

Seismic Hazard Analysis of Northeast India and its Adjoining RegionAnupama Devi¹ and Sarbeswar Kalita²

1- Department of Physics, Arya Vidyapeeth College, Guwahati, Assam, India

2- Dept. of Environmental Science, Gauhati University, Guwahati, Assam, India

anupamabordoloi@yahoo.com

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ABSTRACT

In this study, we make an attempt to analyze seismic hazard of the region using probabilistic approach. At the outset peak ground acceleration of the region is determined, then the probability of occurrence of a seismic event greater than 4.0 mb in the next 50 yrs and 100 yrs is estimated and hazard maps are prepared. Next, seismic hazard map of the region for 10 % and 30% probability of exceedance respectively in 50 years and 100 years is prepared. Here it has been assumed that the earthquake occurrence follows the Poisson distribution. The pga value is found to vary from 0.15g to 0.51g. The probability of occurrence of at least one event with magnitude ≥ 4.0 mb within the next 50 years and 100 years has been found to vary from 0.48 to 0.96 and 0.71 to 0.99 respectively. This analysis highlighted variations of seismicity in the study region. It has been found that the entire study area does not fall under zone V of seismic hazard map. The region has seismicity varying between zone III and zone V.

Keywords: Seismic source, Probability, Peak ground acceleration, Seismic hazard map, Seismic Zone

1. Introduction

Seismic hazard is used to describe the severity of ground motion at a site (Anderson and Trifunac 1978a), regardless of the consequences, while the risk refers to the consequences (Jordanovski et al., 1993). The analysis of seismic hazard of a region is depicted as seismic hazard maps (Lee and Trifunac, 1987) which is used for land-use planning, assessing the needs for remedial measures, and estimation of possible economical losses during future earthquakes (Trifunac, 1989b; Trifunac and Todorovska, 1998). The primary purpose of seismic hazard mapping is to delineate a seismically active region into different zones showing the hazard levels. At present the map prepared by BIS, Bureau of Indian Standards, (2002) has four seismic zones designated as II, III, IV and V with assigned zone factors 0.10, 0.16, 0.24, 0.36 g, respectively. In a recent study made by Sitharam et.al. (2013) peak horizontal acceleration (PHA) and spectral accelerations for periods 0.1 s and 1 s have been estimated for the Indian Subcontinent and contour maps showing the spatial variation of the same have been prepared. It shows that the seismic hazard is moderate in peninsular shield, but the hazard in most parts of North and Northeast India is high. The northeast Indian region has been placed in zone V, the highest level of seismic hazard potential, according to the seismic zonation map of India (BIS 2002). As such there have been incidents of two great earthquakes – 1897 Shillong Earthquake, and 1950 Assam Earthquake in the region. The Global Seismic Hazard Assessment Programme (GSHAP) also classifies the region in the zone of high seismic risk with peak ground acceleration rising to the tune of 0.35 – 0.4g. H.K. Sarmah (1989) analyzed the seismic hazard of the region using both Poisson's model and

Bayesian Statistics. Das et.al (2005) prepared seismic hazard maps for Northeast India in terms of the PSA amplitudes at different natural periods. Sharma and Malik (2006) found that the pga value of the region ranges from 0.05g to 0.6g for 10% exceedance while the pga value ranges from 0.01g to 0.4g for the 20% exceedance in 50 years. Recent seismic hazard analysis of the region has been done by Shankar et.al. (2012) using time – predictable model. The probabilistic seismic hazard analysis offers a framework for risk management by taking account of the frequency or probability of exceedance of the ground motion against which a structure or facility is designed. This is the most commonly used approach to evaluate the seismic design load for the important engineering projects. While there is considerable information on earthquake ground motions and potential future locations of earthquakes, there is also considerable uncertainty in the inputs to the analysis. The essential features of probabilistic seismic hazard assessment are :

- Definition of seismogenic sources.
- Definition of a seismicity model.
- Definition of an attenuation model.
- Calculation of hazard curve for the site.

Here, we make an attempt to analyze seismic hazard of the region using probabilistic approach. The first methodology that was used in this study was first proposed by Kijko and Graham (1999) in an attempt to try and solve the two main difficulties that all probabilistic analysis have, the incompleteness of the seismic catalogues and the need of definition of the seismic zones. The new methodology combines the best features of the deductive (Algermissen et.al. 1982) and non – parametric historic (Veneziano et. al., 1984) procedures and in many cases is free from their main disadvantages. Margaris et. al. (2001) gave a relation to estimate Peak Ground Acceleration of seismic sources based on this methodology. Banitsiotou et. al. (2004) estimated seismic hazard parameters for various sites in Greece using this relation. This relation is applied to estimate the Peak Ground Acceleration of the study region. Next, a Bayesian statistics approach is applied in the seismogenic sources of the region to assess seismic hazard assuming that the earthquake occurrence follows the Poisson distribution. Benjamin (1968) was the first to deal with the Bayesian approach for the probabilistic description of the earthquake occurrence. Ferraes (1986) used a Bayesian analysis to predict the inter – arrival times for strong earthquakes along the Hellenic arc, as well as for Mexico. Tsapanos et .al. (2003) carried out a time independent seismic hazard analysis of Greece from Bayesian statistics. Lastly, the model developed by Poisson for seismic hazard analysis has been applied to prepare a seismic hazard map based on the probability of occurrence of an event greater than a particular value of peak ground acceleration when considered for a certain period of time. Earliest attempts on the application of Poisson’s model in seismic hazard assessment were made by Aki (1956). Recently, Hong and Guo (1995) used Poisson distribution. For NE region, Sarma (1989) made a study on seismic hazard assessment. Here Poisson Model developed by Shah et.al. (1975) will be applied.

