A

DISSERTATION

ON

SEISMIC HAZARD ANALYSIS WITH MOMENT RELEASE CONSTRAINT IN GARHWAL KUMAUN HIMALAYAS

Submitted by

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CANDIDATE DECLARATION

I hereby declare that the study which is being presented in the dissertation entitled **“Seismic Hazard Analysis with Moment Release Constraint in Garhwal Kumaun Himalayas”**, in the partial fulfilment of the requirement for the award of the degree of **Master of Technology** in **Earthquake Engineering, Indian Institute of Technology Roorkee**, in an authentic record of my work May, 2015 to May 2016 under the supervision of **Dr. I.D.Gupta**, visiting professor, Department of Earthquake Engineering, Indian Institute of Technology Roorkee and **Prof. M.L. Sharma** Professor, Department Earthquake Engineering, Indian Institute of Technology Roorkee. The matter embodied in Final report has been submitted by me for the award of my degree or diploma.

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CERTIFICATE

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

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ABSTRACT

The Kumaun - Garhwal Himalaya is located in the most seismic active zone of Himalayan that exhibits many moderate to large size earthquake. To minimising the effect of Earthquake and destruction of important structures there is a need of seismic hazard analysis of Kumaun and Garhwal Himalaya. Due to the plate boundary motion there are more chance of rupture in this Region. For generalized applications, seismic hazard analysis can be used to prepare hazard zoning maps by estimating the strong-motion parameters for a closely spaced grid of sites. The present study provides a short but complete description of the probabilistic seismic hazard analysis (PSHA) method to map the quantity (PGA) with a uniform probability of not being exceeded due to the total expected seismicity during a specified period 0.01second. In this study eleven seismic zones are identify in and around of Kumaun Garhwal Himalaya and the entire area has been divided into 0.2°×0.2° grid size, and the hazard level has been assessed for each grid by considering the seismicity within a 300-km radius around the grid. Using the past earthquake data the seismicity for the area around each grid has been estimated by defining a and b value of the Gutenberg-Richter recurrence relationship and annual occurrence rate has been estimated by constant seismicity and seismic moment release constraints method. Uniform hazard contours for peak ground acceleration as the hazard parameter have been obtained for an exposure time of 50 years and for 90% and 98% confidence level at 0.01s natural periods using constant seismicity and moment release constraint. The trends reflected by the contours are broadly consistent with the major seismotectonic features in the region.

TABLE OF CONTENT

LIST OF FIGURE

LIST OF TABLE

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Seismic hazard is the characterisation of various natural effects of earthquakes occurrence that have enough potential to cause loss of life and property. Seismic hazard is determine from historical, geological and instrumental observations.it occurs naturally without any control over it. Hazard analysis should consider all uncertainties in input data and parameters to have high confidence in the estimated hazard levels.

The Kumaun Garhwal Himalaya lies in Uttarakhand state between latitude 29.0º N to 31.5º N and longitude 77.5º E to 81.0ºE. It falls in high seismically active zones IV and V as per IS Code [IS 1893 (Part 1):2002]. Two most well-known moderate earthquakes in the region are the Uttarkashi earthquake 1991 (magnitude 6.8) and the Chamoli earthquake of 1999 (magnitude ML 6.2).

Several studies have been carried out in the past to determine the seismic hazard in the vicinity of main central thrust (MCT) and main boundary thrust (MBT) of Kumaun and Garhwal Himalaya by using various models and Hazard analysis method. Two methods Deterministic seismic hazard analysis (DSHA) and Probabilistic Hazard analysis (PSHA) are used for determining hazard .Here we are studying on the probabilistic analysis of seismic data of the Kumaun Garhwal Himalaya with seismic moment release constraint. Poisson's distributions exponential Model, Recurrence relation and attenuation relationship are used to estimated Hazard. The moment release rate M_o is used to determine the strength of a seismic or aseismic source. So it is necessary to estimate the seismic moment release rate to constrain the scaling and distribution parameters (a and b value), that define the recurrence relationship for estimating Hazard.

The study of the seismo-tectonics of this region have been made using past earthquake data. This earthquake data is taken from Earthquake catalogue prepared by various sources as USGS, ISC and IMD. These are essential requirements to estimate the seismic hazard

In this study earthquake data have been analyzed using software ZMAP (Wiemer, 2001) to determine the source characteristics. A broad area bounded by longitudes 75.0◦ to 84.0◦ and latitudes 25.0◦ to 34.0◦ has been taken for the digitization of tectonic features, plotting and distribution of earthquakes magnitude-wise, creation of seismogenic source zones, zone boundary co-ordinates, the software Surfer has been used.

The hazard assessment is the effort of earth scientists to provide input for earthquake resistant design of structures or for measuring the safety of an existing structure of importance, such as dams, long-span bridges, nuclear power plants, high-rise buildings, etc. It is very important for public safety and mitigation of risk due to damage of important infrastructures such as water, dam, road and highway, and electric power systems. Many insurance companies use the seismic risk to estimate appropriate insurance policies. Seismic Hazard Analysis also gives an idea about interpreting the micro-seismal locations defining the hazard level according to use of the land. Land use is the simplest things to prevent earthquake losses.

Seismic Hazard analysis is used to prepare in zoning maps of a geographical region which are used in disaster mitigation, construction of building, highway planning, and construction of hazardous and useful structure like Dam etc.

1.2 OBJECTIVE OF THE STUDY

The objective of Seismic Hazard Analysis is to estimate the seismic Hazard and prepared PGA maps for the Uttarakhand state by defining the recurrence relations or various seismic sources with the seismic Moment Release Constraint and compare the results with the conventional Constant seismicity rate recurrence relationship

1.3 ORGANISATION OF THESIS

The study of Seismic Hazard shows the seismicity in the Region. This Report is divided into six Chapters. The First Chapter consist of Introduction and objective the study. The second Chapter describes the ‘Probabilistic Seismic Hazard Analysis method’. The third chapter presents the tectonics and past seismicity of the Kumaun-Garhwal Himalaya. The fourth and fifth chapters consist of the methodology of PSHA applied to Uttarakhand state. The forth Chapter defines the recurrence relations associated to each Source Zone by using constant seismicity as well as using Seismic Moment release Constraint. The fifth Chapter gives estimation and creation of Hazard Zoning Maps using attenuation relations recurrence parameters. The sixth chapter is Summary and Conclusion.

Generally constant moment release constraint approach is advantageous in places of low historical and instrumental seismicity where it is difficult to analyse the maximum credible magnitude and Ground acceleration. The result of study has many important applications like in land use planning, preparedness, and mitigation measures these are taken in measurement before another destructive earthquake in the coverage region.

CHAPTER 2

PROBABILISTIC SEISMIC HAZARD ANALYSIS METHOD

2.1 INTRODUCTION

The seismic hazard analysis deals with the evaluation of the levels of various natural effects of Earthquakes. Several parameters are used for measurement of seismic hazard like peak ground acceleration (Cornell, 1968), surface faulting (Stepp et.al, 2001, Todorovska et al., 2005), soil liquefaction (Trifunac, Todorovska 1999), peak strains (Todorovska and Trifunac, 1996).

Basically Seismic hazard can be represented most frequently in terms of probability of peak accelerations, peak velocities, or peak displacements or the complete response spectrum. Two approaches are commonly used for determining seismic hazard:

- Probabilistic Seismic Hazard Analysis (PSHA), and
- Deterministic seismic Hazard analysis (DSHA).

Seismic hazard is defined by ground motion with very low probability of exceedance. Probabilistic method considers the uncertainties in location, size and rate of occurrence. The objective of PSHA is to quantify these uncertainties, and provide description about distribution of future Earthquake shaking that may occur at different sites.

Generally probabilistic approach is most reliable than deterministic. Most of the parameters in DSHA are fixed which is reality are random. So PSHA method is commonly used for Hazard analysis. Also Probabilistic seismic hazard analysis (PSHA) considers all magnitude earthquakes greater than $M_{\min}$ for all the distances of the site for ground motion which influence the Hazard

2.2 Probabilistic Seismic Hazard Analysis Method

The PSHA approach defines a composite probability distribution function for any strong-motion parameter due to the total expected seismicity in the area around the site. Using the occurrence rate $\upsilon_n\ (M_j\ , R_i)$of earthquake with magnitude M_j and distance R_i in the n^{th} seismic source. The occurrence rate λ (Z > z) for a ground shaking parameter Z exceeding a value z can be defined as, which is a linear combination of $\upsilon_n\ (M_j\ , R_i)$ can also be defined by a Poisson distribution. So the probability of parameter Z > z due to all the earthquakes in all the source zones during a period of Y years can be written as:

$$\lambda(Z > z) = \sum_{n=1}^{n}\sum_{i=1}^{i}\sum_{j=1}^{j} q(\,Z > z|M_j\,,R_i) \times \upsilon_n\,(M_j\,,R_i) \qquad (1)$$

In this expression Y is the period in years, $\upsilon_n\,(M_j\,,R_i)$ is the annual occurrence rate of earthquakes within a small magnitude range (M_j- δM$_j$, M_j+ δM$_j$) and a small distance range (R_i- δR_i, R_i+ δR_i) from a site. Quantity $q(Z > z|M_j\,,R_i)$ is the probability ground motion Z is exceeded the specified value z due to an earthquake of magnitude M_j at distance R_i which can be determine from thee empirical attenuation relations. For the summations in above equation a total of j magnitude ranges and i distance ranges and n sources are considered.

Using the occurrence rate $\lambda(Z > z)$, the probability of not exceeding the value of z of the ground motion parameter Z in exposure period of Y years can be defined under Poisson's assumption as

$$P(Z > z|Y)\ = 1 - \exp(-\lambda(Z > z) \times Y) \qquad (2)$$

The reciprocal of $\lambda(Z > z)$ gives the return period $T(\mathrm{Z} > \mathrm{z})$ which can be defined in terms of P (Z > z| Y) as

$$T(\mathrm{Z} > \mathrm{z}) = 1/\ln(1 - \mathrm{P}(\mathrm{Z} > \mathrm{z}|\,\mathrm{Y})\,) \qquad (3)$$

The plot of the probability P (Z > z| Y) versus z is known as the "hazard curve". The hazard curves are sometimes also plotted as T (Z > z) versus Z. Generally the PSHA can be described by any of the quantities. $\lambda(Z > z)\,, T(\mathrm{Z} > \mathrm{z}|\,\mathrm{Y})$ or $\mathrm{P}(\mathrm{Z} > \mathrm{z}|\,\mathrm{Y})$, which are interrelated by simple relations. The use of $\mathrm{P}(\mathrm{Z} > \mathrm{z}|\,\mathrm{Y})$ provides a direct physical interpretation of the results of PSHA.

2.3 Steps involves in PSHA

For the estimation of this provability $\mathrm{P}(\mathrm{Z} > \mathrm{z}|\,\mathrm{Y})$ PSHA involves following 4 steps which are illustrated in figure 1.

