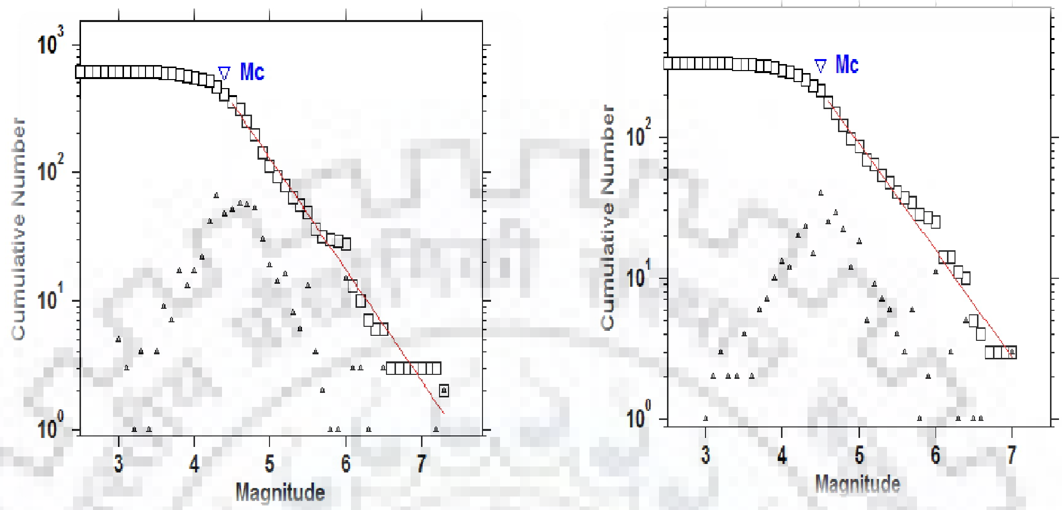
The earth quake catalogue for a particular region completed from different sources by IMD, USGS, ISC, Etc. in this analysis 2885 events are collected and grouped according to their magnitudes like $3 \leq M_w < 4$, $4 \leq M_w < 5$, $5 \leq M_w < 6$, $6 \leq M_w < 7$, and $7 \leq M_w$ the magnitude of the different classes are segregated

3.5 DECLUSTERING OF CATELOGUE

The results obtained in PSHA assumed that the earthquake data used has a Poisson distribution. Earthquake data includes foreshocks and aftershocks which makes it Non-Poisson and effects the results of PSHA. Due to this elimination of aftershocks and foreshocks from the data is essential. This is done using Z-Map which is written in MATLAB.

3.6 a, b and MAGNITUDE OF COMPLETENESS (M_C)

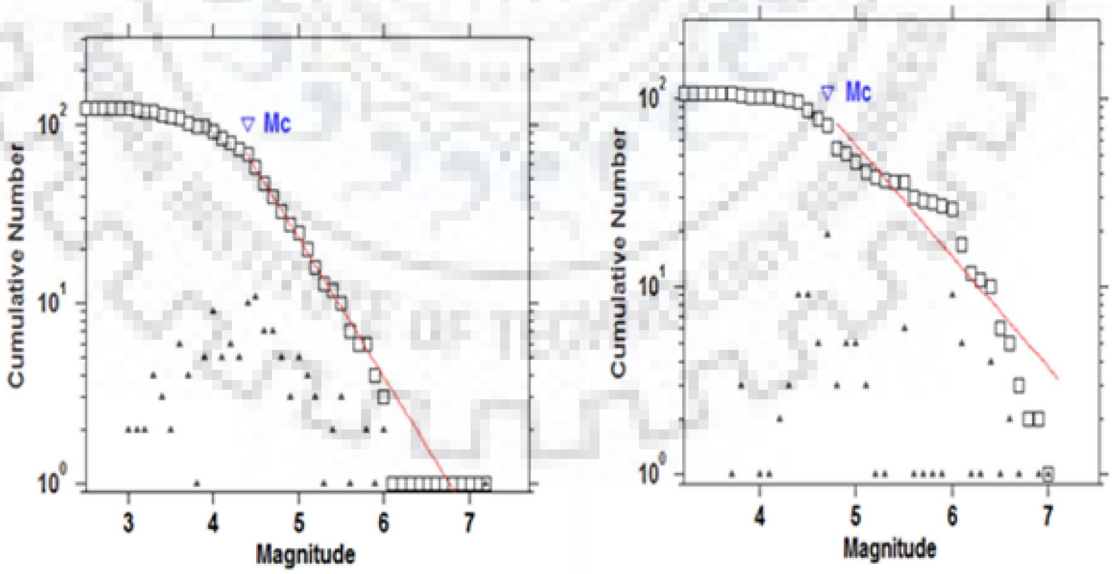
The parameters of the GR relation (a, b and m_c) are important in PSHA of the specific region. In this the parameter a represents seismicity of the particular zone and parameter b represents relative proportion to the large and small magnitude of earthquake. And m_c represents magnitude of completeness or threshold magnitude. The modified entire magnitude range method (EMR) provides comprehensive seismic model. For less earthquake events maximum curvature method is used for better values of a, b and m_c (Woessner, et. al, 2005).For present study a, b and m_c are calculated by using the Z-Map developed by (Wiemer and Wyss,2000). The seismic hazard parameters such as a, b and $m_{c,}$ these parameters are obtained from the instrumental seismicity.



Source Zone - III

Source Zone-IV

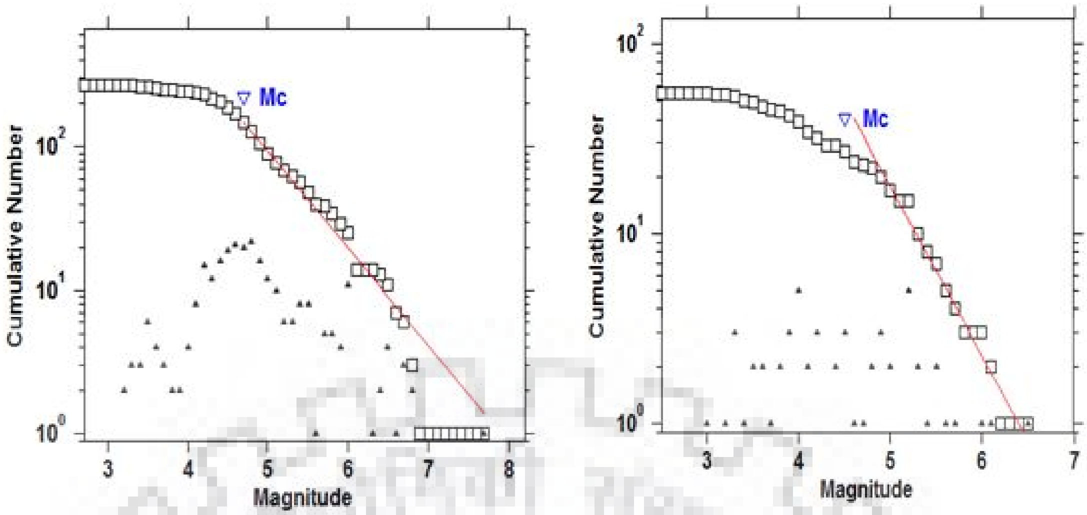
Figure 3.12a, b and m_c for seismogeniczone III and IV using Z-map



Source Zone-V

Source Zone-VI

Figure 3.13a, b and m_c for seismogenic zone V and VI using Z-map



Source Zone-VII

Source Zone-VIII

Figure 3.14a, b and m_c for seismogeniczone VII and VII using Z-map

The seismic hazard parameters obtain is future used in seismic hazard analysis on the following basis:

i) The parameter represents seismicity rate its lower value shows the low seismicity and vice-versa

ii) The return period obtained from the parameter is cross checked with the catalogue

iii) The data after the 1963 has been taken to compute a and b-values which is used for the evaluation of seismic hazard

The seismic hazard parameter of all seismogenic's zones using ZMAP are shown in Figure 3.16