2. Datasource And Methodology

The comprehensive data file prepared by using earthquake catalogues of ISC and USGS that are available for the study region has been used for the period 1909 (1st January) – 2012 (31st July). All seismic events greater than 4.0 mb are considered for this analysis and is shown in figure 1.

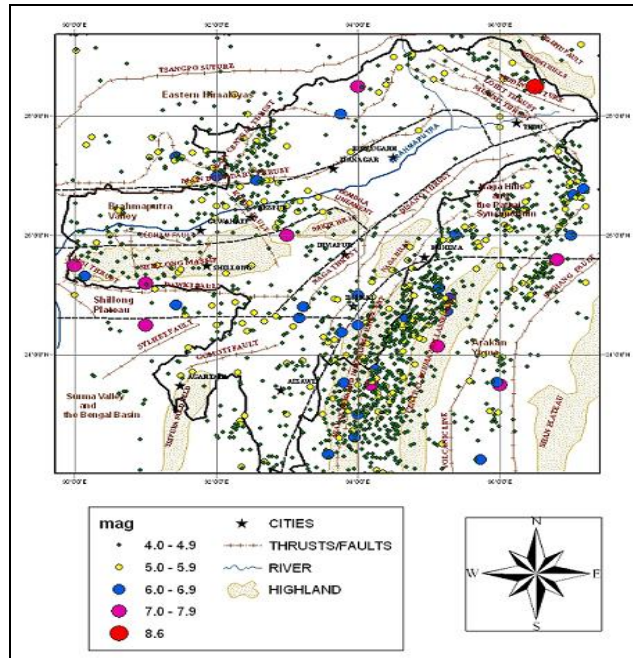


Figure 1: Epicentral plot of the seismic events (1909 – 1912)

2.1. Estimation of PGA using a relation proposed by Margaritis et.al.

The entire study region is divided into a grid of $\{(1/2)^0 \times (1/2)^0\}$. The seismic events in each grid is considered together with their respective magnitude for determining the position of the seismogenic sources. The relation used is:

$$X = (m_1x_1 + m_2x_2 + \dots + m_nx_n) / (m_1 + m_2 + \dots + m_n) \quad \text{----- (1)}$$

$$Y = (m_1y_1 + m_2y_2 + \dots + m_ny_n) / (m_1 + m_2 + \dots + m_n) \quad \text{----- (2)}$$

where, X and Y represent the longitude and latitude of the seismogenic sources. $(x_1, y_1), (x_2, y_2) \dots (x_n, y_n)$ are the co-ordinates in terms of longitude and latitude of each seismic event in the grid and n is the number of seismic events of each grid. The magnitude of each seismic event is given by $m_1, m_2, m_3 \dots m_n$ respectively. The average epicentral distance of the seismic events of each grid is determined. The peak ground acceleration of each seismogenic source of the region is estimated using the relation proposed by Margaritis et. al. (2001).

$$\ln(\text{PGA}) = 3.52 + 0.70 * M - 1.14 * \ln(R^2 + h_0^2)^{1/2} + 0.12 * S \pm 0.70 \quad \text{----- (3)}$$

where, M is the maximum magnitude of the seismic event that has occurred in each grid, R is the average epicentral distance of the seismic events in each of the grid, h_0 is the effective depth of an event which is taken as 7 km for PGA and S is a factor of the soil condition with values 0, 1 or 2 when it refers to hard rock, intermediate soil and soft soil respectively. In the present study we used only intermediate soil conditions, $S = 1$.

2.2. Seismic hazard analysis by Bayesian Statistics :

The number of earthquake events n that occur in a time interval follows poisson distribution. Then the probability function is:

$$P(n, t|\theta) = \frac{(\theta t)^n e^{-\theta t}}{n!} \quad \text{----- (4)}$$

where the positive parameter θ , is the mean rate of earthquake occurrence. Suppose that in a given seismic source n_0 events occurred in t_0 years, which is the time length of the catalogue. The likelihood function is,

$$l(\theta) = P(n_0, t|\theta) = \frac{(\theta t_0)^{n_0} e^{-\theta t_0}}{n_0!} \quad \text{----- (5)}$$

It is reminded that likelihood is the probability of the specific outcome to occur, that is the probability for exactly n_0 earthquakes to occur in the t_0 years covered by the catalogue, as a function of the mean rate of occurrence.