1. Identification of sources;
2. Establishment of recurrence relationships and occurrence rate for each source
3. Selection of attenuation relationship
4. Computation of the site hazard curve

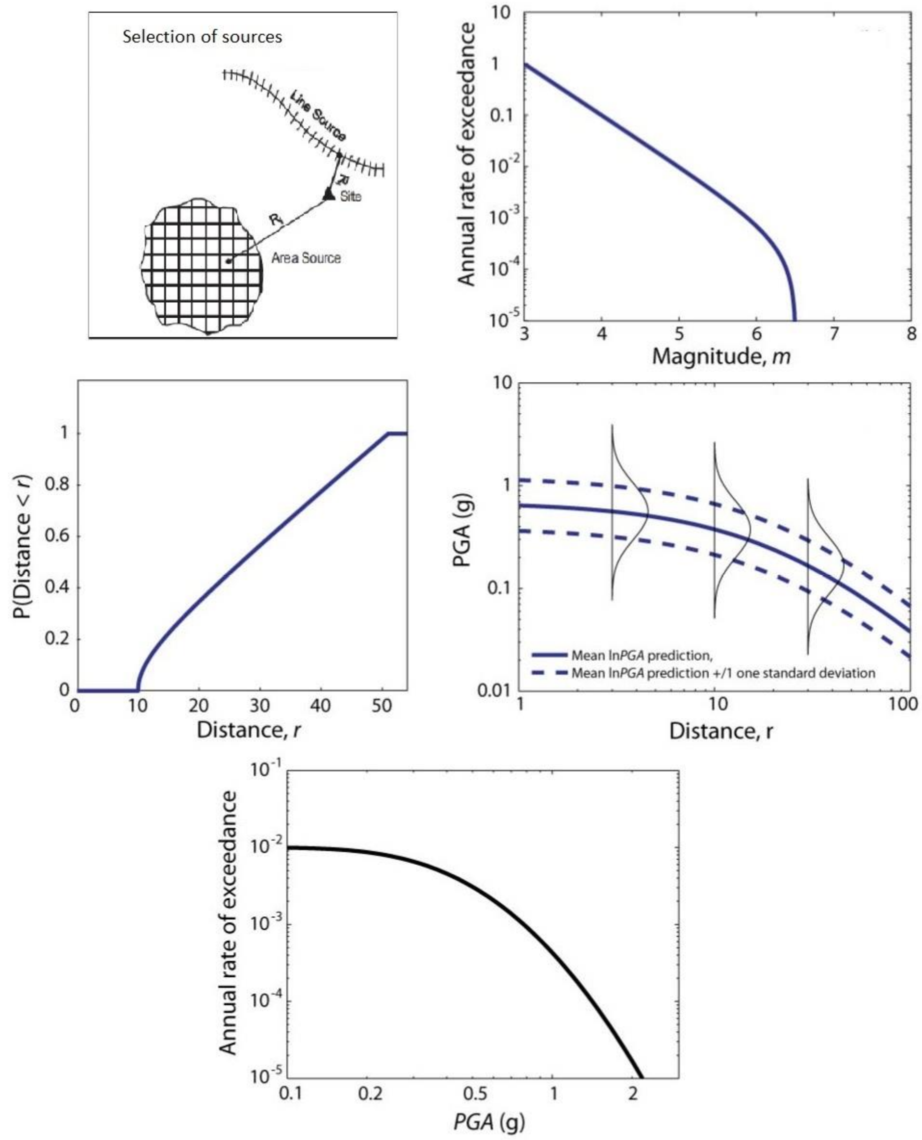


Figure 1: Consecutive steps for Hazard Estimation

2.3.1 Identification or delineate the sources

Generally there may be different types of source .it may be a line type source for known faults, Areal type of sources for known or unknown sources, Tectonic province, Point sources. Sources may be faults, typically planar surfaces identify based on the observations of locations of past earthquake and geological evidence. If faults are not available, then areal source should be taken for a seismic source where earthquakes may occur anywhere. After identification of sources we can identify the distribution of magnitudes and source-to site distances.

2.3.2 Define the magnitude recurrence relation

A recurrence relationship generally defines the annual rate of occurrence N(M) with magnitude greater than or equal to M. Various models are proposed time to time to define the recurrence relation. Anagnos and Kiremidjian (1988) give an idea about the earthquake recurrence models.

Evaluation of seismicity using available data on past earthquakes is most commonly based on the Gutenberg-Richter's, (1954) relation. According to which the annual occurrence rate N (M) with magnitude equal to or greater than M in a source zone can be described by

$$logN(M) = a - bM \tag{4}$$

Where N(M) be the cumulative frequency of occurrence of earthquakes of magnitude greater than M, and a and b are constants for a given source zone. The frequency- magnitude log-linear relation is known as the Gutenberg Richter (G-R) law. For defining the recurrence relationship firstly we need to define the parameter a and b. The value a and b can be determine from regression analysis or maximum likelihood method from the relationship of equation (4), The recurrence relation commonly used in PSHA application is defined with a lower threshold magnitude $M_{\min}$ and upper bound magnitude $M_{\max}$ as Cornell and Vanmarcke, (1969)

$$N(M) = N(M_{min}) \times \frac{e^{-\beta M} - e^{-\beta M_{\max}}}{e^{-\beta M_{\min}} - e^{-\beta M_{\max}}} \tag{5}$$

The above relation is known as constant seismicity model in which $N(M_{min})$ is the total number of earthquake with magnitude $M_{\min}$ or greater as obtained from the relationship of equation (1) and β is related to the parameter b as $\beta = bln10$. Thus after fitting the relation of parameter of equation (1) we define the relation of equation (5).

In constant seismicity models, the numbers of lower magnitude earthquakes are independent of the maximum magnitude M_{max}. Thus, lowering of M_{max} will result in lower moment release rate, which is not suitable. To overcome this constraining of moment release rate in a seismic source or a specific fault segment is necessary so that the lowering of M_{max} is compensated by increasing the total number of earthquakes N(M_{min}) .Such models is are generally based on the following assumptions:

1. If no creep is specified explicitly, the entire slip on a fault or within a seismic source is seismic.

2. The long-term average value of the slip rate is applicable to the future time period of interest and the short term fluctuations in the slip rate are not important.
3. The slip-rate from surface measurements is representative of the slip rates at seismogenic depths and along the entire fault segment of interest.

With these assumptions the long term average annual occurance rate N(M_{min}) is computed by balancing the seismic moment accumulation rate due to average long-term slip rate estimated by geodetic or geological field investigations . Initially seismic moment rate can be determined by expression $M_0 = \mu AS$ (Brune, 1968) .The moment accumulation rate associated with any volume can be further modified in the form of strain rate as:

$$\dot{M}_0 = 2\mu DLW\dot{\epsilon} \tag{6}$$

Where $\dot{M}_0$ is the total seismic moment rate due to the strain rate (Kostrove, 1974, Savage and Simpson, 1997), μ is the modulus of rigidity in dyne/cm^2 of the crustal rock, L is the length of seismic source, W is width and $\dot{\epsilon}$ is the strain rate. The seismic moment released during an earthquake can also be related empirically to the magnitude through an expression of the form $\log \dot{M}_0\,(M) = c + dM$ where c = 16.0 and d= 1.5 for $\dot{M}_0$ in units of dyne-cm (Hanks and Kanamori, 1979). Thus, the seismic moment release rate due to all the earthquakes up to magnitude M_{max} can theoretically be defined assuming the density function n(M) to be known as

$$\dot{M}_0 = \int_{M_{min}}^{M_{max}} M_0(M)n(M)dM \tag{7}$$

Using the exponential density function the expression for the moment release rate by way of earthquakes is obtained in terms of the occurrence rate N(M_{min}) and the upper bound magnitude M_{max} as follows

$$\dot{M}_0(M) = N(M_{min}) * e^{-\beta(M-M_{\min})} * \dot{M}_0(M_{max}) * \frac{b}{d-b} \tag{8}$$

In these expressions, $\dot{M}_0(M_{max})$ represents the moment released by the upper bound magnitude of M_{max}. Equating the moment release rate $\dot{M}_0$ from the source using the long-term geological slip rates with that given by the above expression gives the occurrence rate N(M_{min}) satisfying the constant moment release constraint in exponential model. It is thus possible to modify the constant seismicity recurrence models by using the $N(M_{min})$ estimated using the geologically determined moment release rate $\dot{M}_0(M_{\max})$ for given M_{max} and b-value (Anderson, 1979; Molnar, 1979; Shedlock et al., 1980; etc.).Once the relationship has been defined for a particular source zone, the number of earthquakes $N(M_j)$ in small magnitude range (Mj- δMj, Mj+ δMj) in the nth source zone can be obtained as

$$N_n(M_j) = N_n(\mathrm{Mj} - \ \delta\mathrm{Mj}\ ) - N_n(\mathrm{Mj} + \ \delta\mathrm{Mj}) \tag{9}$$

To determine the ground shaking at a site, it is also necessary to distribute these numbers over the complete source zone. For all earthquake source, it is assumed that the Earthquakes occur with same probability at all. Thus an area source is discretised into a mesh of small size element and the number $N_n(M_j)$ is divided equally among all the elements. The distance R_i is also estimated from the centre of the element to the site to get the occurrence rate $\lambda_n(M_j, R_i)$.

Generally several type of distances are used in PSHA like epicentral distance, hypocentral distances, distance from projection of rupture to the site or the closest distance of rupture plane from the site Note that some distance definitions account for rupture depth, while others consideration distance from the projection of the rupture surface.

2.3.3 Selection of attenuation relationship

The ground motion model used in PSHA is referred to as an Attenuation Relationship. Attenuation relationship must be simple and easier for computation .The attenuation relationship defines the ground motion level in terms of PGA ,PGV etc. as a function of magnitude and distance, and parameter related to different type of site (e.g., rock or soil) or styles of faulting .Generally mean parameter Z can be defined on log normal scale as

$$\ln(z) = \ln(PGA) = f(M, R, site\ characterstics)$$

According to log normal distribution the probability q (Z>z|M_j , R_i) defines the probability of PGA will exceeds a specified PGA z, for a given magnitude M_j and at distance R_i. The probability q (Z>z|M_j , R_i) can be determined by the function of mean value of $\ln(z)$ and standard deviation $\sigma_{\ln(z)}$

$$\mathrm{q}\left(\mathrm{Z} > \mathrm{z} \middle| M_j , R_i\right) = \frac{1}{\sqrt{2\pi}\ \sigma_{\ln(z)}} \int_{-\infty}^{\ln(z)} e^{-\frac{1}{2}\left(\frac{\ln(Z) - \mu_{\ln(z)}}{\sigma_{\ln(z)}}\right)^2} \tag{10}$$

2.3.4 The computation of the hazard curve

An important part of seismic hazard analysis is the quantitative measurement of strong ground shaking likely to occur at a site, is denoted as Peak Ground Acceleration, (PGA). .After determining the probability of exceeding the PGA> z, hazard curves are drawn between parameter PGA and probability of exceedence or annual occurrence or Return period. For easier way to understand we prepare hazard map by joining sites of equal ground motion PGA. In this study of Kumaun and Garhwal the PGA values shows the hazard intensities at a particular sites within the region.

CHAPTER 3

SEISMOTECTONICS AND SEISMIC SOURCES

The Kumaun Garhwal shares high seismicity of the north-western Himalayan region .It is falling in between the seismic gap of 1934 Bihar–Nepal earthquake and 1905 Kangra earthquake in the central Himalaya active region .Most of the part of Kumaun-Garwal Himalaya comes in Zone-4 and Zone-5 (BIS-1893:2000 Part 1).

3.1 Tectonics and Tectonic Map

The data on past seismicity shows that the various tectonic features faults, folds, shear zones, lineaments, etc. are most important components required to describe the seismic sources and prediction of the future earthquakes .The mostly used tectonic units are faults and thrusts considered for seismic hazard. Initially, regional tectonics of the region was examined for determining the seismicity. For the study of the Kumaun Garhwal Himalaya adjoining seismically active region of the North West Himalayas including the state boundaries of Jammu - Kashmir, Himachal Pradesh and Nepal(from 25-34˚in latitude and 75 to 84 in longitude) would be consider for describing the seismic features .

The tectonics of this region is dynamic which can be described by intercontinental drift theory. Due to collision of Eurasian and Indian plate and the organic processes resulting in the formation of the Himalayan ranges. It is still moving with the Indian plate at a rate of 17 mm/year (Molnar, 1990). A major part of the movement cause the crustal shortening of Indian plate by the formation of nappes, thrust, folding and faulting. The rest of the movement in the lateral direction (Molnar and Tapponnier (1979)), resulting the formation of strike-slip faults, like Altyn Tagh fault and other faults. For the tectonic point of view the region can be subdivided into the Kumaon Garhwal Himalayas and central or Nepal Himalayas, Karakoram ranges, and Tibetan plateau, Trans-Himalayas and Indo-Gangetic plains respectively.