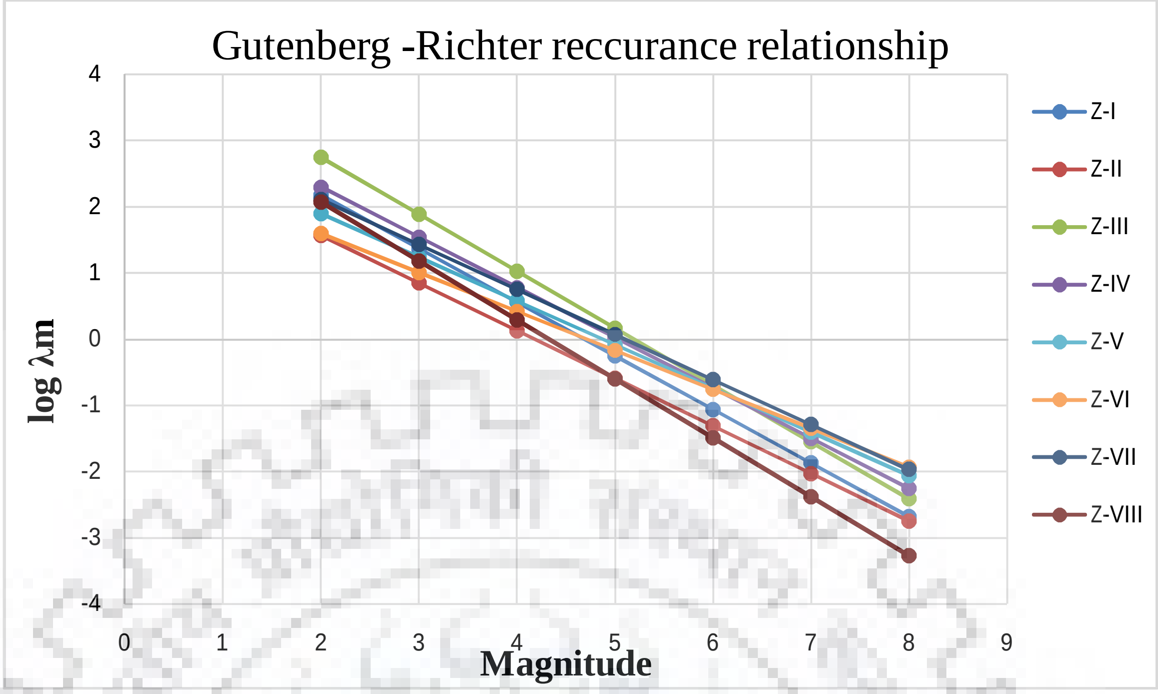


Figure 3.15G-R Recurrence Relation

The above table shows that source zone-III is most seismically active in this region after that source zone-I, source zone-VIII are also active due to its high value of ‘a’. And the variations in magnitude is more prominent in zone-VII and zone-VI due to its high value of ‘b’.

The G-R recurrence relation is shown in below figure that plots relation between magnitudes versus return period for all zones.

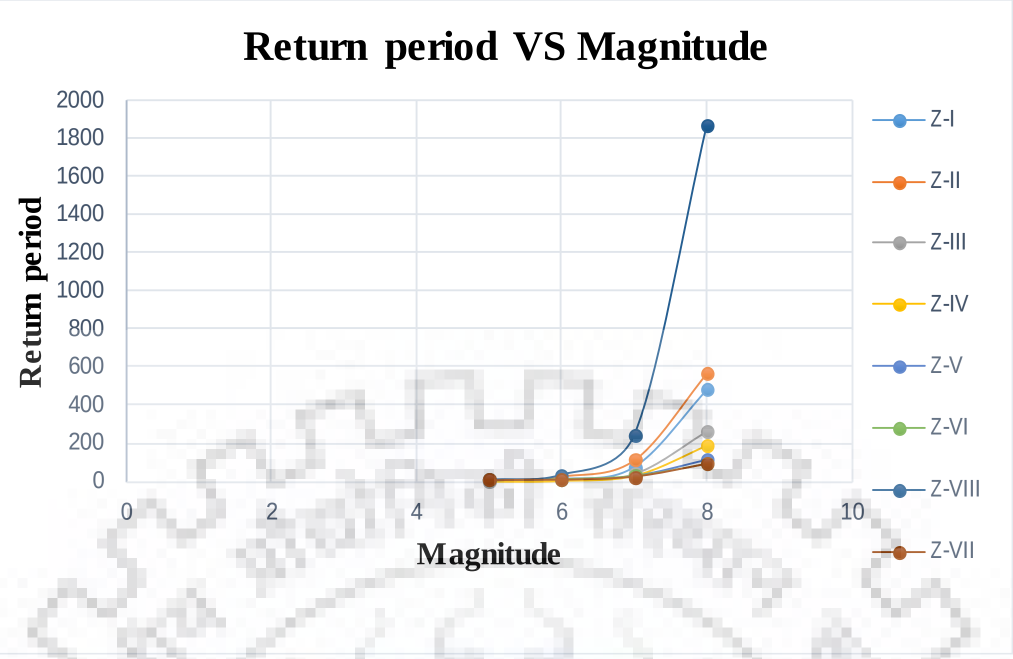


Figure 3.16Return period for particular Magnitude(check for one zone)

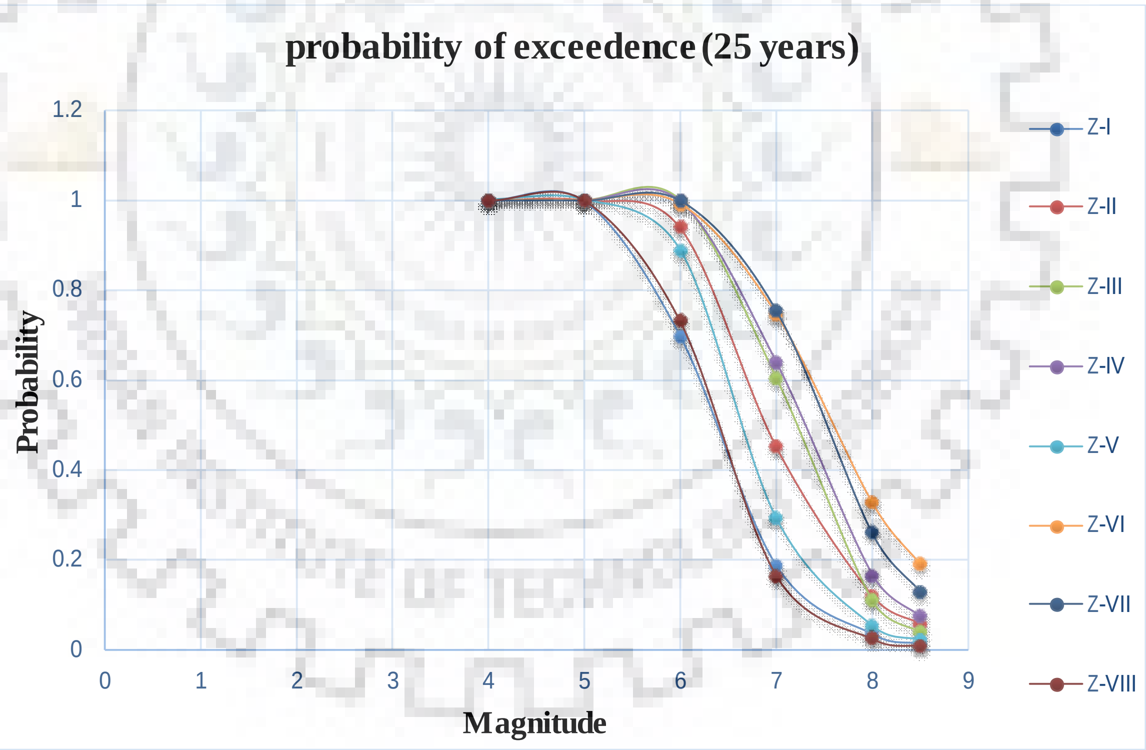


Figure 3.17The probability of exceedance for a particular earthquake for 25 years

3.7 ESTIMATION OF PROBABILITY OF EXCEEDANCE

Seismic risk is the quantitative estimation in term of the probability of earthquake occurs. This risk is expressed as annual exceedance of probability in the expected lifetime of the structure. The return period, T_R and annual exceedance probability, P is expressed as (Reiter, 1990).