The prior distribution for θ , $f'(\theta)$ is assumed to be uniform. This is equivalent to stating that the mean rate of occurrence can have any value, as long as it is not negative, with the same probability. From the Bayesian theory, its posterior distribution, will be:

$$f''(\theta) = cf'(\theta)L(\theta) \quad \text{----- (6)}$$

where c is a constant such that the resulting function can be a probability density function, that is:

$$\int_0^{+\infty} f''(\theta) d\theta = 1 \quad \text{----- (7)}$$

Now, because $f''(\theta)$ is independent of θ , the factor $k = cf'(\theta)$ is constant, so that Eq. (6) can be rewritten as

$$f''(\theta) = kL(\theta) = k \frac{(\theta t_0)^{n_0} e^{-\theta t_0}}{n_0!} \quad \text{----- (8)}$$

This expression is normalized for $k = t_0$. Now let us consider the posterior probability of n events occurring in t years. This will be the probability $P(n, t|\theta)$ weighted in respect to the posterior distribution of θ :

$$P''(n, t) = \int_0^{\infty} P(n, t|\theta) f''(\theta) d\theta = \int_0^{\infty} \frac{(\theta t)^n e^{-\theta t}}{n!} \frac{t_0 (\theta t_0)^{n_0} e^{-\theta t_0}}{n_0!} d\theta \quad \text{----- (9)}$$

Integration yields (Benjamin, 1968):

$$P''(n, t) = \frac{(n+n_0)!}{n!n_0!} \frac{(t/t_0)^n}{(1+t/t_0)^{n+n_0+1}} \quad \text{----- (10)}$$

Applying eq. (10), the posterior probability of no events occurring in t years is:

$$P(0, t) = (1 + t/t_0)^{-n_0 - 1} \quad \text{----- (11)}$$

Therefore, the probability of exceedance of a selected lower magnitude, M_0 , that is the probability of at least one event of $M \geq M_0$ occurring in next t years is:

$$\bar{P}(0, t) = 1 - (1 + t/t_0)^{-n_0 - 1} \quad \text{----- (12)}$$

From the above relation the probabilities of exceedance of magnitude $M_0 \geq 4.0$ mb is computed. In this study $t_0 = 103.58$ years, t is taken to be 50 years and 100 years respectively and n_0 is the number of seismic events greater than or equal to 4.0 mb in each grid point.

2.3 Seismic Hazard Analysis using Poisson's model:

2.3.1 Recurrence Relationship

Before the Poisson's Model is developed for the purpose of forecasting future seismic events, we consider the grouping of seismic events into different seismic sources. This is done taking into consideration the distribution and concentration of the different earthquake epicenters in the region under consideration. If the source of earthquakes is closely concentrated in space relative to its distance from the sites it may be assumed to be a point source. Here we have taken thirteen sources. The depth of each source was computed as an average hypocentral depth of all earthquakes in the source and earthquakes with no depth information were not included in the averaging process. However, they are considered in determining the location of the seismicity of the sources. Next the recurrence relationship for each individual source is obtained by fitting,

$$\ln N(M) = \alpha + \beta M \dots\dots\dots (13)$$

where, $N(M)$ is the number of seismic events whose magnitude is above M .

For most of the sources a single regression line gives unreasonably high magnitude occurrences and in such cases two regression lines are fitted to the data with an user cut off magnitude. Let α' be the normalized value of α .

Again let,

$$N'(M) = \frac{N(M)}{T} \dots\dots\dots (14)$$

Here, T is the time for which data was obtained.

Then,

$$\ln N'(M) = \alpha' + \beta M \dots\dots\dots (15)$$

and,

$$\alpha' = \alpha - \ln(T) \dots\dots\dots (16)$$

In this way we obtain the recurrence relationships associated with all the seismic sources for the whole of north – east India region. The magnitude of seismic event where the two recurrence line meet is also noted i.e. the point where the slope of recurrence line changes. Now the recurrence relationship give the mean number of events of magnitude greater than M due to a given source in a given time period.

Further we have normalized the mean number of events with respect to time and these normalized relationships give a quantitative recurrence formula for each of the sources. These relationships will then be used in the formulation of Poisson’s model which will be applied in the seismic hazard analysis of the region.

The recurrence relationships represent the past seismic history of the study region. But based on the past seismic history the future forecasting of seismic events is to be done. Here the Poisson’s Model for the forecasting of future seismic events based on the past data is discussed.

2.3.2 Formulation of Poisson’s Model

Let us consider a stochastic process $X(t)$, whose value at any time t is the random number of arrivals or incidents which have occurred since time $t = 0$. Just as samples of a random variable X are numbers $X_1, X_2, \dots\dots\dots$ and so on., so also the observations of a random process $X(t)$ are sample functions of time $X_1(t), X_2(t), \dots\dots\dots$. Now for any fixed value of the time parameter t , say $t = t_0$, the value $X(t_0)$ of a stochastic process is a sample random variable with an appropriate mean, variance etc. In general, this distribution, mean and variance are functions of time. In addition the joint behavior of two values, say $X(t_0)$ and $X(t_1)$ of a stochastic process is governed by a joint probability law. For example one might be interested in studying the conditional distribution of a future value $X(t_1)$, given an observation at the present time $X(t_0)$, in order to predict that future value.

The result of the study of stochastic processes is that the distribution of the random variable $X(t_0)$ is the poisson distribution with parameter λt_0 if the stochastic process $X(t)$ is a poisson process with parameter λ . Now the earthquake occurrence can be modeled using the poisson probability law. For earthquakes to follow the poisson process the underlying physical mechanism of earthquake process must satisfy the following assumptions:

- i. Earthquakes are spatially independent.
- ii. Earthquakes are temporarily independent.