In the north of the Uttarakhand there exists the Indus Tsanpo Suture Zone (ITSZ) and Bangong Nujiang Suture (BNS), which separates the Indian and Tibetan plate .Thrust fault are predominantly spread in Uttarakhand, which have high potential to cause earthquakes. It consist of main central thrust (MCT) & the main Boundary Thrust (MBT), Southern Tibetan detachment (STD), and Main Frontal Thrust (MFT). The region is spread from STD to MFT and extended up to Gangetic plane are most seismic tectonically active faults which are subjected to rupture time to time and cause generally shallow crustal earthquakes.

The MFT being the youngest series of Himalaya and the MCT in the Kumaon–Garhwal Himalaya is near about 50 km wide zone bounded in the south by the Munsiari Thrust (MT) and in the north by the Vaikrita Thrust (VT).some other main thrust faults present NAT(North Almora thrust), SAT (South Almora Thrust), Garhwal Thrust (GT), Higher Himalaya Crystalline (HHC), Bhatwari thrust (BT), Munsiari Thrust (MT), Vaikrita Thrust (VT), Ramgarh Thrust (RT), Jwalamukhi fault (JMT)), Kishtwar Fault, Tankpur Fault, Kamali Fault, Samea Fault and Dhangsi Fault etc extending in NW direction. It may also be seen that the faults in the north and northwest directions more active than the other faults (Gupta, 2006). Except these thrust fault some normal faults, transverse faults, gravity faults, lineament are also present like Alaknanda fault (AF), Drang fault (DT), Sundar Nagar Fault (SNF), Karakoram Fault (KKF), Kaurik Fault etc.

The Indo-Gangetic plains are the youngest deposits at the southern part of the Himalayas. The moderate seismicity in the region is due to the influence of Himalayan tectonics and the presence of transverse faults. The Mahendragarh-Dehradun fault (MDF), great boundary fault (GBF), Moradabad fault (MF), Delhi-Haridwar ridge (DHR), and Mathura fault (MF) are some transverse fault that some time induce the seismicity of the region (Agrawal and Chawla, 2006).

The Uttarakhand region, a part of the north-west Himalaya lies between the high seismically active zones. The geologic and tectonic features such as faults, thrusts, suture zones and lineaments, identified and digitized, using SURFER software, are shown in Figure:3 The study area of kumaun Garhwal , for which seismicity was studied, was spread to a distance of near about 300 km from every farthest point of Uttarakhand.

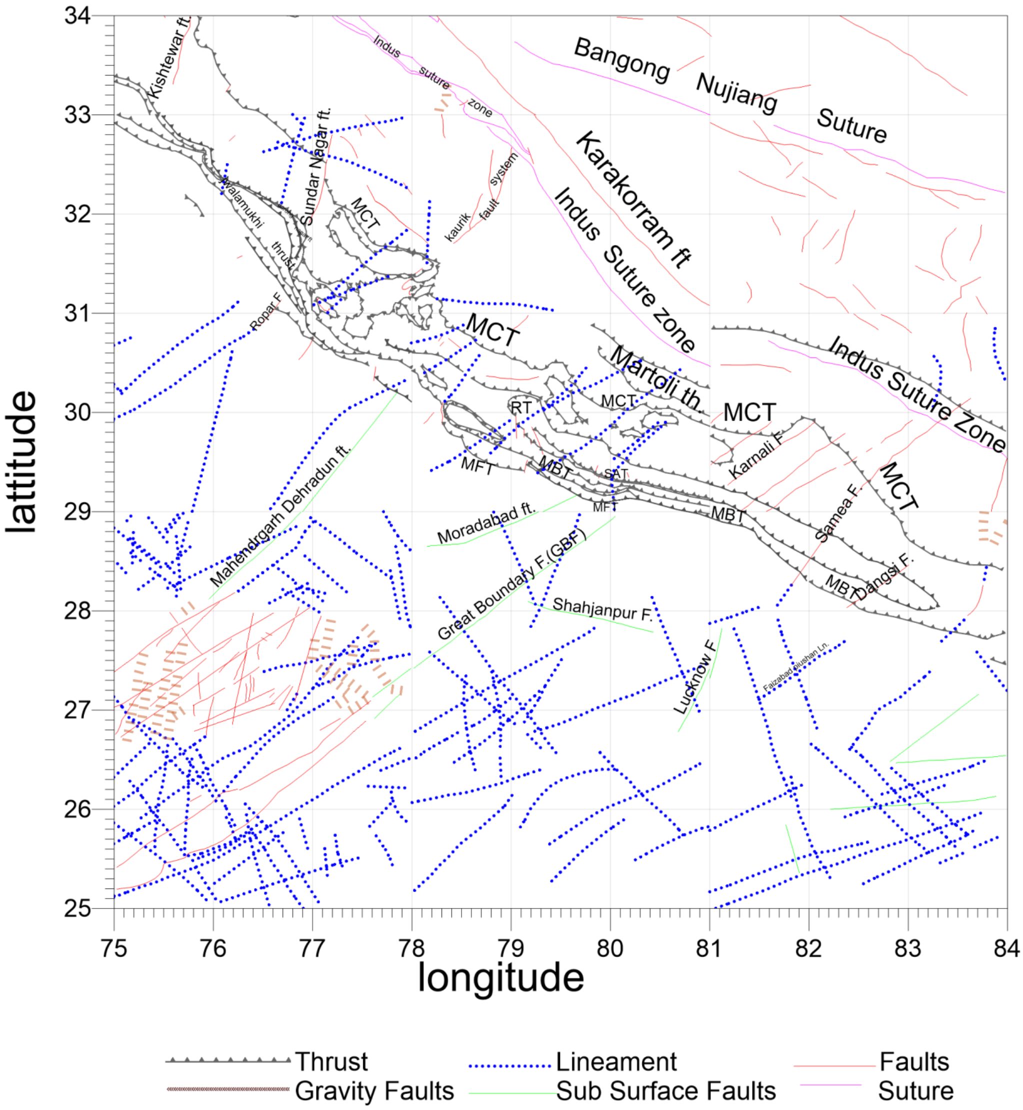


Figure 2: Tectonic features of Kumaun and Garhwal Himalaya and faults present in these zone as NAT (North Almora Thrust), SAT (South Almora Thrust), Garhwal Thrust (GT), Higher Himalaya Crystalline (HHC), Bhatwari Thrust(BT), Munsiari Thrust(MT), Vaikrita Thrust, Ramgarh Thrust (RT),TZ-7,TZ-2, Jwalamukhi Fault(JMT) etc. and Alaknanda fault (AF), Drang Fault (DT), Sundar nagar fault(SNF), Mahendragarh Dehradun fault (MDF),Karakoram Fault (KKF), Kaurik Fault, Great Boundary Fault (GBF)

3.2 EARTHQUAKE DATA

For the accurate analysis of seismic hazard, a sufficient amount of high quality data on past earthquakes is necessary. The data are generally taken from earthquakes catalogues. But many of existing catalogues are inhomogeneous and incomplete, so special care must be taken to correct these defects in catalogues. To study the seismicity and hazard of the seismic region a comprehensive (unpublished) catalogue based on past earthquakes magnitudes 3.5 or more, compiled by Dr. I.D. Gupta for the period 1501–2015, is used. This catalogue has been made from several sources covering regional and worldwide.

The main sources of non-instrumental and historical data considered are taken for periods prior to 1890 Baird-Smith (1843a, 1843b), Oldham (1883), Milne (1911), Lee et al. (1976), Quittmeyer and Jacob (1979). For the consideration of early instrumental data for the period from 1890 to 1964 are taken from Gutenberg and Richter (1954), Gutenberg (1956), Rothe (1969), and Quittmeyer and Jacob (1979). A lot of improved publications have presented of historical and early instrumental data. Among those some important publications are Abe (1981), Abe and Noguchi (1983a, 1983b), Pacheco and Sykes (1992), Engdahl and Villasen˜or (2002), Ambraseys (2000), and Ambraseys and Douglas (2004). The instrumental data from 1964-2015 is available at website of International Seismological Centre (ISC) http://www.isc.ac.uk/ of UK, National Earthquake Information Center (NEIC) of USGS http://earthquake.usgs.gov/earthquakes/search/ , Northern California Earthquake Data Centre http://www.ncedc.org/cnss/ , and at http://www.globalcmt.org/ under the project of global centroid-moment-tensor (CMT) , is used. In addition. Catalogues prepared by Indian Meteorological Department (IMD), Bapat et al. (1983), Raghukanth (2010) and Nath et al. (2010) have been used .

The compiled catalogue gives the information about local magnitude Richter's scale ML, surface wave magnitude MS, body wave magnitude mb, and moment magnitude Mw for each event. This information is not complete for any magnitudes scale. So homogenization of the catalogue is important .In the process of homogenization all the magnitudes are converted into one magnitude Mw moment magnitude by using empirical conversion relations.

3.3 CORELATION OF SEISMICITY WITH TECTONICS

The seismicity of the region is due to the continued convergence of the Indian plate against the Eurasian plate. Due to this convergence motion of Indian plate towards Eurasian plate large seismicity occurred in this zone and the formation of thrusts, i.e. The Main Central Thrust (MCT), The Main Boundary Thrust (MBT), Southern Tibetan detachment and Main Frontal thrust (MFT), and several other thrust and lineaments along the entire Himalaya. A main feature of seismicity of Kumaun Garhwal Himalaya is that the major distribution of epicenters of earthquakes are in the mountain range of Himalaya. A large proportion of epicenters of moderate earthquakes lie between the main central thrust (MCT) and main boundary thrust (MBT) and their occurrence is due to most active thrust faults lies in the upper crust. The most of the earthquake occurred at shallow depth 12-18 km (Kumar Arjun, 2014).

3.4 Identification of seismogenic source zones

For the estimation of PSHA of the Kumaun -Garhwal Himalaya, a region around Uttarakhand up to 300 km from the Uttarakhand boundary from latitude 25° to 34.0° and longitude 75° to 84° has been selected and earthquake data has been extracted from the Eathquake Catalogue. After plotting this earthquake data with the tectonic map the region is divided into several seismogenic source zones based on geologic conditions, tectonic features and seismicity. The region has been divided into elven seismogenic source zones. Each seismogenic source zones along with seismicity and tectonic features are shown in figure-3.