$$T_R = \frac{-T}{\ln(1 - P(Z > z)}$$

The probability of earthquake of particular magnitude occurs at least once in a given time is

$$p = 1 - e^{-Nt} = 1 - e^{-(10^{a-bM})*t}$$

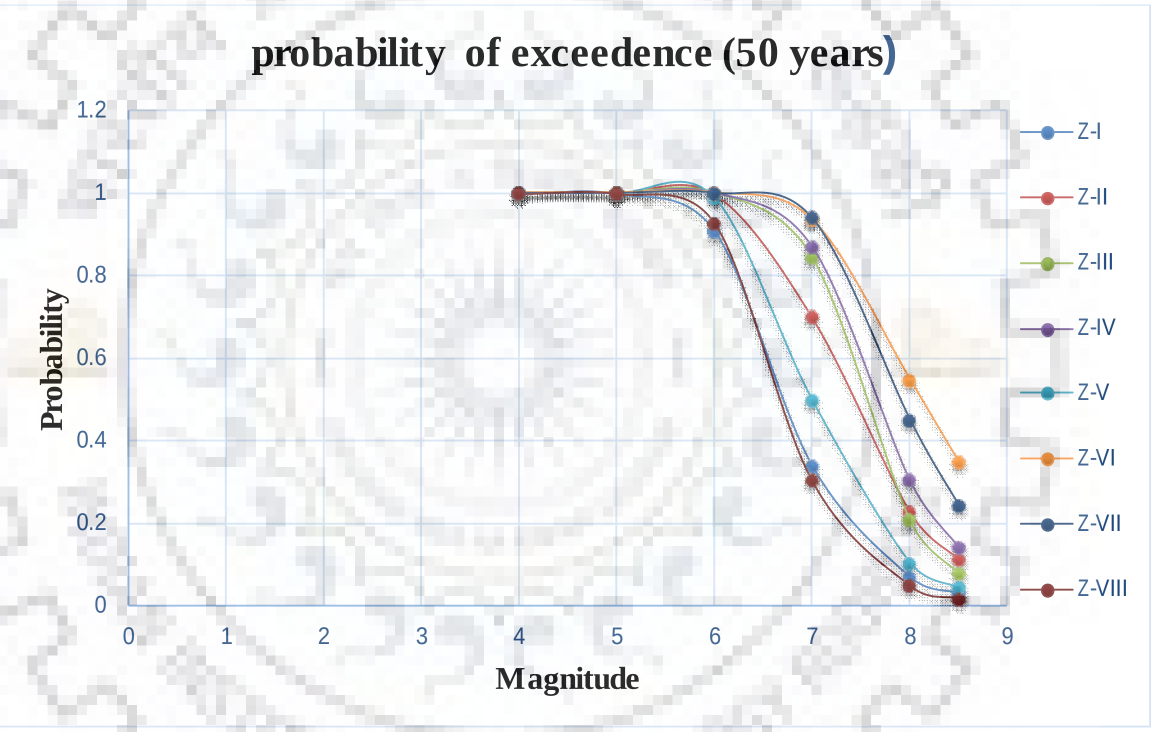


Figure 3.18The probability of exceedance for a particular earthquake for 50 years

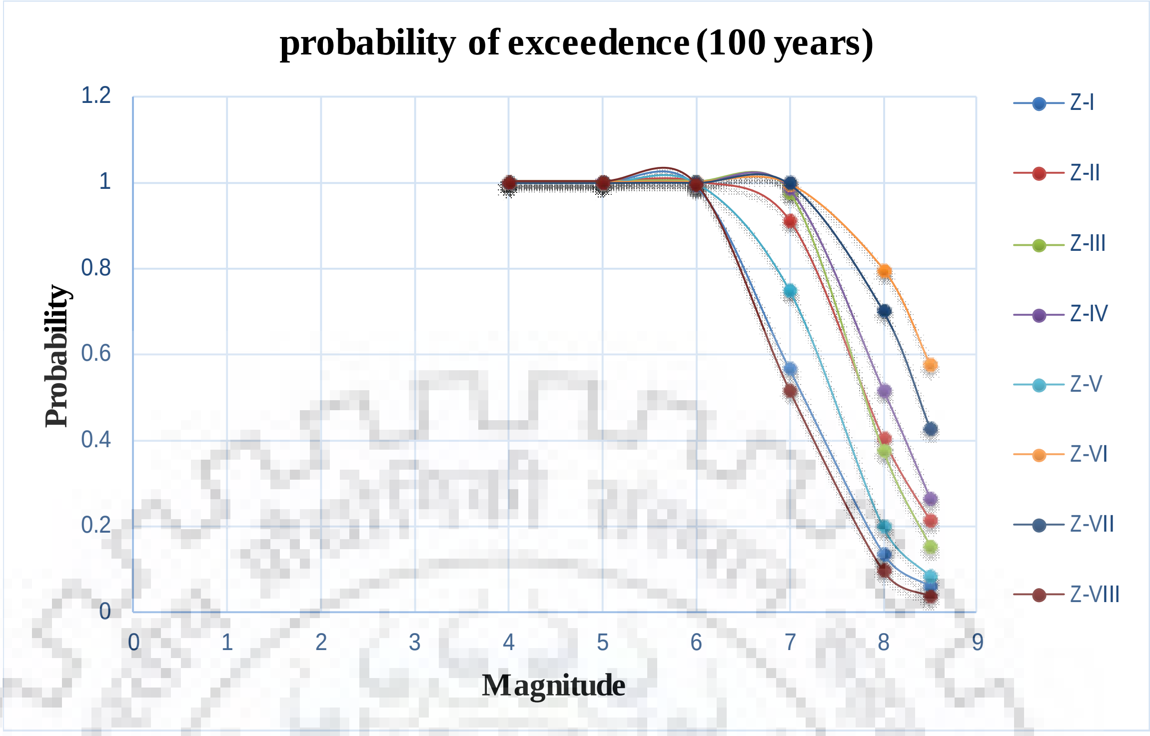


Figure 3.19The probability of exceedance for a particular earthquake for 100 years

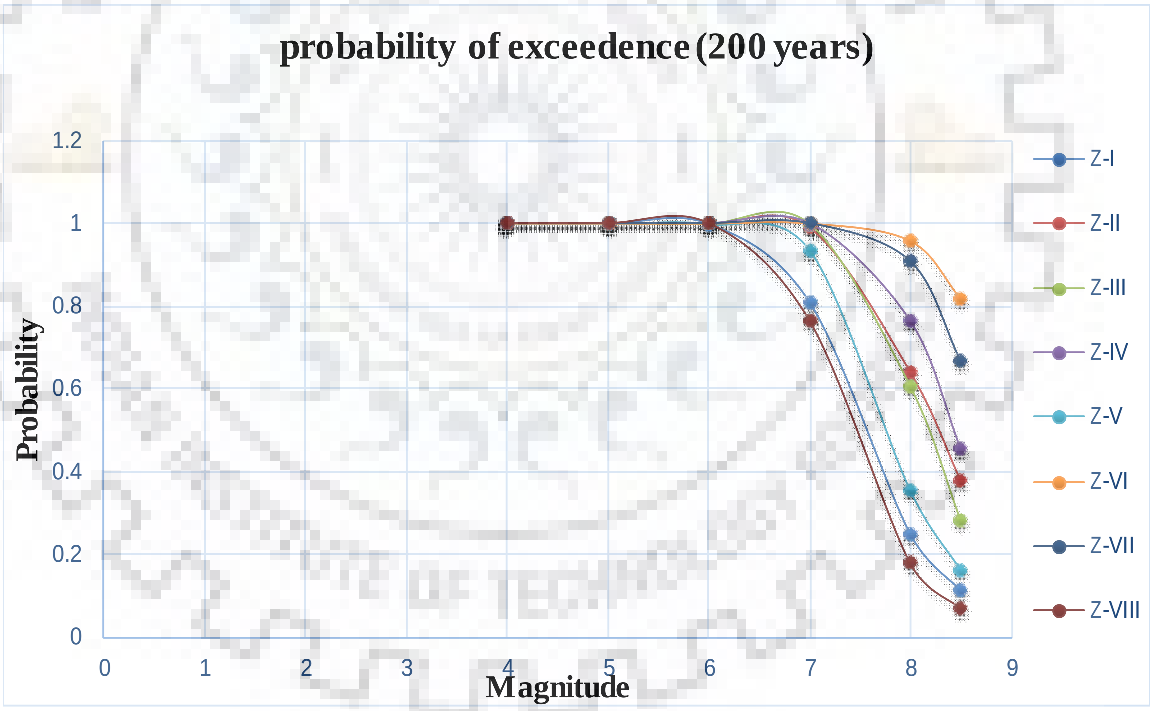


Figure 3.20The probability of exceedance for a particular earthquake for 200 years

3.8 DISCUSSION

The hazard parameters obtained from the Gutenberg-Richter such as a, b and m_c are more important in PSHA. The variation in these causes more significant change in seismic hazard, return period and probability of exceedance hence in this chapter there is calculation of seismic hazard parameters by combing all the zone and varying the value of b. the seismic hazard is calculated on the basic of Entire Magnitude Range Method as shown below.