- iii. The probability that two seismic events would take place at the same time and at the same instant of time approaches zero.

According to the first assumption, the occurrence or non – occurrence of any seismic event at one site does not affect the occurrence or non – occurrence of another event at some other site. According to the second assumption, seismic events do not have memory in time. From the third assumption we have that the probability of two or more seismic events occurring in a short interval of time is negligible. i.e. to say that more than one seismic event cannot occur within a small interval of time Δt .

In its most general form the poisson distribution can be written as,

$$P_x(t) = \frac{(\lambda t)^x e^{-\lambda t}}{x!} \dots\dots\dots (17)$$

where, $x = 0, 1, 2, \dots\dots\dots$

$P_x(t) =$ Probability of having X events in time period t.

X = Number of events

and

$\lambda =$ Mean number of occurrences per unit time.

For a given source the two recurrence relationships are given by,

$$\ln N'(M) = \alpha'_1 + \beta_1 M, \text{ where } M_0 \leq M \leq M_1 \dots\dots\dots (18)$$

$$\ln N'(M) = \alpha'_2 + \beta_2 M, \text{ where } M_1 \leq M \leq M_2 \dots\dots\dots (19)$$

Here, M_1 is the magnitude at which the two recurrence lines intersect, M_2 is the upper cut off magnitude of a given source and M_0 is the minimum magnitude of the seismic events. Using eq. (18) and eq. (19), eq. (17) becomes,

$$P_x(t) = \frac{\exp[-\exp(\alpha'_1 + \beta_1 M)t] [\exp(\alpha'_2 + \beta_2 M)t]^x}{x!} \dots\dots\dots (20)$$

Eq. (20) gives the probability of observing X events above magnitude M in time period t, based on the seismic history of a given source.

Using eq. (15), eq. (20) becomes,

$$P_x(M > m, t) = \frac{\exp[-N'(M)t] [N'(M)t]^x}{x!} \dots\dots\dots (21)$$

The above relation gives the probability that there will be X events of magnitude greater than m in time period t.

For engineering purposes one usually determines the probability of at least one event greater than m in time period t. Now, the probability is given by,

$$P[\text{at least one event of magnitude } M > m \text{ in time period } t] = 1 - P[\text{no of earthquakes of magnitude } M > m \text{ in time period } t]$$

Hence, from eq. (21) we have,

$$P[\text{at least one event of magnitude } M > m \text{ in time period } t] = 1 - \exp[-N'(m)t] \dots\dots (22)$$

2.3.3 Estimation of Peak Ground Acceleration

The most commonly used parameter to describe the seismic loading at a site is Peak Ground Acceleration. Also we have obtained the probability of exceeding a magnitude level in time t, by poisson's model. But for engineering purposes, the seismic loading at a site away from the epicenter is to be found out. Thus, if we are to obtain probabilistic information about Peak Ground Acceleration at a site, the parameters necessary are:

- i. Probabilistic information of earthquake magnitude for a source as a function of future time t.
- ii. Distance of the site from the source.

iii. Attenuation of Peak Ground Acceleration from source to site.

The attenuation relation given by Donovan is,

$$A = \frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} \dots\dots\dots (23)$$

The values of the parameters b_1, b_2, b_3 and b_4 have been determined and found to be, $b_1 = 1080, b_2 = 0.5, b_3 = 1.32$ and $b_4 = 25$ using these values eq. (23) becomes,

$$A = \frac{1080 \exp(0.5M)}{(R_h + 25)^{1.32}} \dots\dots\dots (24)$$

where R_h is the hypocentral distance of a seismic event of magnitude M .

For probabilistic determination of PGA at a site due to seismic source by using eq. (15) in eq. (22) we have,

$$P(M > m, t) = 1 - \exp[-\exp(\alpha' + \beta M)] \dots\dots\dots (25)$$

For determining the probabilistic distribution of an seismic event having Peak Ground Acceleration, a , we have by using eq. (23)

$$P[A > a] = P\left[\frac{b_1 \exp(b_2 M)}{(R_h + b_4)^{b_3}} > a\right] = P\left[M > \ln\left\{\frac{a}{b_1} (R_h + b_4)^{b_3}\right\}^{\frac{1}{b_2}}\right] \dots\dots (26)$$

From eq. (25) and eq. (26) we have,

$$P[A > a] = 1 - \exp\left\{-\gamma \left(\frac{a}{b_1}\right)^\delta (R_h + b_4)^\rho t\right\} \dots\dots\dots (27)$$

Here,

$$\gamma = e^{\alpha'} ; \delta = \frac{\beta}{b_2} \text{ and } \rho = \delta b_3.$$

Eq. (27) gives the probability of peak ground acceleration due to a source located some distance away. But usually a site is surrounded by a number of sources, hence if there are N seismic sources, then the probability distribution is given by,

$$P[A > a] = 1 - \exp\left[-\sum_{i=1}^N \left\{\gamma_i \left(\frac{a}{b_1}\right)^{\delta_i} (R_h + b_4)^{\rho_i} t\right\}\right] \dots\dots\dots (28)$$

The above equation can be used to determine the probability distribution function of peak ground acceleration as function of time and space. And as seen from eq. (28) at a given site, the probability of $A > a$ increases with time. Thus, we consider the whole region and determine the acceleration at different sites for a specific exposure time and specific probability for $A > a$.