The seismogenic source zones SZ-6, SZ-7 and SZ-8 cover the major portion of seismicity of Kumaun and Garhwal where seismic hazard to be estimated. Source zone SZ-5 comes under himachal Pradesh, SZ-9 in covers western Tibbet, SZ-2, SZ-3, SZ-4 are the Trans Himalayan zone, and SZ-10, SZ-11 are comes in Gangatic plane. Some of the faults and lineaments are spreading almost orthogonal to the Himalayan arc. Some tectonic features and seismic features of the each source are given below in the Table-1and Table-2

Table 1: TECTONIC FEATURES OF SOURCE ZONES

SOURCE	TECTONIC FEATURES
SZ-1	Bangong Nojiang Suture
SZ-2	Indus Suture Zone, KKF(Karakoram fault), SNF(Sundar nagar Fault)
SZ-3	Indus Suture Zone, KKF(Karakoram fault), MT(Martoli Thrust), STD(Southern Tibbetian Detachment), KF(Kaurik fault)
SZ-4	Indus Suture Zone(ISZ), Takkoba Graban, Samea Fault
SZ-5	SNF(Sundar Nagar fault), Kistawar fault, JMT(Jwalamukhi Thrust)
sz-6	SNF(Sundar Nagar fault), JMT(Jwalamukhi Thrust), NAT, TZ-7, MFT, DT(Drang fault)
SZ-7	MT(Martoli Thrust), MT-1, MCT, TZ-1, TZ-2, NAT, SAT, RT, MFT, VT, Tanakpur fault
SZ-8	MT(Martoli Thrust), SAT, RT, MFT, Tanakpur fault, Karnali fault
SZ-9	Samea fault, Dangsi fault, Barigad Fault, Takkoba Graban
SZ-10	Mahendragarh –Dehradun fault
SZ-11	Moradabad fault, GBF(Great boundry fault), Lucknow fault, Sharda Depression, Gandak Depression

Table 2 : SOME SEISMIC FEATURES OF SOURCE ZONE

SOURCE	Area (Km^2)	Total No EQ	No of Earthquake for different magnitude						Big Event time	Highest magni-tude
			<4	4-4.9	5.0–5.9	6.0-6.9	7.0-8.0	>8.0		
SZ-1	56256	129	18	99	10	2	0	0	28-01-1955	6.4
SZ-2	39824	63	6	47	9	0	1	0	19-01-1955	7
SZ-3	63072	92	9	64	14	3	2	0	01-09-1801	7.5
SZ-4	85344	288	33	212	32	11	0	0	17-10-1944	6.8
SZ-5	36480	374	27	264	71	5	7	0	09-04-1905	7.8
sz-6	43968	180	16	124	35	5	0	0	10-10-1991	6.8
SZ-7	35712	213	20	147	36	9	1	0	25-07-1720	7.5
SZ-8	21376	264	8	206	45	3	2	0	28-08-1816	7.5
SZ-9	34368	132	9	99	22	0	1	1	06-06-1505	8.2
SZ-10	30384	68	14	43	10	1	0	0	15-07-1720	6.9
SZ-11	416624	103	16	70	15	2	0	0	18-10-1833	6.3

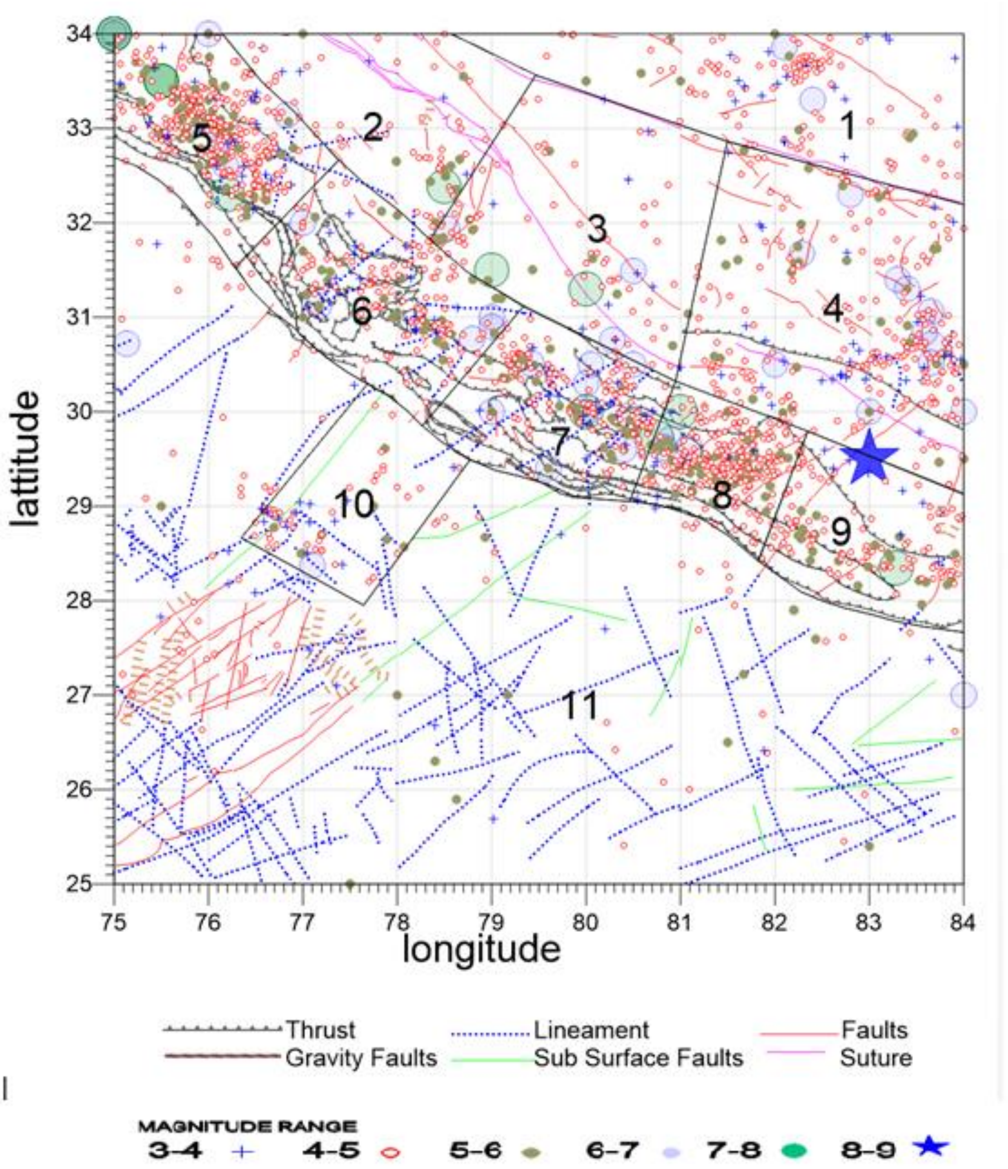


Figure 3: ‘Identification of seismogenic source zones based on tectonics, geology and seismicity’

CHAPTER 4

RECURRENCE RELATIONSHIP

4.1 INTRODUCTION

The second step involved in a PSHA is the establishment of earthquake recurrence relationships, magnitude distribution, and average occurrence rates. A recurrence model specifies the number of earthquakes N(M) , with magnitude greater than or equal to M. For exact estimation of annual occurrence rate the complete qualitative dataset is important. So de clustering and Completeness analysis is carried out before the determination of recurrence relation.

4.2 DECLUSTERING OF CATALOGUE

The data from Earthquake catalogue consisting all earthquakes foreshocks, main shocks and aftershocks. For seismic hazard analysis earthquake catalogue must have the independent main shocks following Poisson's distribution. The foreshocks and aftershocks being dependent on the main shocks tend to cluster in space and time close to the locations and times of occurrence of the main shocks. Generally there is no standard criteria for assign an earthquake as an aftershocks, foreshocks. But there are given a working conditions used in the statistical analysis of hazard as the seismic hazard analysis is generally based on the assumption of the Poisson's occurrence of earthquakes.

The largest shock is generally considered as the main shock. The early aftershocks are easy to identify. However, it becomes much difficult to identify accurately the later aftershocks, because there is no physical difference between the low magnitude main shocks and the later aftershocks. Therefore, de-clustering of an earthquake catalogue cannot be performed in a completely error freeway, and several different methods have been therefore proposed for the purpose by different investigators.

In this study window method is used for removing foreshocks & aftershocks proposed by Gardner and Knopoff (1974), and Uhrhammer (1986). Initially 2399 earthquake events are present in the catalogue and we are getting 1912 independent event after de-clustering the catalogue.

4.3 COMPLETENESS ANALYSIS

Earthquake catalogues are the main important products part of seismic hazard analysis. They provide a data which is useful in various seismological studies like in seismotectonics, earthquake physics, seismicity and hazard analysis. For the qualitative scientific analysis the data must have quality, consistency, and homogeneity .Every earthquake catalogue is prepared based on the recorded signals of temporally complex heterogeneous network related to seismometers. These records of these signals processed by several of software and assumptions. Thus, a best earthquake catalogues is also inconsistent and heterogeneous in space and time

Generally entire earthquake data is not available in any catalogue centre. Small Earthquakes had left in consideration due to non-availability of records of past data of earthquake. Completeness analysis is necessary for a min magnitude for which the data is complete in a specific space and time. For this purpose we draw the time history cumulative no of earthquake verses time curve and estimate the duration for which the catalogue should be complete considering a min magnitude of completeness M_c value.

The methods of completeness and seismicity analysis can be done by using ZMAP. The code is available with software package ZMAP Wiemer, 2001), which is a written in Mathworks software Matlab (http://www.mathworks.com).

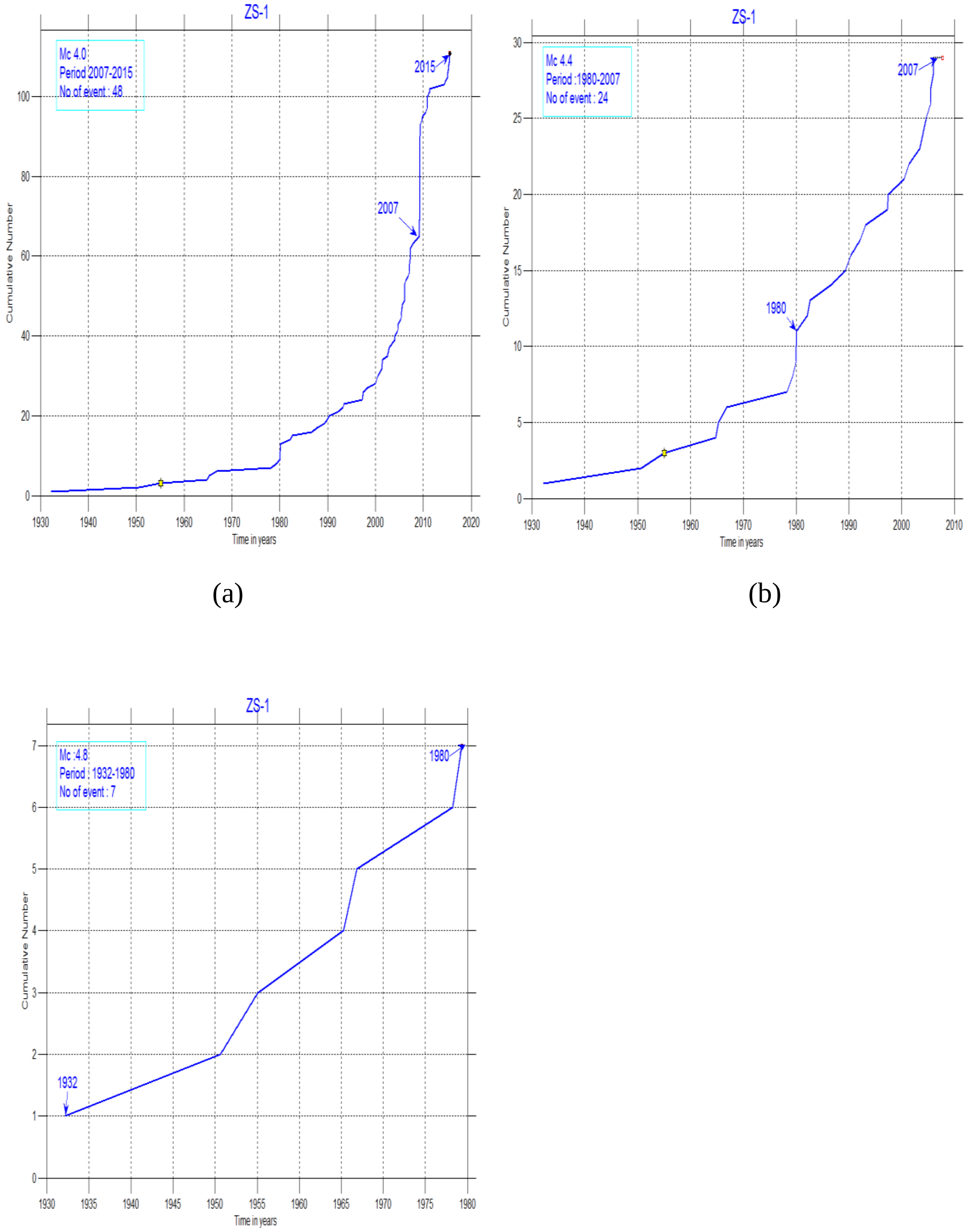
For the completeness analysis slope method (Tinti, S. and F. Mulargia ,1985) is used .In this analysis we draw time history by ZMAP software for the different minimum magnitudes and estimate the duration for which the earthquake is complete and the slope is constant. The results of completeness analysis foe each source zone are shown below in Table -3 with their time history.