The following return period, probability of exceedance, are listed in a tabular format below

Table 3.1: The seismic hazard parameters

Source / CAT Input			**Output from ZMAP**				**Estmations ERP**			**Output for Crisis**							
SZ	**$M_{max,o}$**	**T_{cat}**	**a**	**b**	**e_b**	**M_c**	**6**	**7**	**8**	**Mc**	**λ**	**β**	**e_β**	**U_m**	**σ**	**M_{low}**	**M_{high}**
I	8.7	274	3.2	0.8	0.2	4.5	21	120	692	4.5	0.66	1.75	0.53	8.7	0.3	8.7	9.2
II	7.3	1054	3.1	0.7	0.2	4.6	9	42	195	4.6	0.97	1.54	0.41	7.3	0.3	7.3	7.8
III	7.3	1187	4.9	0.9	0.1	4.5	3	27	214	4.5	6.61	2.07	0.21	7.3	0.3	7.3	7.8
IV	7.5	433	3.9	0.8	0.1	4.5	4	25	138	4.5	3.05	1.73	0.12	7.5	0.3	7.5	8
V	7.2	248	3.7	0.8	0.1	4.4	11	72	457	4.4	1.66	1.84	0.25	7.2	0.3	7.2	7.7
VI	8.5	145	2.5	0.5	0.1	4.7	5	18	63	4.7	0.96	1.24	0.30	8.5	0.3	8.5	9
VII	7.7	280	3.4	0.7	0.1	4.7	4	18	83	4.7	1.95	1.54	0.32	7.7	0.3	7.7	8.2
VIII	6.5	114	3.9	0.9	0.5	4.8	19	138	1000	4.8	0.56	1.98	1.08	6.5	0.3	6.5	7

Where,

SZ-Source Zone T_{cat} = catalogue of EQ e_b- error in b e_β = error in β

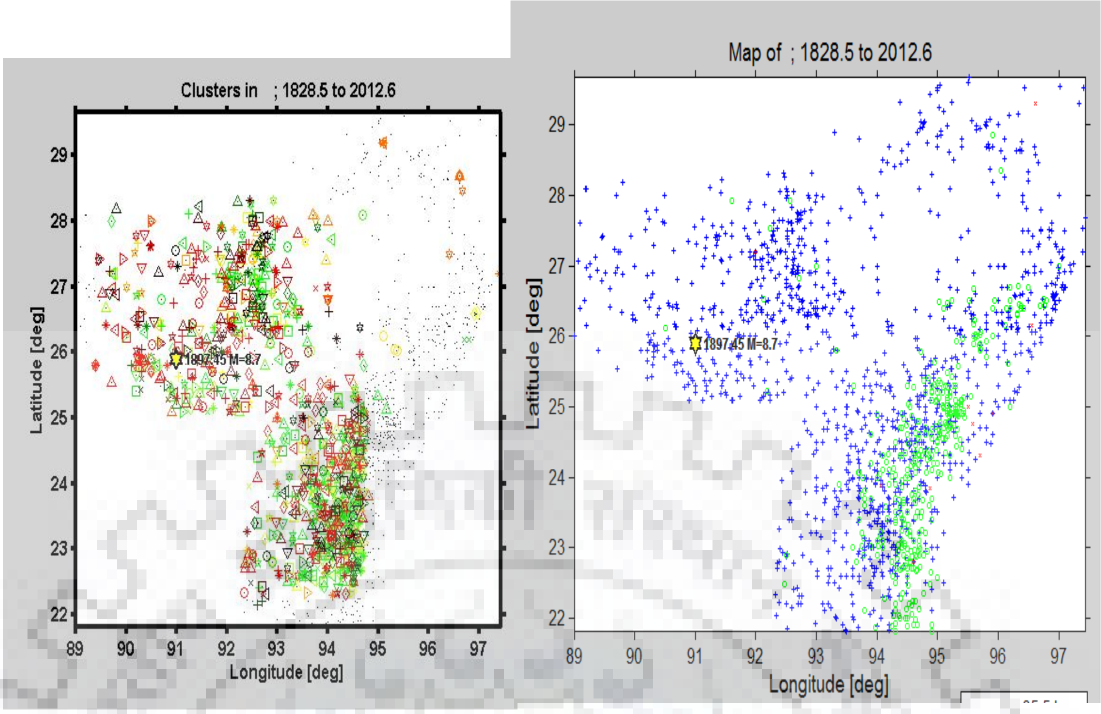


Figure 3.21seismicity of complete region after de-clusters

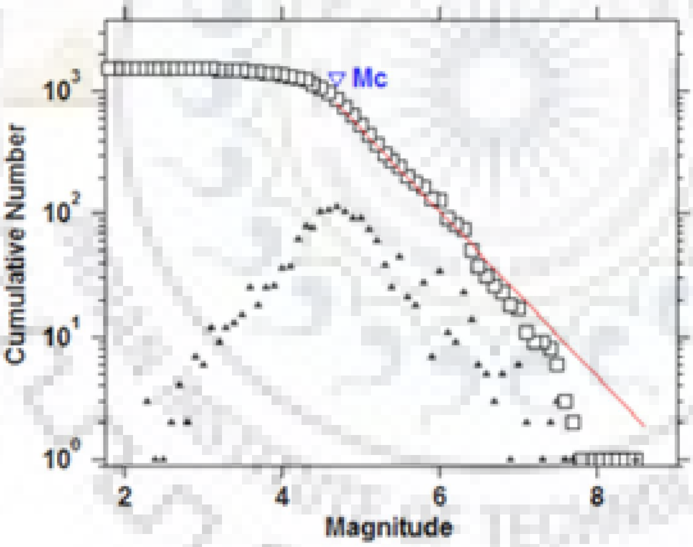


Figure 3.22a, b and m_c for whole study area using Z-map

4 CHAPTER

SEISMIC HAZARD ESTIMATION

4.1 GENERAL

PSHA of the region of North-east part of India. The region lies in between latitude of 20°N-30°N and longitude 87°E-98°E and also it includes near countries like China, Bangladesh, Bhutan and Myanmar. This region contains of various seismogenicsources such as faults, thrusts, and inter plate movement are present in this region. To calculate the seismic hazard (PGA, PSA) in this regionthe study area is divided into different source zones. At present study area has been divided into 1720 small grid points of size 0.2°×0.2° is put in complete region. At this point only it obtains all seismic hazard parameters. In present study I took source seismicity as G-R relation and attenuation models developed by Abrahamson and Silva(1997), Abranhamsion and Silva(2007), Akkar and Bommer(2007), Boore and Atkinson(2008), Akkar and Bommer (2010), Arroyo et al.(2010), Idriss(2008) and Lin and Lee(2008)are to be used to compute the both PSA and PGA at different time periods.

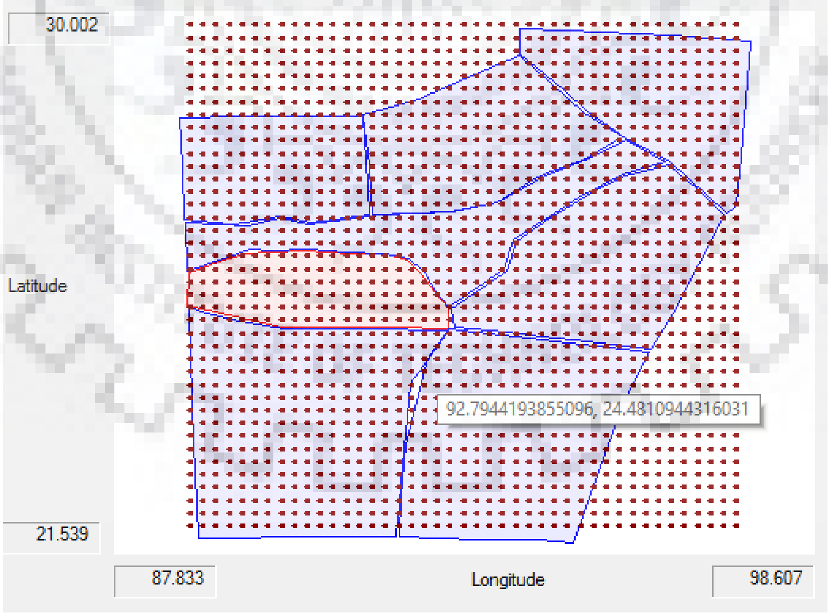


Figure 4.1Study are comprised of NE India and adjoining region divided into 0.2°×0.2° grids.