3. Results and Observations

3.1. Seismic Hazard Analysis using Margaritis relationship

The pga as percentage of g value at each source point obtained by using eq. (1) and eq. (2) is obtained by using the relation given by Margaritis et.al. (eq. 3) and is represented in Figure(2). The general pattern of the contours is consistent with some of the geological features of the region. A high value of hazard level at an area reflects the fact that lots of earthquakes have taken place close to that region. Earthquake energy is dispersed in waves from the epicenter, causing ground movement horizontally (in two directions) and vertically. PGA records the acceleration (rate of change of speed) of these movements.

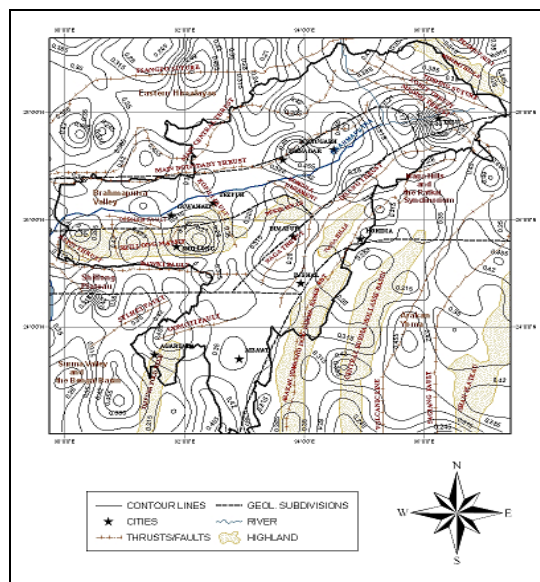


Figure 2: Contour lines representing the PGA values

These values vary in different earthquakes, and in differing sites within one earthquake event, depending on a number of factors. These include the length of the fault, magnitude, the depth of the quake, the distance from the epicenter, the duration (length of the shake cycle), and the geology of the ground (subsurface). Shallow-focused earthquakes generate stronger shaking (acceleration) than intermediate and deep quakes, since the energy is released closer to the surface. The northeast India and its adjoining areas fall in Zone V (BIS code) which implies that the intensity of seismic events of this region will be more than IX in MSK (Medvedev-Sponheuer-Karnik) scale with the magnitude of peak ground acceleration being 0.36g. But from the above analysis it is seen that the value of peak ground acceleration is not same in the entire study region. Its value varies from 0.15g to 0.51g. In the Eastern Himalayas, along the MBT and MCT, the value of PGA varies from around 0.35g to 0.51g. But the value decreases to 0.24g towards the North near the Tsangpo Suture. The value of PGA along the Lohit and Mishmi Thrust together with Tidding Suture is almost same as the MBT and MCT but decreases towards northeast near the Po Chou and towards southwest near the boundary of Brahmaputra Valley where it is about 0.17g. It again increases as we move towards west and its value is around 0.38g near the Kopili Fault. In the Shillong Plateau block the value is around 0.21g. Near the Dawki fault it is about 0.45g. At the Surma valley and Bengal Basin the variation of the peak ground acceleration is from 0.28g to 0.42g. Near the Sylhet fault it is about 0.35g and along the Tripura fold belt it is about 0.42g. In the Arakan – Yoma tectonic block the variation is between 0.25g to 0.45g. The value increases in the northeastern direction. The pga value along the EBT, Volcanic line and Sagiang fault does not vary much. It is about 0.42g at Shan Plateau. At the Naga Hills the value increases from 0.28g to 0.49g along the northeastern direction. Thus it is seen that the study region does not fall under zone V (BIS code) alone some areas fall under zone IV and zone III also which was also stated from peak ground acceleration as determined by S.Das et.al.(2006). Even microzonation map of Guwahati done by S.K. Nath et. al. (2009) revealed that whole of Guwahati does not fall under zone V. Moreover the pga value in some areas were found to be higher than that ascertained for zone V which was also stated by S. Kolathayar et.al. (2012).

3.2. Seismic Hazard map using Bayesian Statistics

The probability of occurrence of at least one event with magnitude ≥ 4.0 mb within the next 50 years and 100 years respectively has been estimated using Bayesian statistics and hazard map obtained is shown in Figure 3 and Figure 4 respectively.

The probability varies from 0.48 to 0.96 when the occurrence of a seismic event greater than 4.0mb within the next 50 years is considered while it varies from 0.71 to 0.99 when the occurrence of the same event within next 100 years is taken into consideration. From both the contour maps it has been observed that the probability increases in eastern direction towards the Lohit and Mishmi Thrust and Po Chu fault in the Eastern Himalayas. It decreases in southwest direction at the Brahmaputra Valley but a region of high probability is found around the Kopili Fault. The Shillong Massif together with the eastern side of Dawki Fault shows a high probability of occurrence of a seismic event. In the Surma Valley and Bengal Basin the probability along the Sylhet Fault is more than the rest of the tectonic block. The Arakan Yoma and Indo - Burma Range, Central Burma Molasse basin together with the volcanic line is an area of high seismic activity. The probability is almost uniform in the Naga Hills and Patkai Synclinorium with a small area of high seismic activity near 96° E longitude and 24° N latitude.