Table 3 : COMPLETENESS ANALYSIS OF EACH SOURCE

Source	Completeness analysis											
	Mc 1	**t1**	**n1**	**Mc2**	**t2**	**n2**	**Mc3**	**t3**	**n3**	**Mc4**	**t4**	**n4**
SZ-1	4	2007 -2015	48	4.4	1980 -2007	24	4.8	1932 -1980	7			
SZ-2	4	2001 -2015	27	4.4	1959 -2001	25						
SZ-3	4	1966 -2015	76	4.4	1963 -1966	4						
SZ-4	4	2001 -2015	182	4.4	1978 -2001	87	4.8	1913 -1978	17			
SZ-5	4	1998 -2015	25	4.4	1980 -1998	45	4.8	1995 -1980	44	6	1740 -1949	11
SZ-6	4	1997 -2015	81	4.4	1972 -1997	47	4.8	1809 -1972	9			
SZ-7	4	2001 -2015	97	4.4	1962 -2001	67	5.2	1720 -1962	10			
SZ-8	4	1994 -2015	186	4.4	1962 -1994	64	4.8	1916 -1962	4			
SZ-9	4	1982 -2015	113	4.4	1936 -1982	9						
SZ-10	4	1999 -2015	26	4.4	1960 -1999	8						
SZ-11	4	1990 -2015	68	4.4	1925 -1990	16						

4.4 COMPLETENESS ANALYSIS TIME SERIES CURVE

SOURCE ZONE 1

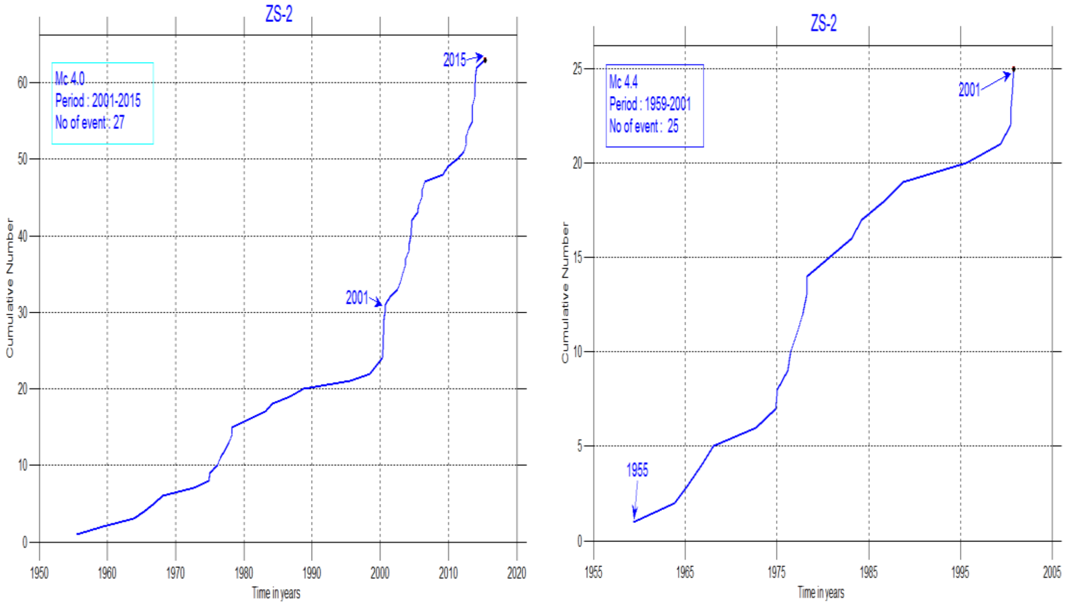


(a) (b)

(c)

Completeness curve for Source Zone -1(a, b, c)

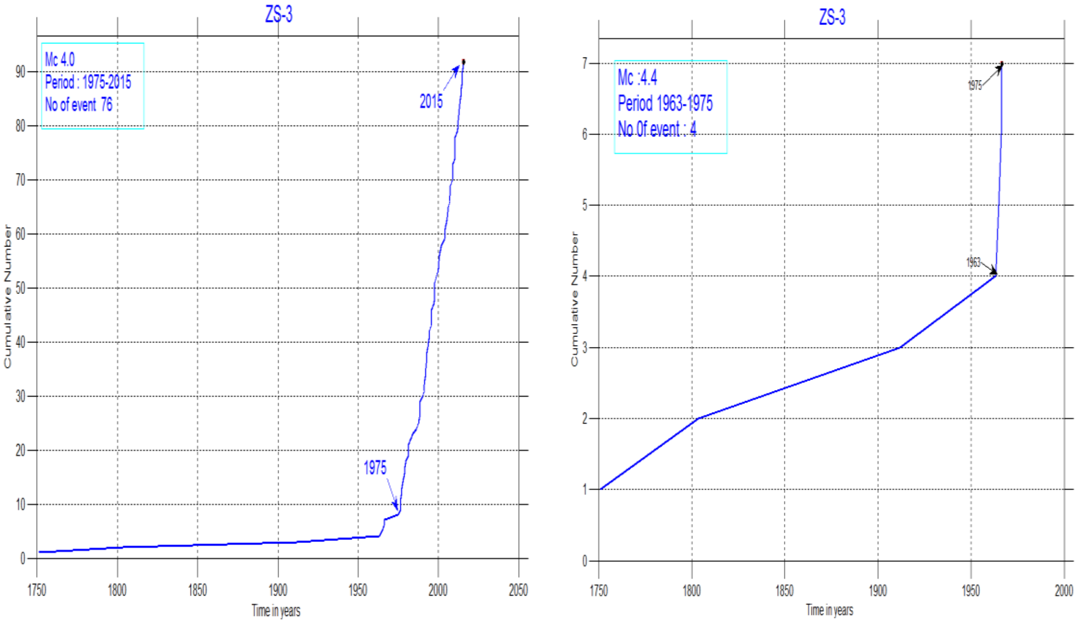
SOURCE ZONE 2



(a) (b)

Completeness curve for Source Zone 2 (a, b)

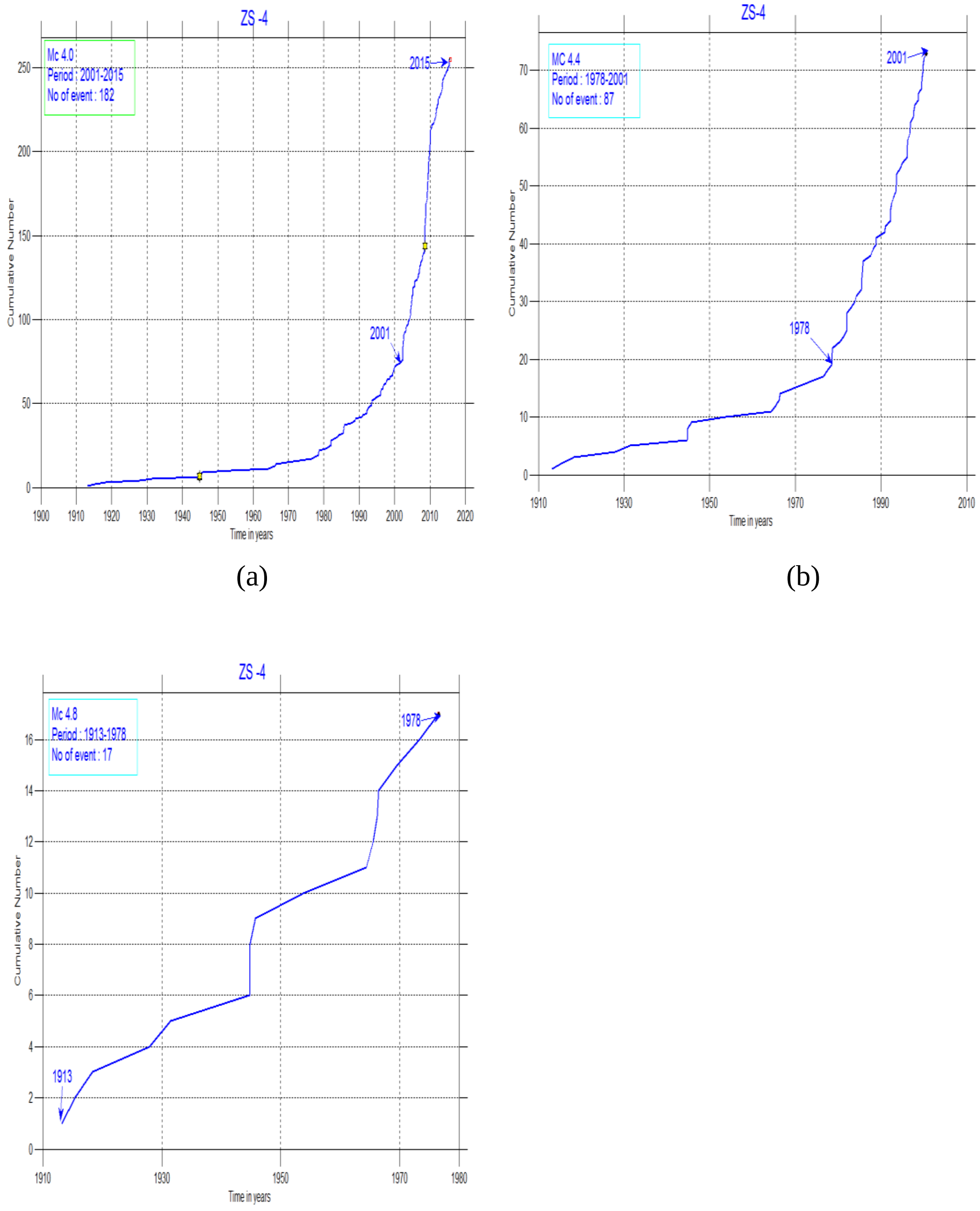
SOURCE ZONE 3



(a) (b)

Completeness curve for Source Zone 3 (a,b)