4.2 ATTENUATION MODELS

Boore et al(2014) has proposed an attenuation model in which horizontal spectral acceleration for shallow crustal earthquake in tectonic active region, world-wide and acceleration spectrum varies from 0.01 to 5 and distance in the range of 0.1 to 200, magnitude 4-7.5, soil type like rock or shallow soil and deep soil, fault type reverse or oblique. cambell(2014) has proposed attenuation model. This model attenuation relation obtained from 532 accelerograms from the strong motion databank of Europe and Middle East. Spectral period is in the range of 0 to 4, Valid distance 1-100 km, valid magnitude 5-7.6 Mw, damping 2%, 5%, 10%, 20%, and 30% for the fault type like normal and reverse and also ground type soft soil and stiff soil this model is to be used. Same model further developed by removing the percentage of damping and including more accuracy by cambell(2014). Abrahamson,silva,kamai(2014) with sigma reduction and without sigma reduction both model does not give much different in north-east India. In this model attenuation relationship for PGA and 5% damping PSA, for shallow crustal earthquake in active tectonic environments world-wide has been incorporated. Acceleration spectrum ranges from 0-10, distance 1-200, magnitude 5-8, ground type by varying Vs30, fault type like unspecified, strike-slip, Normal and thrust/reverse, also includes geometric mean of Vs30 and ground type. This model also considers the uncertainty term in order to obtain precise value of ground motions. The attenuation model is described by the fallowing equation.

$$\ln Y = F_M(M) + F_D\left(R_{JB}, M\right) + F_S\left(V_{s30}, R_{JB}, M\right) + \varepsilon\,\sigma_T$$

In this equation F_M, $F_S\ and F_D$ signifies magnitude scaling,site amplification and distance function. M is magnitude moment, R_{JB} is the nearby distance to the surface projection of the rupture V_{s30} is the shear-wave velocity above the top 30m (m/s). The coefficient ε is the fraction number of standard deviation of a particular predicted value of lnY away from the average value of ln Y. All terms, including the co-efficient σ_T are period dependent it is obtained by

$$\sigma_T = \sqrt{\left(\sigma^2 + \tau^2\right)}$$

Where σ is the intra-event aleatory uncertainty and τ is the inter-event aleatory uncertainty. For the present work shear wave velocity V_{s30} is taken as 13000 m/s that mean peak ground motion is computed at bed rock level (30m below the surface).

Table 4.1 Boore et al (2014)

Brief description	Horizontal spectral accelerations for shallow crustal earthquakes in tectonically active regions, world-wide
Original units	cm/s/s
Dimension	Acceleration
Spectral period range	0.01 to 5
Valid distance range	0.1 to 200
Valid magnitude range	4 to 7.5
Type of distance metric	Rrup
Residuals distribution	LogNormal
Tectonic region	Active_Shallow_Crustal

Table 4.2 cambell(2014)

Brief description	Attenuation relation obtained from 532 accelerograms from the strong motion databank of Europe and Middle East
Original units	cm/s/s
Dimension	Acceleration
Spectral period range	0 to 4

Valid distance range	1 to 100
Valid magnitude range	5 to 7.6
Type of distance metric	JyB
Residuals distribution	LogNormal
Tectonic region	Active_Shallow_Crustal

Table 4.3 Abrahamson,silva,kamai (2014)

Brief description	Attenuation relation obtained from 532 accelerograms from the strong motion databank of Europe and Middle East.
Original units	cm/s/s
Dimension	Acceleration
Spectral period range	0 to 3
Valid distance range	1 to 100
Valid magnitude range	5 to 7.6
Type of distance metric	JyB
Residuals distribution	LogNormal
Tectonic region	Active_Shallow_Crustal

Table 4.4 Idriss(2010)

Brief description	Spectral horizontal accelerations (5% damping) on rock for Mexican subduction-zone interface earthquakes
Original units	cm/s/s
Dimension	Acceleration
Spectral period range	0 to 5
Valid distance range	16 to 400
Valid magnitude range	5 to 8.5
Type of distance metric	Rrup
Residuals distribution	LogNormal
Tectonic region	Subduction

Othter attenuations

4.3 SOFTWARES USED

A number of programme have been developed and are available to compute seismic hazard for the region. Most of the programme works on probabilistic methodology developed by Cornell (1968). In the present study of PSHA has been computed using CRISIS 2012 software (Ordaz, 2004). Some salient features of the programme are listed below:

CRISIS is an open-source PSHA programme that calculates the hazard curve and uniform hazard spectrum at a given site. it predicts the hazard map for the grid of sites according to input parameters. The programme allows taking various type source geometrics such as point, line and area sources depending up on seismicity of the region. The seismicity model for the occurrence of the earthquake with time can be represents either by poissonian process or characteristic earthquake process. To represent the magnitude distribution of the earthquakes, CRISIS takes into account Bounded Gutenberg-Richter recurrence relation. This relation is truncated at minimum and exponentially smoothing at maximum magnitude. The programme also assigning of different strong motion of different seismogenic sources

The fallowing input parameters enter into programme:

i) Grid site: the coordinates of the area or grid of site of interest for which the hazard will be calculated,

ii) Source geometry: the coordinates of the quadrilateral defining the seismic zone

iii) Source seismicity: the parameters of the Gutenberg-Richter recurrence relationship such as mean annual rate of exceedance λ_m for the earthquakes with the magnitude m, parameters β, minimum magnitude $m_o$and maximum magnitude m_{max}.

iv) Attenuation data: the attenuation relation is tabular from to fallow the ground motions,

v) Spectral ordinates: the type and number of value for which PSHA has to be calculated

Global parameters: the parameters which control the spatial integration process and the desired return periods.

4.4 RESULTS AND DISCUSSION

The spectral acceleration for the different models are taken which are Boore et al (2014) 2% damped , Cambell(2014) 5% damped, Abrahamson,silva,kamai (2014)and Idriss(20014) at a specific grid point (89,22),(longitude is 89°N and latitude 22°E) spectral acceleration given by the different models are listed below for 2475 Return period.

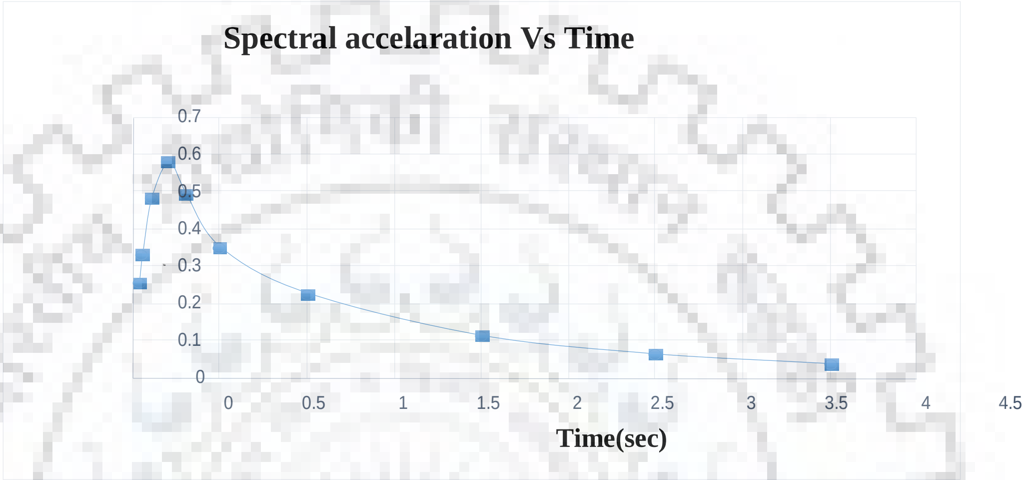


Figure 4.2Spectral accelerationvs.time(Abrahamsion,kamai,Silva, 2014 model)

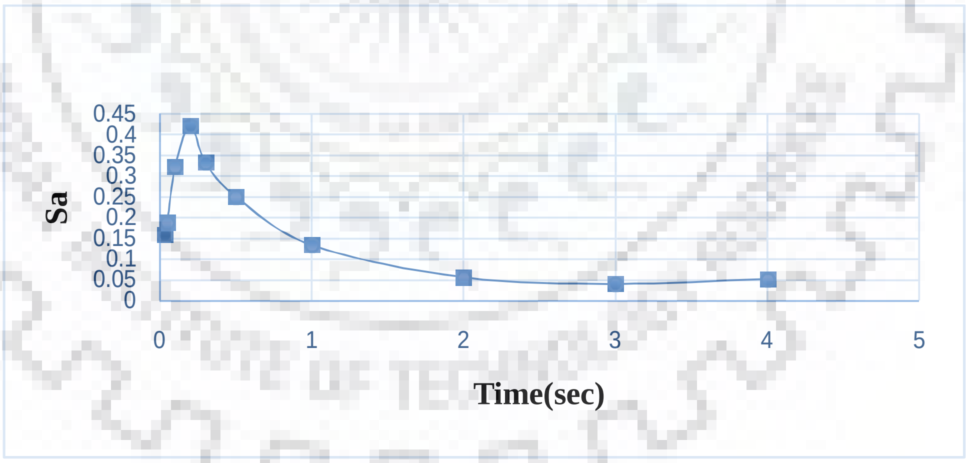


Figure 4.3 Spectral accelerationVs. Time (boore et al (2014) 2% damping model)