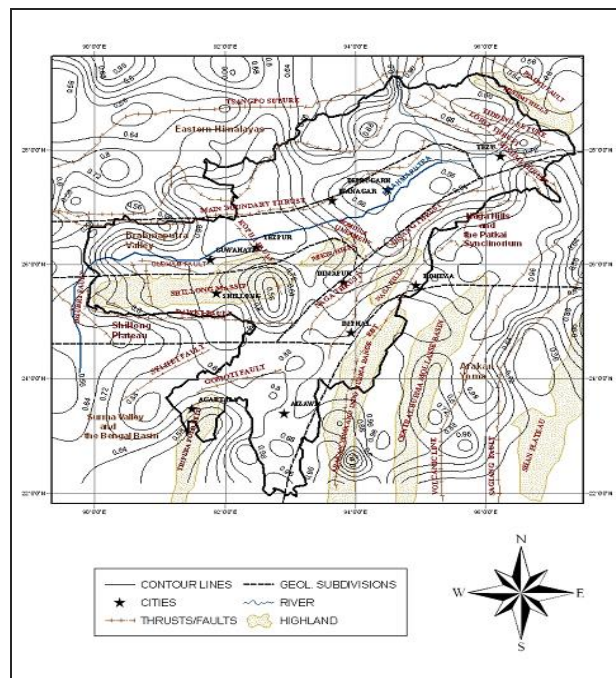


Figure 3: Contour curves showing the probability of occurrence of an event ≥ 4.0 mb in the next 50 years

4. Formulation of Poisson's model and Probabilistic Seismic Hazard Analysis

Probabilistic seismic hazard analysis is also done by applying Poisson's model. The seismic events of the entire study region are grouped by dividing it into a grid of $\{(\frac{1}{2}^0 \times \frac{1}{2}^0)\}$ and thirteen point sources are considered which is given in table 1.

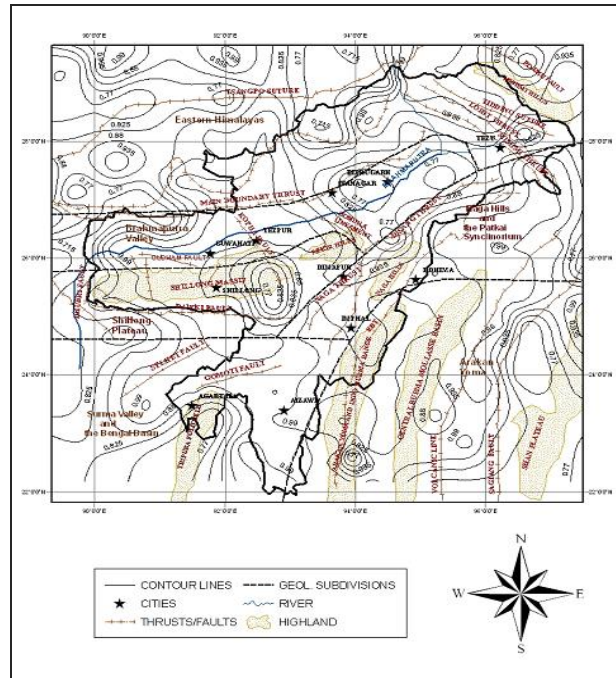


Figure 4: Contour curves showing the probability of occurrence of an event ≥ 4.0 mb in the next 100 years

Table 1: Seismic Sources

Source	Longitude(deg.)	Latitude(deg.)	No of events	Average Depth(km)
Source 1	90.17	29.27	102	24.68
Source 2	91.35	27.07	194	34.68
Source 3	95.13	28.72	185	42.68
Source 4	95.36	24.56	302	64.1
Source 5	97.04	24.56	145	30.19
Source 6	92.62	25.5	265	44.77
Source 7	92.24	23.26	139	33.39
Source 8	95.2	26.11	192	60.05
Source 9	96.92	26.83	170	41.56
Source 10	95.74	22.76	38	37.48
Source 11	94.18	23.78	395	67.42
Source 12	93.97	22.47	202	76.69
Source 13	90.21	24.84	117	35.21

Recurrence relation for each source is found from magnitude frequency relationship, from which the source parameters are determined and is represented in table 2.

Table 2: Source Parameters

Source	α_1	β_1	α_2	β_2	Mag (br.pt.)	R_{max} (rec)	R_{max} (graph)
Source 1	2.64031	-0.1895	5.85718	-0.96851	4.01	6	6.04
Source 2	3.09527	-0.24161	7.72605	-1.29047	3.9	6.1	6.14
Source 3	2.86104	-0.17549	6.4926	-1.0438	3.98	6	6.22
Source 4	2.92855	-0.13796	6.36264	-0.9555	4.1	6.6	6.78