SOURCE ZONE 4

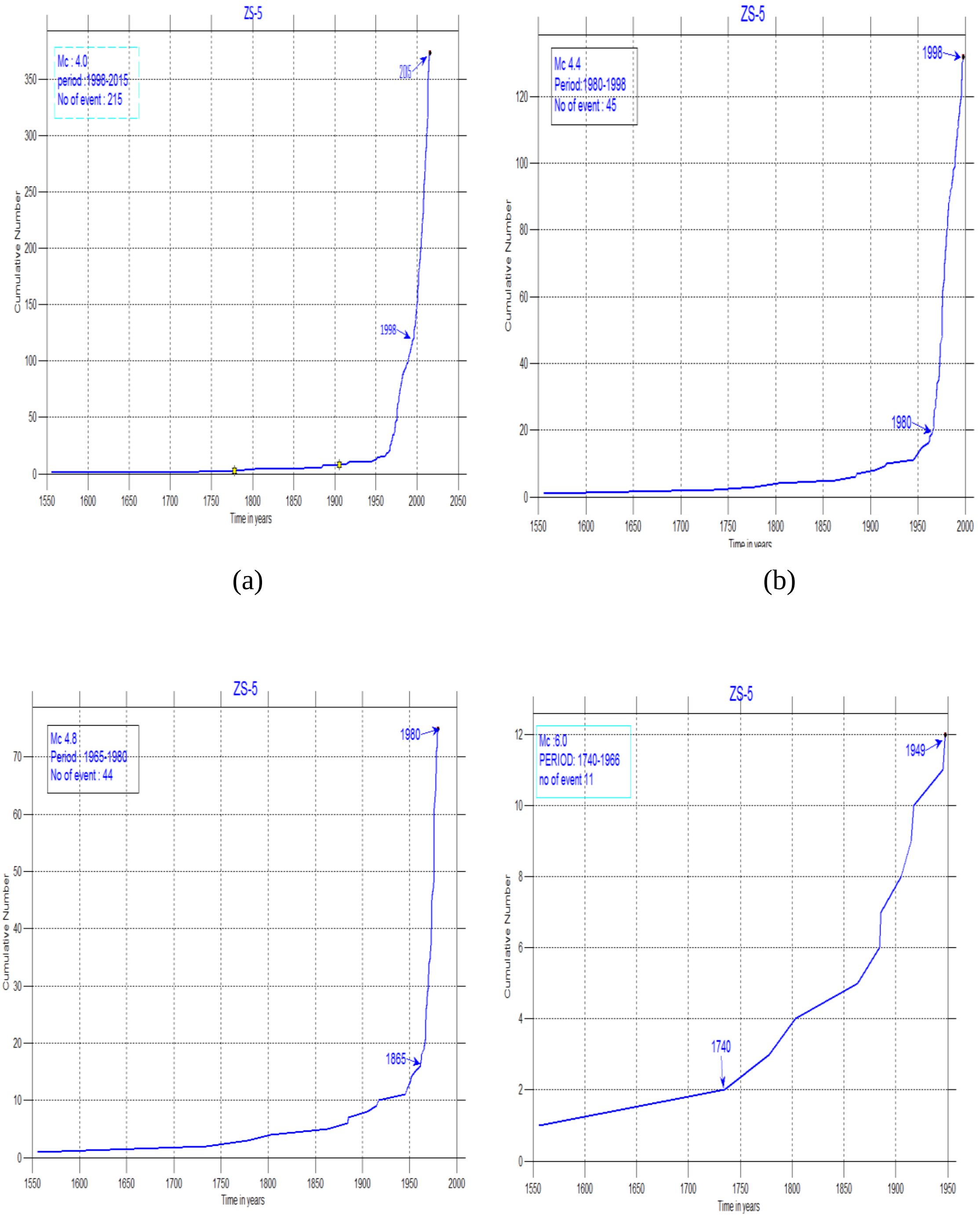


(a) (b)

(c)

Completeness curve for Source Zone 4 (a,b,c)

SOURCE ZONE 5

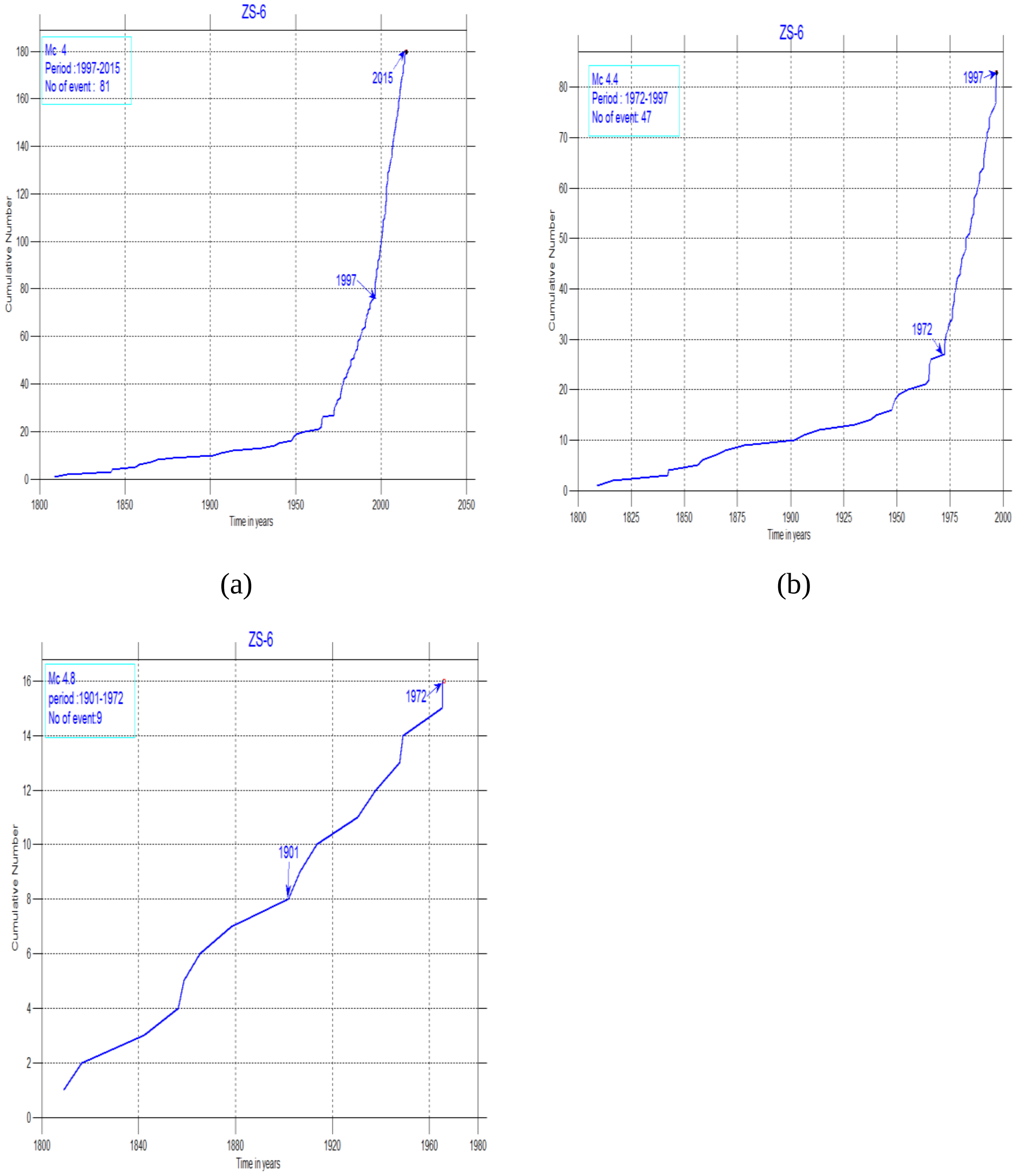


(a) (b)

(c) (d)

Completeness curve for Source Zone 5 (a, b, c, d)

SOURCE ZONE 6



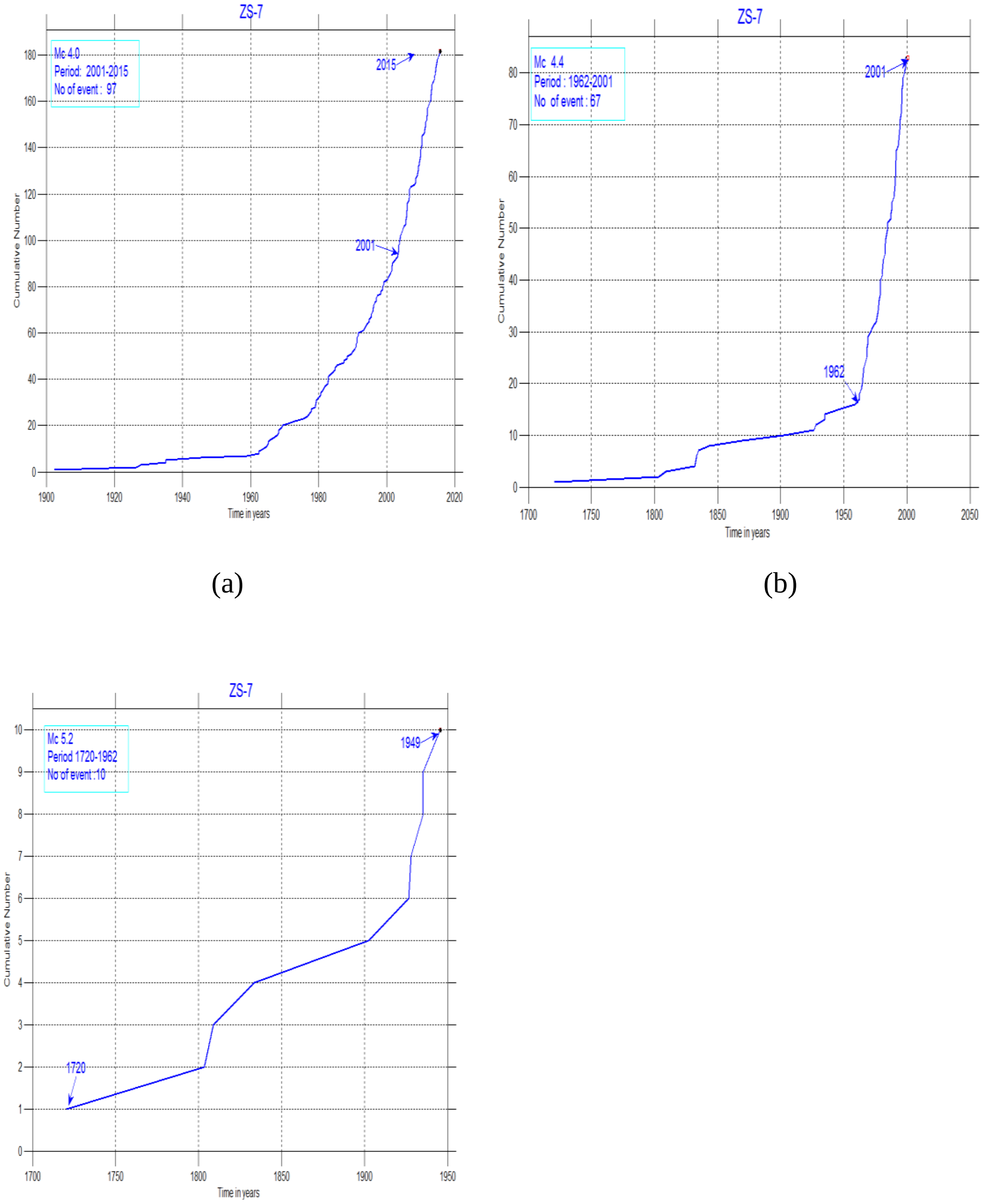
(a)

(b)

(c)

Completeness curve for Source Zone 6 (a, b, c)

SOURCE ZONE 7



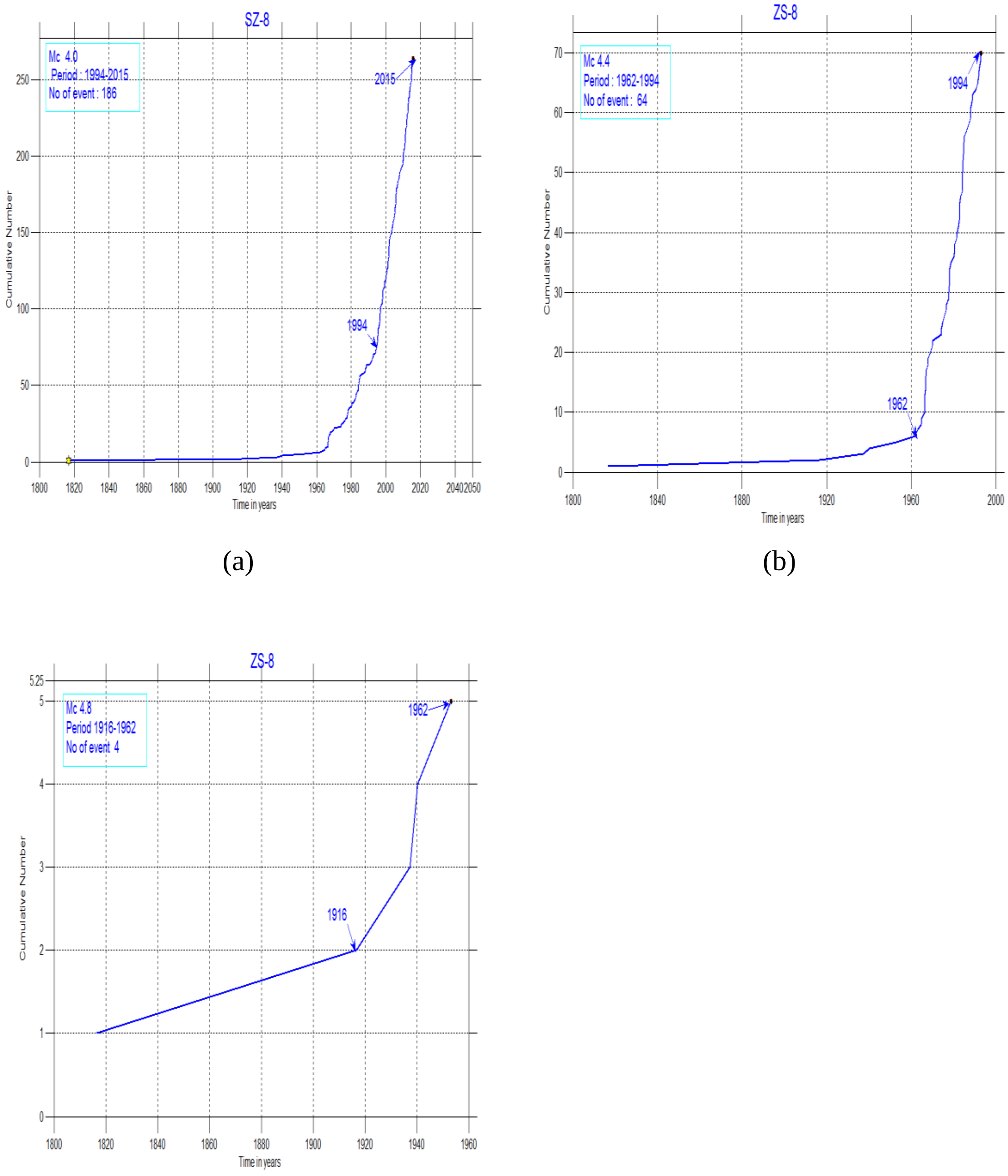
(a)