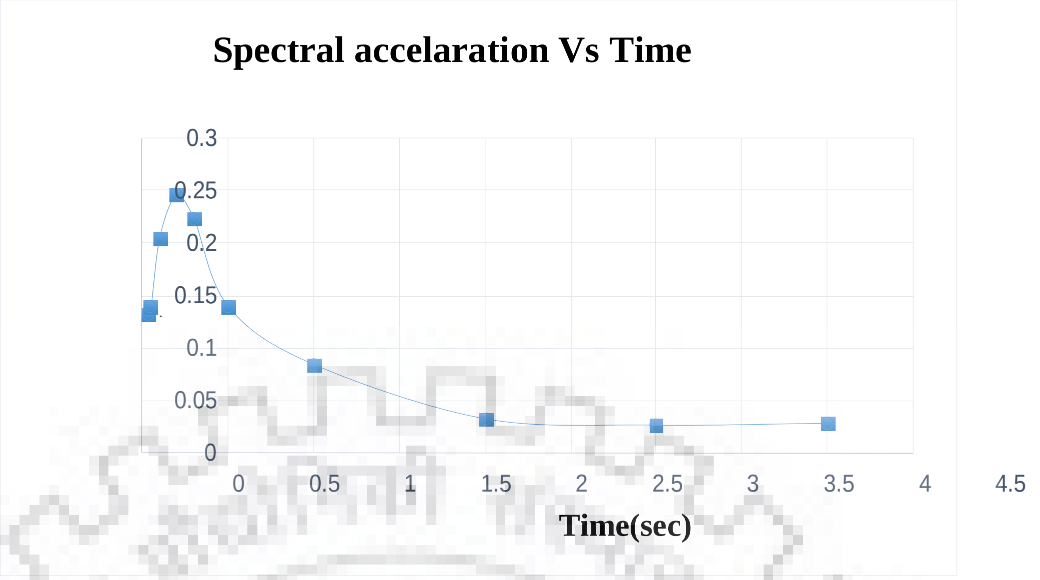


Figure 4.4 Spectral accelerationVs. Time of idriss(2014) 5% damping model

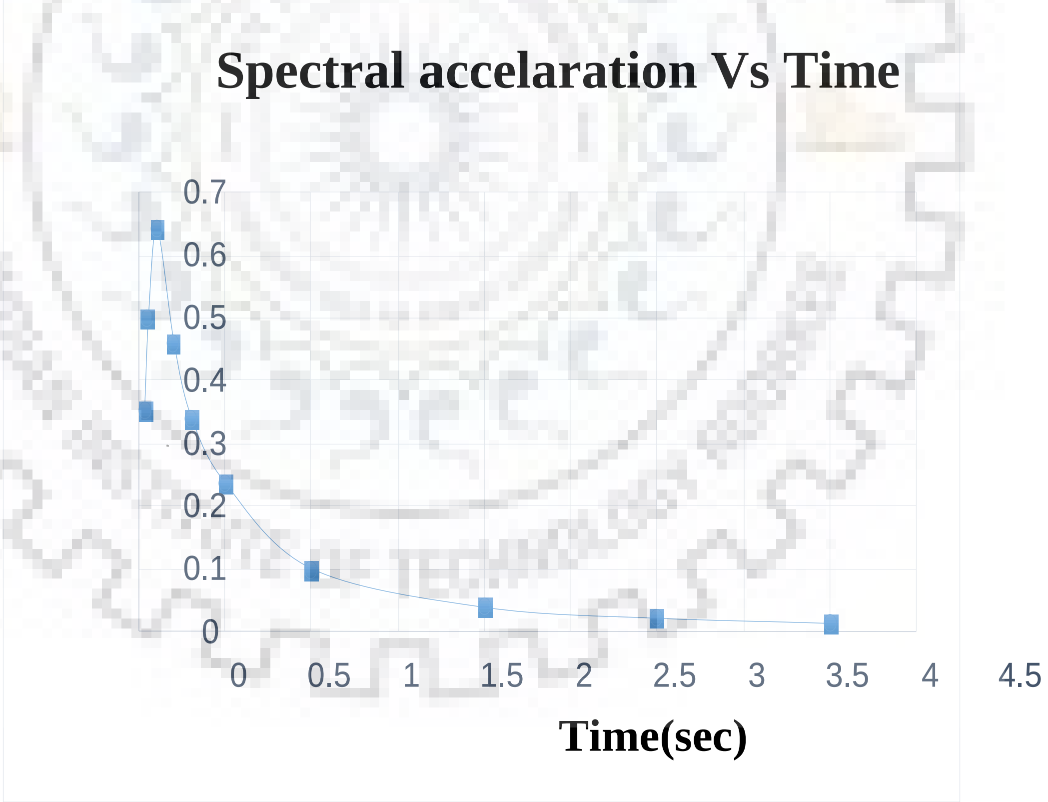


Figure 4.5 Spectral accelerationVs. Time of cambell(2010) model

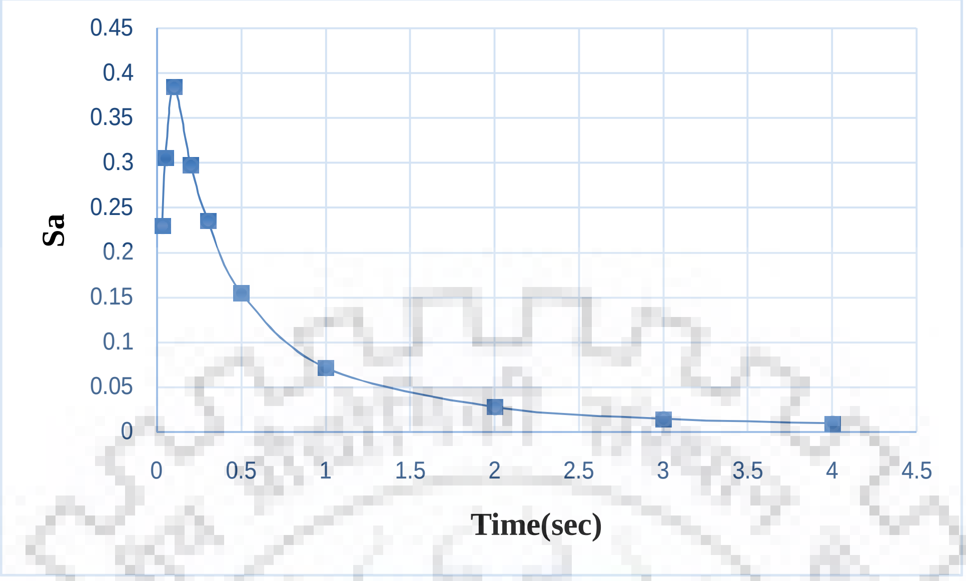


Figure 4.6 Spectral accelerationVs. Time of Arroyo et al (2010) model

AS stared that peak ground acceleration (PGA) has been estimated by using attenuation model of Boore et al (2014) , Cambell(2014), Abrahamson, silva,kamai (2014)and Idriss(20014) there also considering for 2%, 5%, 10% damping for the probability of exceedance in 50 years. The computed PGA values of the region are shown in the following mapsprepared using ArcGIS10.

Table 4.5 Comparison of computed PGA with other studies for 10% probability of exceedance at selected cities for 50 Years

	LATITUDE	LONGITUDE	NDMA (Iyengar et al., (2010)	GSHAP (Bhatia et al.,1999)	BIS (2002)	Nath and Thingbaijam (2012)	Sharma and Malik (2006)	Das (2013)	Present study
GUWAHATI	26.14	91.736	0.23	0.3	0.18	0.98	0.5	0.244	0.26
GANGTOK	27.33	88.6	0.15	0.25	0.18	0.5	0.35	0.146	0.37
SHILLONG	25.36	93.88	0.25	0.3	0.18	1.1	0.48	0.316	0.34
AIZWAL	23.72	92.71	0.18	0.3	0.18	0.6	0.3	0.114	0.15
IMPHAL	24.78	93.88	0.35	0.45	0.18	0.99	0.4	0.144	0.101
PASIGHAT	28.21	94.72	0.2	0.3	0.18	0.7	0.5	0.182	0.22