Source 5	3.30243	-0.33051	8.25364	-1.43031	4.3	5.9	6.01
Source6	2.89352	-0.14396	8.26345	-1.39258	3.97	5.8	6.1
Source 7	3.30184	-0.34064	7.1772	-1.24171	4.07	5.9	5.98
Source 8	2.86104	-0.17549	6.4926	-1.0438	3.96	6.4	6.44
Source 9	2.88218	-0.19958	5.93916	-0.93936	3.96	6.2	6.31
Source 10	2.47679	-0.25698	8.18608	-1.53976	4.38	5.1	5.17
Source 11	3.12648	-0.16406	7.68703	-1.25809	3.83	5.8	6.28
Source 12	2.70813	-0.12539	7.07284	-1.20461	3.89	6	6.05
Source 13	2.48357	-0.12809	8.53611	-1.57664	5.39	5.2	4.03

The source parameters represented in the above table together with Donovan's attenuation relation is applied in probabilistic seismic hazard analysis using Poisson's model. For a specified probability of exceedance, in other words, for a specified hazard level the peak ground acceleration values are obtained. The iso – acceleration hazard maps so obtained is shown from Figure 5 to Figure 8.

From all the four hazard maps it is seen that probability increases if the exposure time is increased keeping the threshold value of pga same and decreases if threshold value of pga is increased keeping the exposure time same. Seismic high is observed in the northeastern part of the Eastern Himalayas which is the meeting place of Himalyan arc and the Burmese arc and is called the Syntaxis Zone. The Mishmi Thrust and the Lohit Thrust are the major discontinuities identified in the Syntaxis Zone. Part of the eastern portion of the Brahmaputra valley is less active. But the region around the Kopili fault shows that the probability of occurrence of an event is more. Shillong Plateau, eastern side of Dawki Fault and the southern end of Arakan Yoma range shows a high probability. In the Bengal basin the probability of occurrence of a seismic event is high in the region near the Sylhet fault and Tripura fold belt. Seismic activity in the Naga Hill tectonic block is less.

From the analysis of seismic hazard of northeast India and its adjoining region five areas have been identified where the probability of occurrence of an seismic event is high. They are: Northeastern corner consisting of the Lohit and Mishmi Thrust, the area around the Kopili fault, the Shillong Massif and the eastern side of Dawki fault, area around the Sylhet fault and the Tripura fold belt and the southern end of the Arakan Yoma range. Khatri et. al. (1984) found that the largest probabilistic accelerations are in the seismotectonic belts of Kirthar, Hindukush, Himalaya, Arakan-Yoma, and the Shillong massif where values of over 70% g have been calculated. The result obtained is also comparable to the studies made by Sarma (1989), Das et.al. (2006) and Shankar et.al. (2012).

5. Conclusion

The seismic hazard of the study region has been analyzed using three different models. Presently, major requirements of the society is the prediction of earthquake related hazards with reasonably high degree of probability which eventually help mitigating expected hazards that would save loss of lives and property. Nonetheless, it is not an easy task to predict precisely the time, magnitude and location associated with future earthquakes with any accuracy, despite many efforts being made worldwide by scientific community. Because of the lack of required density of seismological stations/ instrumentations and technologies, it would be almost impossible to unravel the tectonic processes occurring inside the earth that eventually trigger the earthquakes.

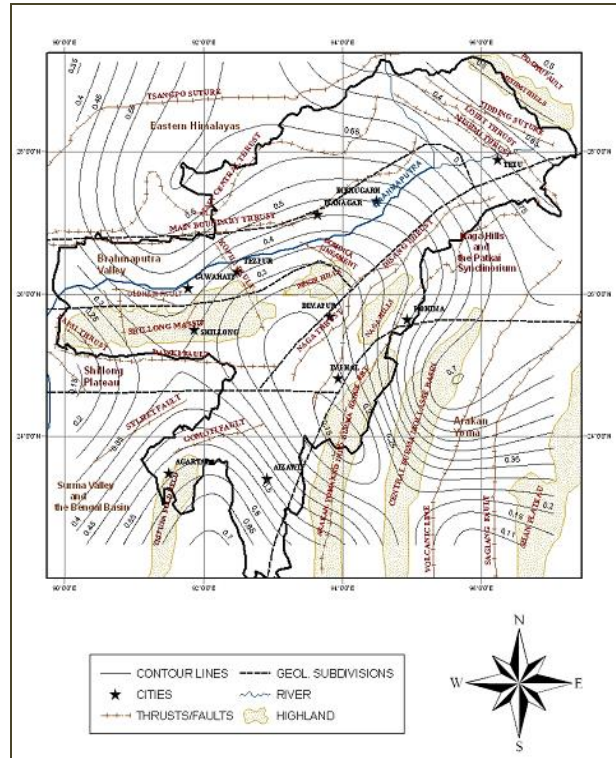


Figure 5: Seismic hazard map of Northeast India and its adjoining region for 10 % probability of exceedance in 50 years