(b)

(c)

Completeness curve for Source Zone 7 (a, b, c)

SOURCE ZONE 8



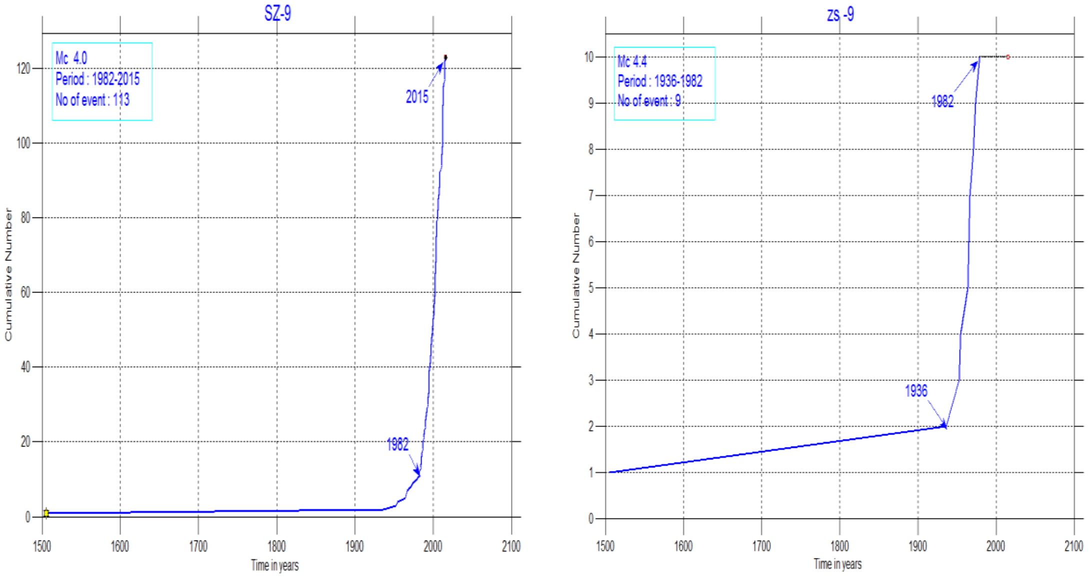
(a)

(b)

(c)

Completeness curve for Source Zone 8 (a, b, c)

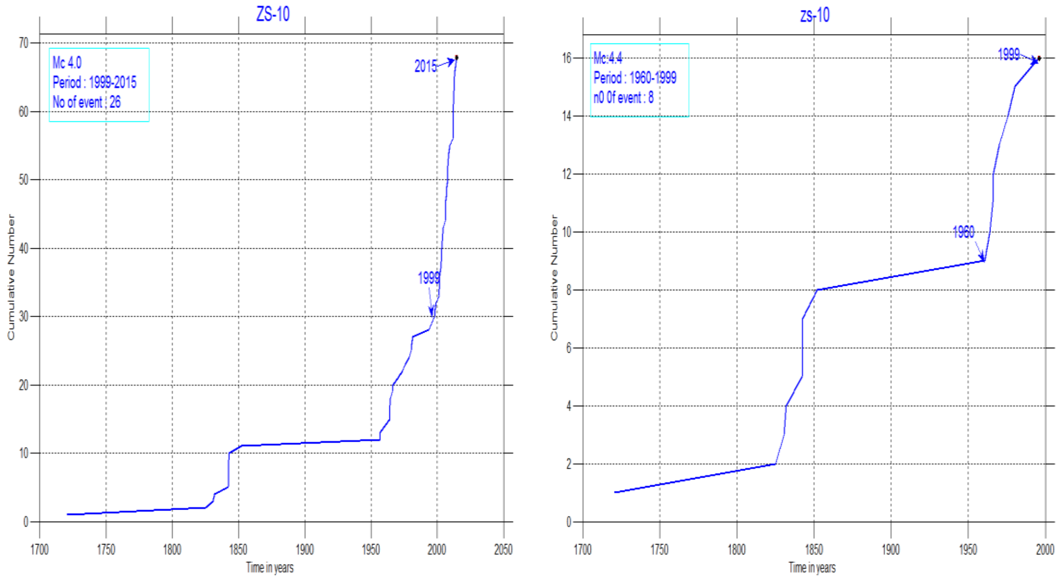
SOURCE ZONE 9



(a) (b)

Completeness curve for Source Zone 9 (a, b,)

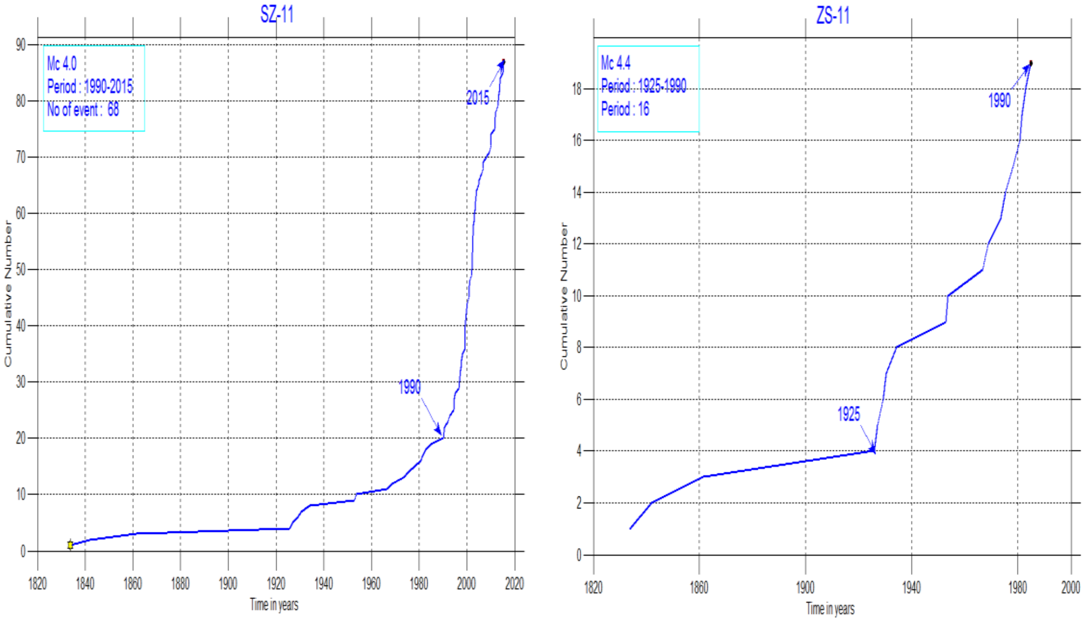
SOURCE ZONE 10



(a) (b)

Completeness curve for Source Zone 10 (a, b, c)

SOURCE ZONE 11



(a) (b)

Completeness curve for Source Zone 11 (a, b, c)

Figure 4: Time series for all the Source Zone (completeness curve for source 1 to source 11)

4.5 ESTIMATION OF RECURRENCE PARAMETER ‘a’ AND ‘b’

The recurrence parameter a and b represents the frequency-magnitude relationship. Generally occurrence of earthquakes follows Gutenberg Richter relation (G-R relationship) expressed as.

$$logN(M) = a - bM \tag{11}$$

Where N(M) be the cumulative frequency or annual occurrence rate of earthquakes of magnitude greater than and equal to M, and a and b are both constants. The ‘a’ value indicates the overall rate of earthquakes in a region, and the ‘b’ value indicates the change in occurrence rate with magnitudes. The parameter b is related toβ; $\beta = b \times ln10$; The parameter β can then be evaluated by using the maximum likelihood method as (Aki, 1965; Bender B 1983, Utsu, 1965)

$$\beta = \frac{1}{\bar{M} - Mc}; \quad \beta = b \times ln10; \tag{12}$$

$$\bar{M} = \frac{\sum M_i \times n_i}{N} \tag{13}$$

Where N is total no earthquake and N_i is the no of earthquake for different lower threshold magnitude Mc for different period of completeness.

Kijko and Smit (2012) have extended the Aki-Utsu b-value estimator for magnitude grouped data. If M_1, M_2 ,…..,Mk are the minimum magnitudes of completeness for periods t_1 t_2 t_3…. t_n with number of events in various intervals as N_1,N_2…. N_n, respectively. Then, the generalized Aki-Utsu β -value estimator is given by

$$\beta = \frac{1}{\sum_{i=1}^{n} \frac{r_i}{\beta_i}} \tag{14}$$

Where $r_i = \frac{N_i}{N}$ and N=$\sum N_i$ is the total number of events in all the intervals of completeness

and β_i is the Aki-Utsu estimator for i^{th} interval . Kijko and Smit (2012) has been developed the relation for occurrence rate $N(M_{min})$ with the magnitude greater than or equal to threshold magnitude M_{min} expressed as:

$$N(M_{min}) = \frac{N}{\sum_1^s ti \times \exp(-\sum \exp(-\beta(Mc_i - M_{min})))} \tag{15}$$

The parameter a value is also determined by using Gutenberg Richter relationship taking the threshold magnitude $M_{min} = 0$ and a value becomes $a = LogN(M)$

Table 4 : RECCURENCE PARAMETER ‘a’ AND ‘b’ VALUE

Source	a value	b value
SZ-1	2.688815	1.05566
SZ-2	3.455992	0.99485961
SZ-3	3.060834	0.739225
SZ-4	3.011018	0.97571266
SZ-5	3.188127	1.098817
SZ-6	2.874895	0.926765
SZ-7	1.334449	0.84056997
SZ-8	2.414817	0.88745614
SZ-9	2.810512	0.801774
SZ-10	3.815958	.9844008
SZ-11	2.746179	1.02186937

4.6 RECURRENCE RELATION WITH CONSTANT SEISMICITY

In the constant seismicity method the recurrence rate depends on the upper bound magnitude M_{max} as well as lower bound magnitude M_{min} by the relation described in equation (5). For the computational purpose M_{min} has been taken as 4 in this study and maximum magnitude M_{max} can be determined by the relationship given by Kijko (2004) expressed as:

$$M_{max} = M_{max}(obs) + \frac{E_1(n_1) - E_1(n_2)}{\beta \times \exp(-n_2)} + M_{min} \times exp(-n) \tag{16}$$