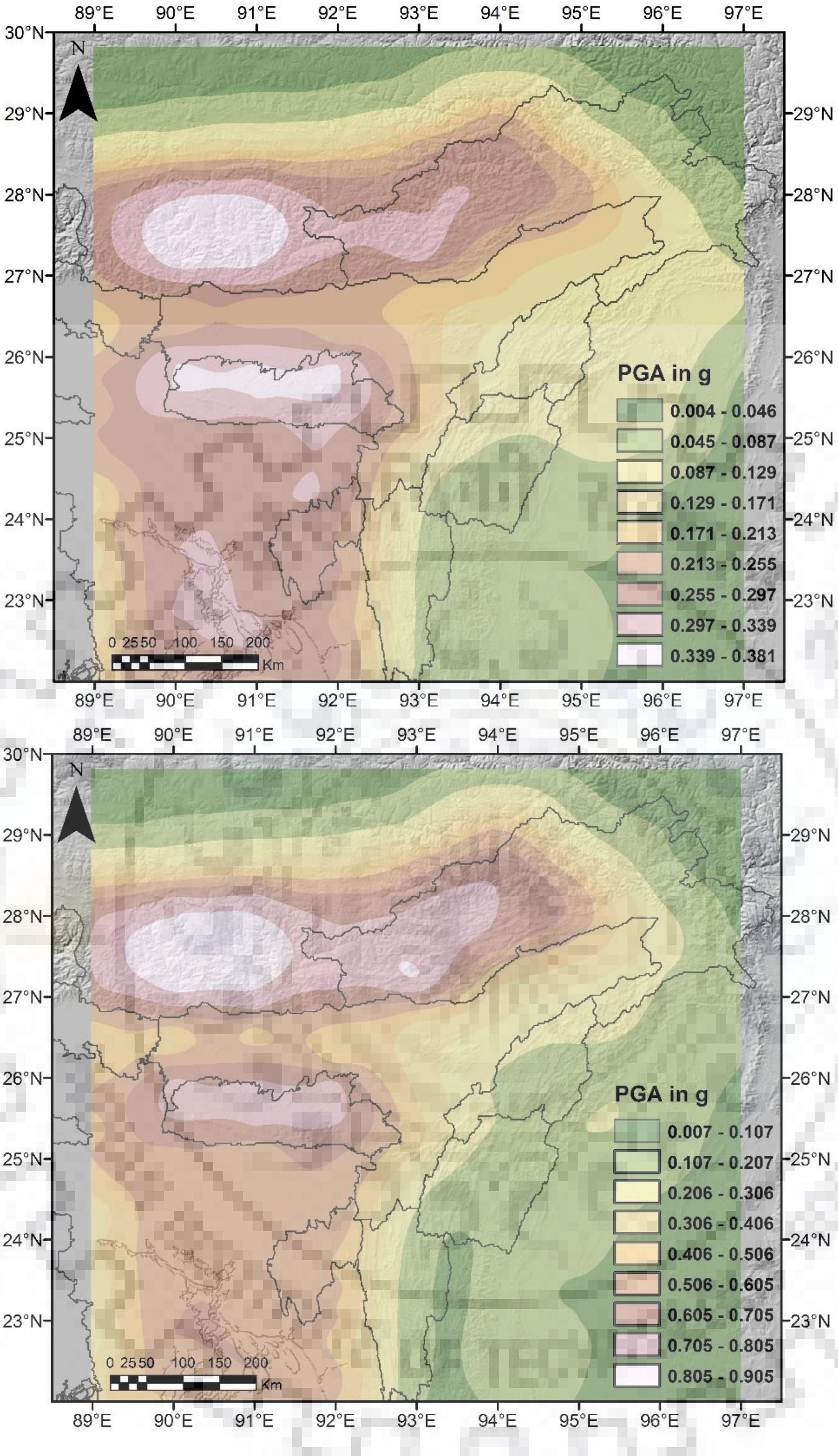


Figure 4.7 PGA zones for return period of 475 and 2475 years, campbell(2014) attenuation model

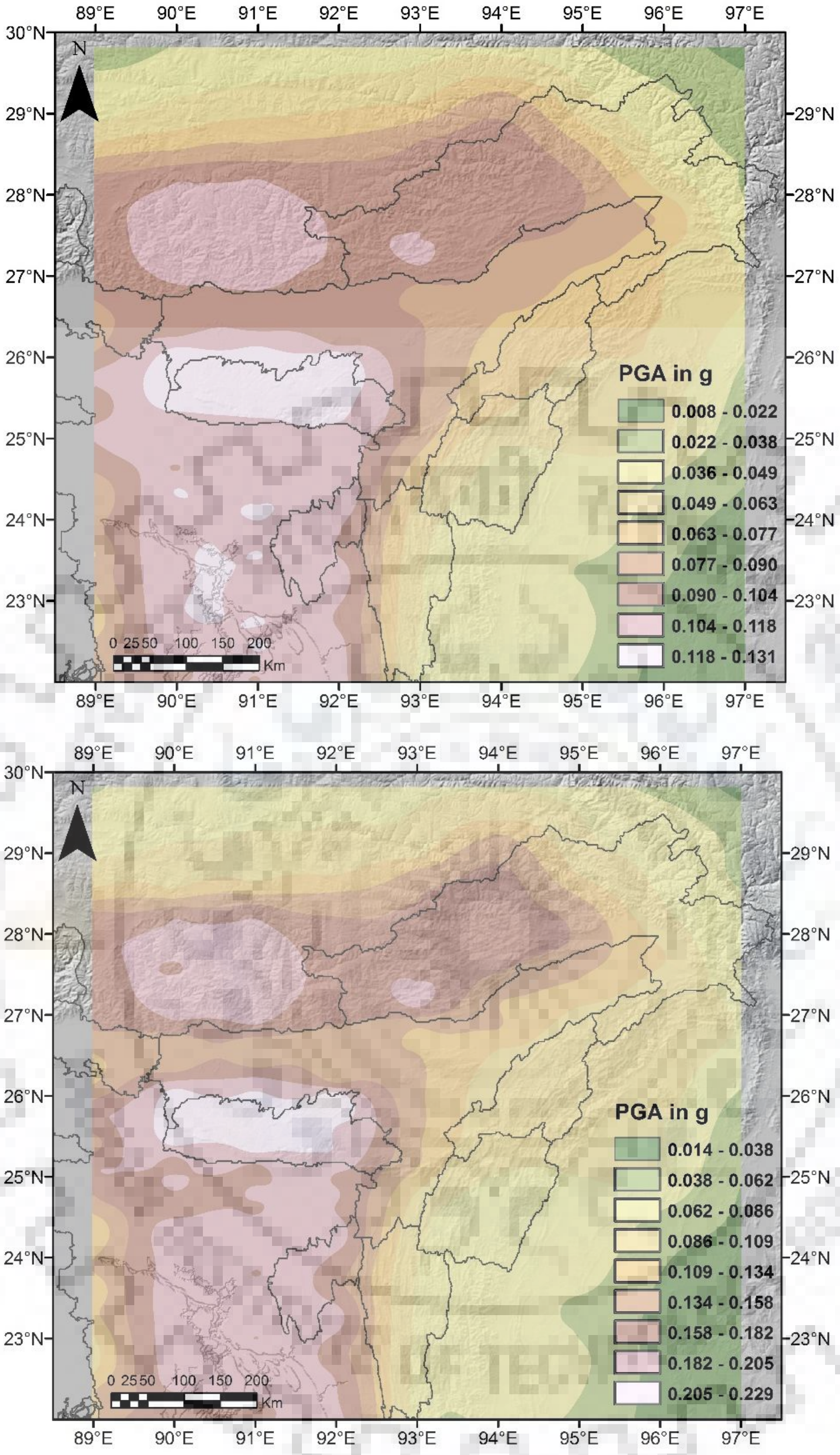


Figure 4.8 PGA zones for return period of 475 and 2475 years' in Abrahamson,silva kamai(2014) attenuation model