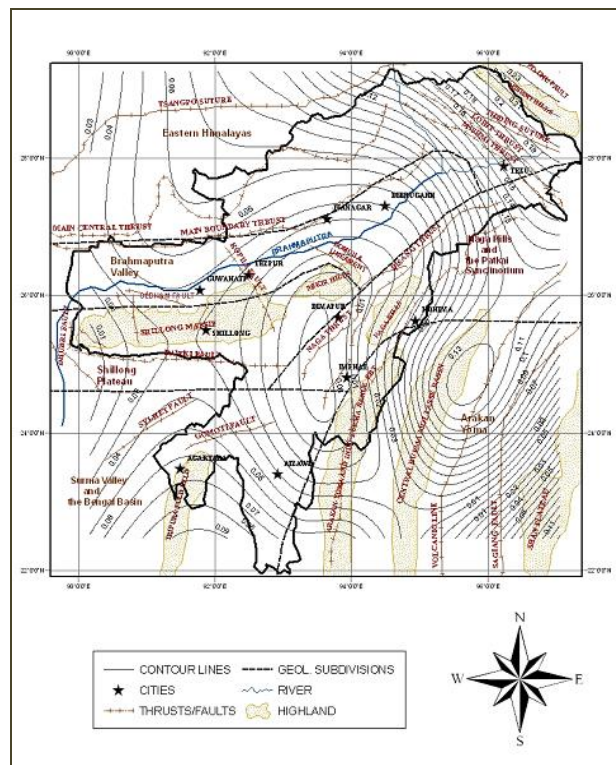


Figure 6: Seismic hazard map of Northeast India and its adjoining region for 30 % probability of exceedance in 50 years

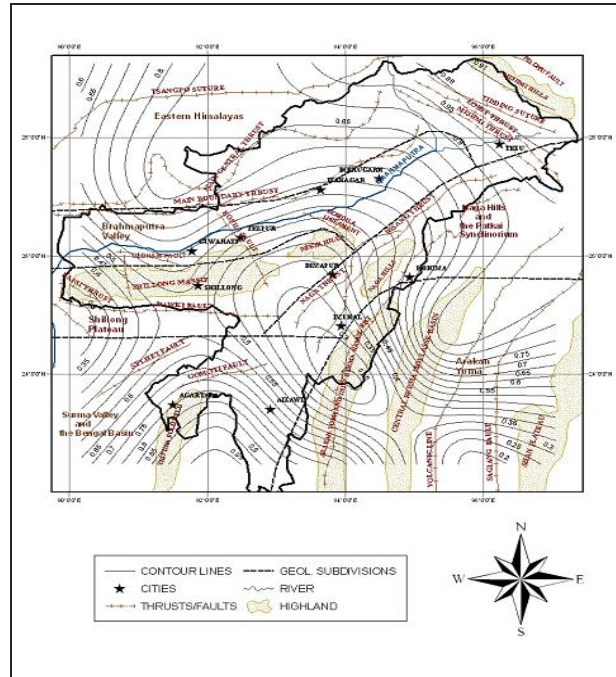


Figure 7: Seismic hazard map of Northeast India and its adjoining region for 10 % probability of exceedance in 100 years

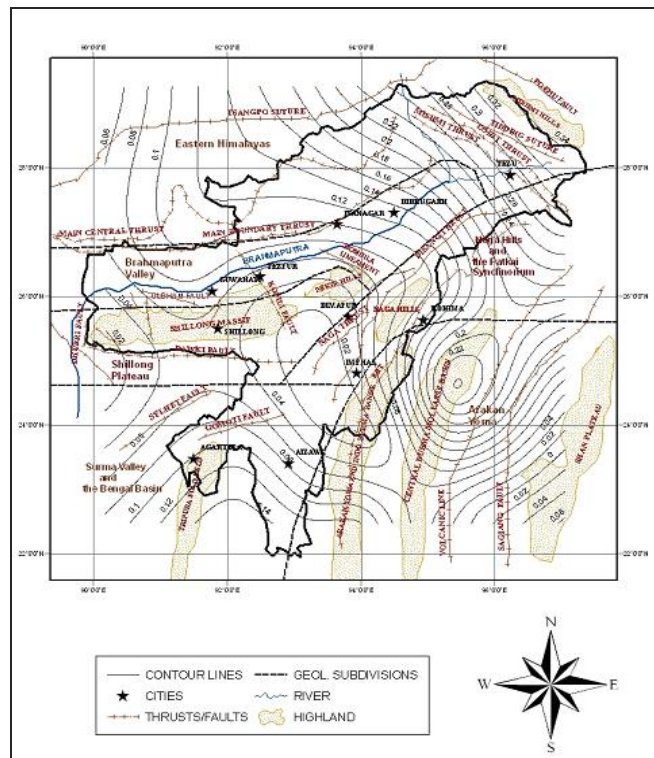


Figure 8: Seismic hazard map of Northeast India and its adjoining region for 30 % probability of exceedance in 100 years

In this study, the pga value is found to vary from 0.15g to 0.51g. The probability of occurrence of at least one event with magnitude ≥ 4.0 mb within the next 50 years and 100 years respectively has been estimated using Bayesian statistics and has been found that The probability varies from 0.48 to 0.96 when the occurrence of a seismic event greater than 4.0 mb within the next 50 years is considered while it varies from 0.71 to 0.99 when the occurrence of the same event within next 100 years is taken into consideration. Probabilistic seismic hazard analysis is done using Poisson's model. For a specified probability of exceedance which means for a specified hazard level the probabilistic peak ground acceleration values are obtained. This analysis highlighted variations of seismicity in the study region. It has been found that the entire Northeast region and its adjoining area does not fall under Zone V of seismic hazard map. The region has seismicity varying between zone III and zone V. Thus, the microzonation map so obtained could be studied by the structural engineers before making any major constructions.

6. References

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