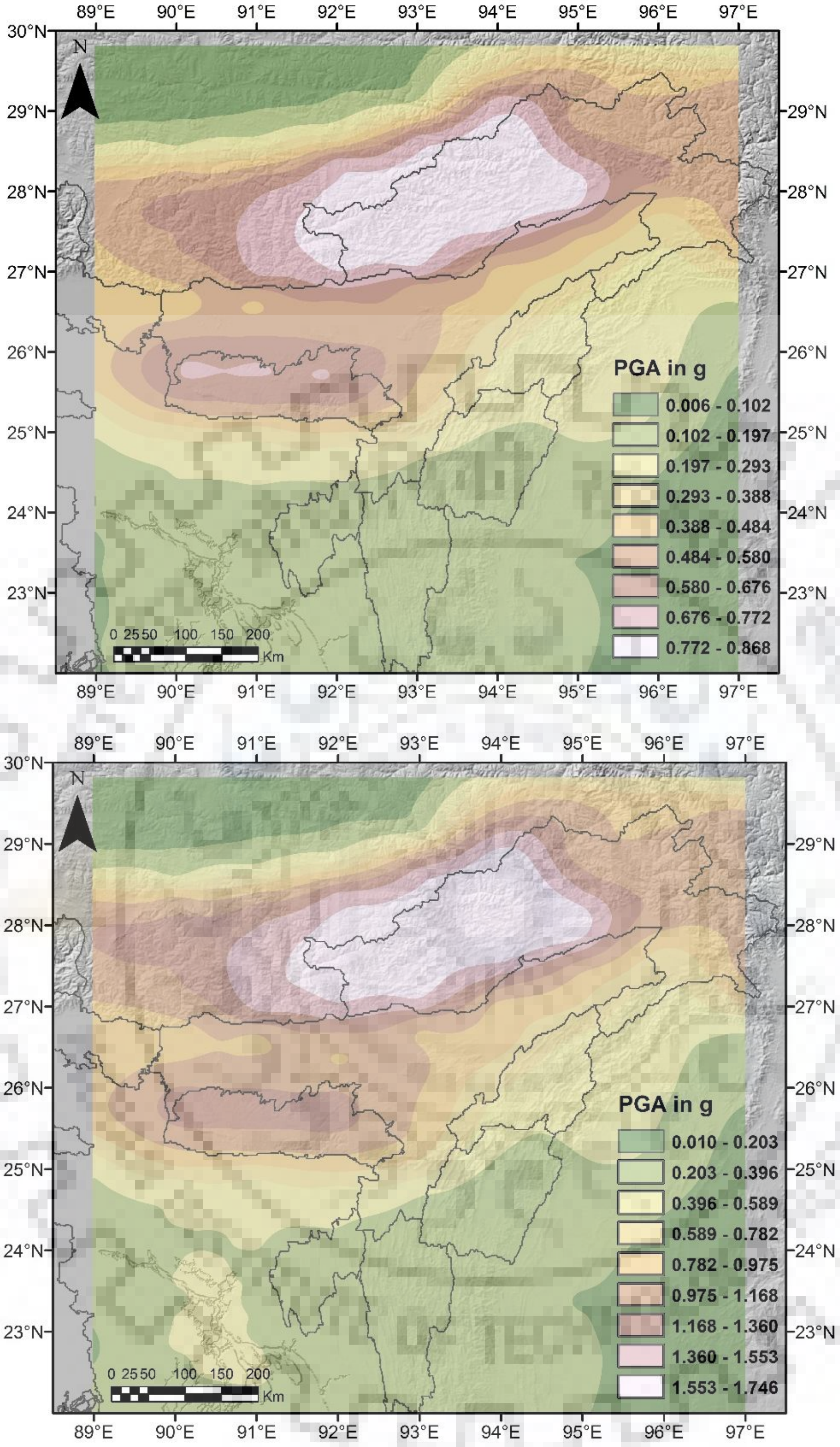


Figure 4.9 PGA zones for return period of 475 and 2475 years' in Idriss(2014) attenuation model

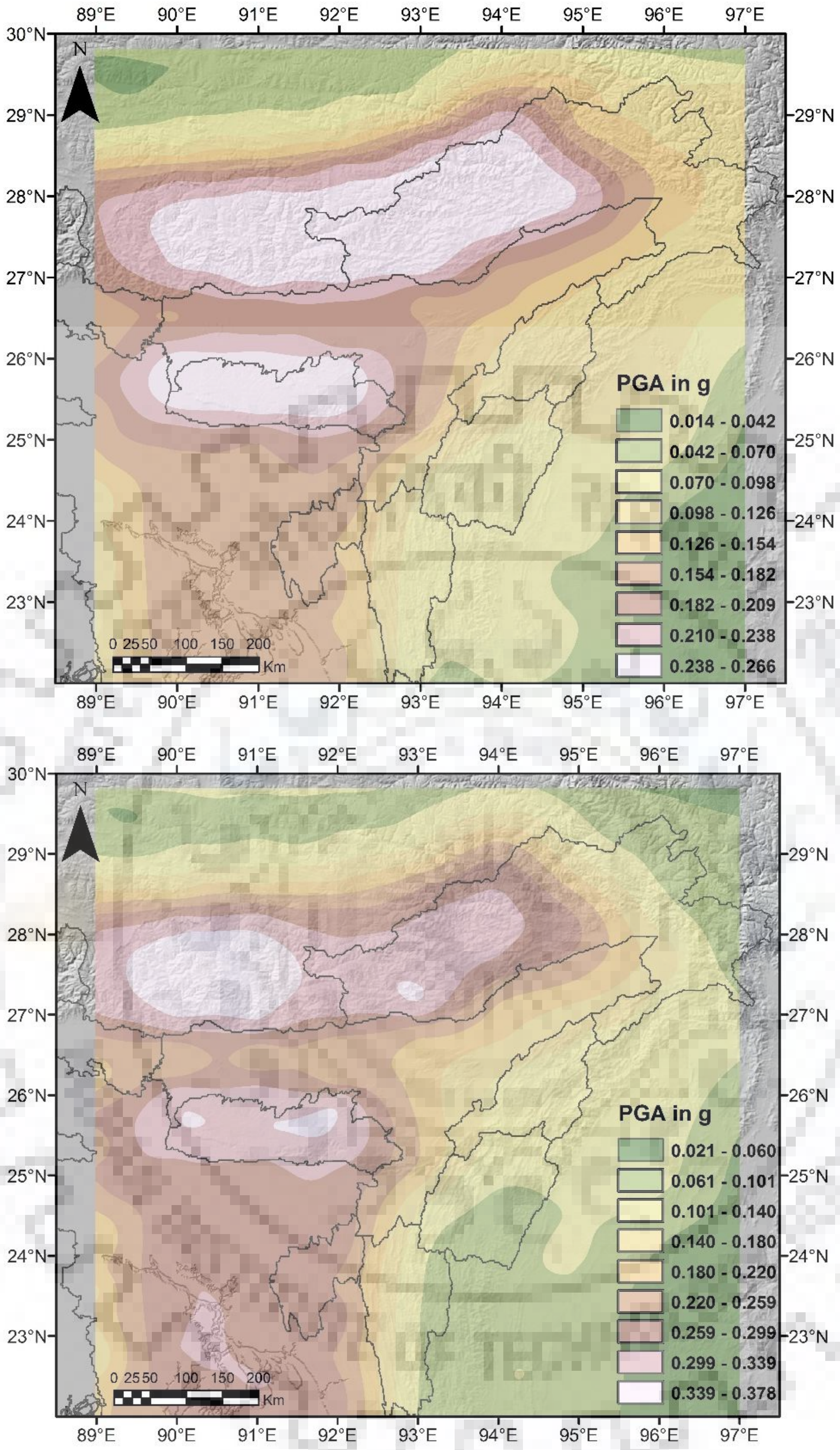


Figure 4.10 PGA zones for return period of 475 and 2475 years, Boore et al (2014) Average attenuation model

5 CHAPTER

SUMMARY AND CONCLUSION

In this study the estimation of PSHA for the region of North-East India has been carried out. For that purpose, the region has been divided into eight seismogenicsources using available information on geology, tectonic, and seismicity of the region. Seismic hazard parameters in terms of PGA and PSA have been estimated for different return periods. These parameters have been estimated considering estimated b-value for each source seismogenicsource. The attenuation model developed by boore et al (2014),Campbell (2014), Abrahamson,silva,kamai(2014), Idriss(2014) has been adopted to compute both PGA and PSA by varying Vs30 values according to the site condition.

Fallowing broad conclusions have been drawn from the study:

i. The estimated PGA and PSA values of the region would get amplified/modified when the effect of soil layer between the rock and ground surface is taken into account

ii. The higher PGA values are observed in Gantok region

iii. According to Abrahamson, Silva,kamai(2014) attenuation models the estimated PGA values are higher in the source zones-I,II and VIII. In source zones-I and VII there exists gantok are hard rocks but in source zone-II mainly Bangladesh have soil amplification.

iv. Idriss(2014) predicted PGA values for return period 475 and 2475 years of whole region seems to be lesser than other models but Idriss(2014) model gives higher values for Himalaya region but whereas cambell(2014) predicts higher ground motion in the region of Gantok

v. According to Boore et al(2008) model the PGA values are more in the region. At some regions it is showing more value, which appears to be overestimations. In this model it emphasises more on soil amplification so that we can see more value of PGA in the region of Brahmaputra basin.

vi. The attenuation model cambell(2014)predicted PGA values more in the source region zone-I,VII and VIII. Gantok regions which are hard rock area sand obtained higher values of ground motions.

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