Where M_{max} is the maximum magnitude, M_{max} (obs) is observed maximum earthquake magnitude, M_{min} is minimum magnitude of completeness and n is the number of earthquakes equal greater than M_{min} taken as $n = N(M) \times T$, T is the period for which the maximum magnitude is computed. Generally M_{max} is independent of M_{min}. Here for the purpose of calculation M_{min} has been taken as 4 and M_{max} is estimated by the expressions given below:

$n_1 = n/(1 - \exp[-\beta(M_{max} - M_{min})]);$ $n_2 = n1 * \exp[-\beta(M_{max} - M_{min})]$

$$E_1(z) = \left[\frac{z^2 + a1 * z + a_2}{z(z^2 + b1 * z + b2)}\right] \times exp(-z)$$

a_1= 2.334733; a_1= 2.334733;

$b1 = 3.330657;$ $b2 = 1.681534$

$\beta = bln(10);$

The values of M_{max} for the the period of 500 years and period as in catalogue is given below in Table 7

Table 5: MAXIMUM MAGNITUDE OF EACH SOURCE ZONE

Source	a value	b value	β	**Mmax (obs)**	Catalogue period	**Mmax for period 500 year**	Mmax for catalogue period	Mmax adopted
SZ-1	2.68881	1.05566	2.430769	**6.4**	83	6.498	6.649	6.7
SZ-2	3.45599	0.994859	2.290749	**7**	60	7.308	7.609	7.5
SZ-3	3.06083	0.739225	1.702128	**7.5**	264	7.709	7.665	8.0
SZ-4	3.01101	0.975712	2.246661	**6.8**	102	6.873	7.118	7.0
SZ-5	3.18812	1.026277	2.363091	**7.8**	460	8.241	8.415	8.2
SZ-6	2.87489	0.926765	2.133956	**6.8**	114	6.918	7.052	8.2
SZ-7	1.33444	0.840569	1.935484	**7.5**	295	7.935	7.749	8.2
SZ-8	2.41481	0.887456	2.043443	**7.5**	199	7.704	7.896	8.2
SZ-9	2.81051	0.801774	1.846154	**8.2**	510	8.760	8.55	8.2
SZ-10	3.81595	0.984400	2.266667	**6.4**	295	6.5449	6.473	6.8
SZ-11	2.74617	1.021869	2.352941	**6.3**	182	6.4109	6.403	6.5

4.7 RECURRENCE RELATIONS WITH MOMENT RELEASE CONSTRAINT

Before the estimation of recurrence rate by Seismic Moment Release Constraint method we have to determine the seismic moment associated with the sources. According to the Kostrove, 1974 the seismic moment associated with any volume is given by the relations $\dot{M}_0 = 2\mu DLW\dot{\epsilon}$ as described in equation (5). This seismic moment is depend on the strain rate for all sources. So the accurate measurement of the strain rate is necessary.

4.7.1 SLIP RATE STUDY AND ESTIMATION OF SEISMIC MOMENT

Collision of India continent with Eurasian plate is spread in a wide range about 400 km width and about 2500 km long stretch of Himalayan arc (Molnar & Tapponnier 1977) which contribute high elevation, formation of fold, fault and large crustal shorting along the arc. GPS measurement and various plate motion model indicates that Indian plate is penetrating into Asian plate at the rate of 45 mm/year (Sella et al,2002).The translational and rotational motion creates left lateral slip of 42 mm/year in Baluchistan and right lateral slip of 55 mm/year relative to Asia (Bilham Roger,2004). India convergence into Asia approximately 18 mm/years (Wang et al, 2001).

Roger Bilham, 2005 indicates the calculated average slip rate (5 mm/year) of entire Himalaya is less than 1/3 of the convergence rate (18 mm/year) measured from the GPS. M. Ponraj, S. H. Mahajan, 2010 estimates the slip velocity using historic data is 10 mm/year on the basis of Non Uniform Creep (NUC) model

Recently Kundu Bhasker, 2014 measures the convergence of Karakoram and Nepal Himalaya and the slip indicate the N-S oblique motion is 17± 2 mm/year (5± 2 mm/year due to dextral motion and 13.6± 2 mm/year due to azimuth N198E) into Kashmir Karakoram range and 19-20 mm/year (6.7±1 mm/year dextral and 11.8± 1 normal thrust motion along N185E) in Nepal. Eastern Tibet plateau moves faster (21-26 mm/year) then the North China (14-17 mm/year) and South China (6-10 mm/year, Devchandra Singh, Arun Kumar, 2013). Holt, 2010 studied the west central region between 77-99 longitude and measures slip 16-19 mm/year.

Ader, 2012 studied the geodetic strain rate of Nepal and Southern Tibbet using GPS time series and found convergence rate 17.8±0.5 mm/year in central and Eastern Nepal and 20.5±1 mm/year in western Nepal. Lave and Avouac also gave slip rate 21.5±1 mm/year on time scale in HFT of central Nepal after study of several thousand year uplift of Holocene terraces in Doon valley. Mugnier et al, 2003 estimates slip of 19±6 mm/year in western Nepal and Bettinelli et al 2006 measures 19±2.5 in Central and Eastern Nepal. Recent GPS measurements in the Nepal Himalaya indicate a convergence rate of 17.7±2 mm/year for the advance of India beneath Tibet (Bilham et al., 1997).

Powers et al. (1998) analysed in the Kangra and Dehradun re-entrants the estimated rates of shortening is 14±2 mm/year and 6-16 mm/year, respectively. An analysis of the strain rate distribution in-the mobile zone between India and Eurasia using finite element analysis has predicted a strain rate of 18 mm/year in the Assam and Nepal regions which gradually reduces in the western direction to 15 mm/year in the Garhwal Himalaya and to 10 mm/year in the Jammu Himalaya (Peltzer and Saucier, 1996.

Table 6 : SLIP P RATES OF DIFFERENT PARTS OF HIMALAYA

NAME	SLIP (mm/year)	AREA OF STUDY	YEAR	REMARKS
Bhaskar kundu	17±2	Kashmir and Karakorum range	2014	GPS measurement
	19-20	Nepal region		
Devendra Singh and Arun kumar	21-26	Tibbet plateau (76-99)	2013	After study of active deformation measurement
Holt ,W E	16-19	West central tien shan 77-99	2000	
M. Ponraj	10 (avg)	Western Himalaya	2010	Historic data using NUC model
NAME	SLIP (mm/year)	AREA OF STUDY	YEAR	REMARKS
Roger Bilham and Nicholas Ambreseys	5-8(avg)	Entire Himalaya	2005	historic data measurement
	18 mm/year			GPS measurement
Bang et al	18 mm/year	India convergence	2001	
Ader	17.8±0.5	Central and Eastern Nepal	2012	Geodetic strain usin GPS time series
	20.5±1	Western Nepal		
Bilham	17.7±2	India Eurasia convergence India beneath tibbet	1997	GPS measurement
Lave and Avouac	21.5±1.5	Central Nepal and Dehradun valley	2000	Slip rate on time scale measurement
Mugnier et al	19±6	Western Nepal	2003	
Bettinelli	19±2.5	Central and eastern Nepal	2006	
Banerjee	16 mm/year	Eastern Nepal	2008	
Molnar	17 mm/year		1990	Study on Seismic moment release in great earthquake
Power et al	14± 2 and 6-16	Kangra and Dehradun valley	1998	

Finally analysing the all slip rates estimated by all researcher we can conclude that for hazard analysis of Uttarakhand Himalaya from longitude 75-84 can be devided into two parts. Slip rate of western part including SZ-2, SZ-3, SZ-5, SZ-6, SZ-7 can be taken from Karakoram range slip 17±2 mm/year (Bhaskar kundu), and slip for eastern part including SZ-4, SZ-8, SZ-9 can be taken 20.5±1 mm/year (ader,2012) from central Himalaya or western Nepal.

The slip given by the various researcher is given for the entire width of Himalaya. So we have to distribute total slip 17 mm/year and 20.5 mm/year into their respective source zone. Slip is caused due seismic moment. So we can distribute this slip in the ratios of annual seismic moment release obtained from the past earthquake data. The seismic moment and corresponding slip is given below for each Himalayan source in the Table-7

Table 7: SEISMIC MOMENT ESTIMATION USING SLIP IN SEISMIC MOMENT RATIOS

Source	LengthL (km)	shear modulus μ (dyne/ cm^2)	Depth km D	SLIP (W*ϵ) cm/year	Seismic moment using slip in moment ratios $\dot{M}_0 = 2\mu DLW\dot{\epsilon}$
SZ-2	214.1338	3.20E+11	20	0.249417	6.84E+24
SZ-3	283.2857	3.20E+11	20	0.80622	2.92E+25
SZ-4	329.3533	3.20E+11	20	0.23607	9.95E+24
SZ-5	222.7992	3.20E+11	20	1.450583	4.14E+25
SZ-6	282.0658	3.20E+11	20	0.89378	3.23E+25
SZ-7	225.9093	3.20E+11	20	0.89378	2.58E+25
SZ-8	166.676	3.20E+11	20	1.81393	3.87E+25
SZ-9	225.1551	3.20E+11	20	1.81393	5.23E+25

4.7.2 ANNUAL OCCURANCE RATE

For the estimation of occurrence rate through seismic moment release rate initially we have to bound the upper limit seismic moment released during the earthquakes can also be related to the Magnitude by an expression $\dot{M}_0(M) = c + dM$ where c = 16.0 and d= 1.5 for $\dot{M}_0$ in units of dyne-cm (Hanks and Kanamori, 1979). Using the expression given in equation (8) the annual occurrence rate N(M_{min}) is determined by

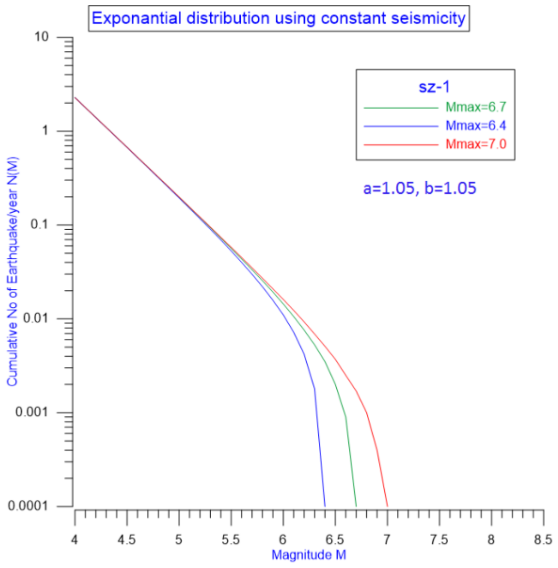
$$N(M_{min}) = \frac{\dot{M}_0(M)}{e^{-\beta(M-M_{\mathrm{min}})} \times \dot{M}_0(M_{max}) \times \frac{b}{d-b}} \qquad (17)$$

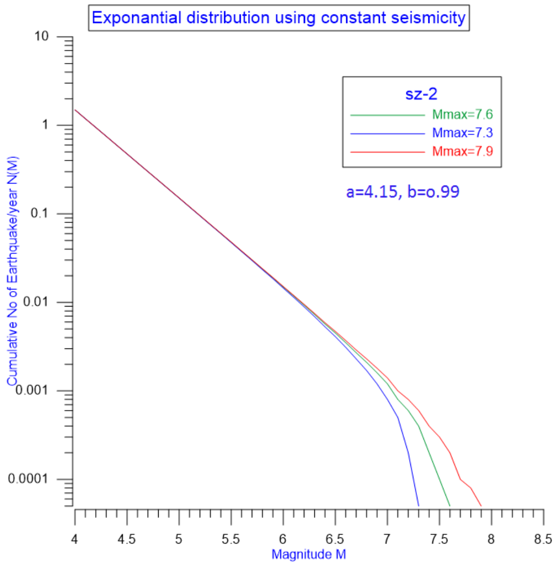
The annual occurrence rate using seismic moment release constraint are shown below in the Table -8

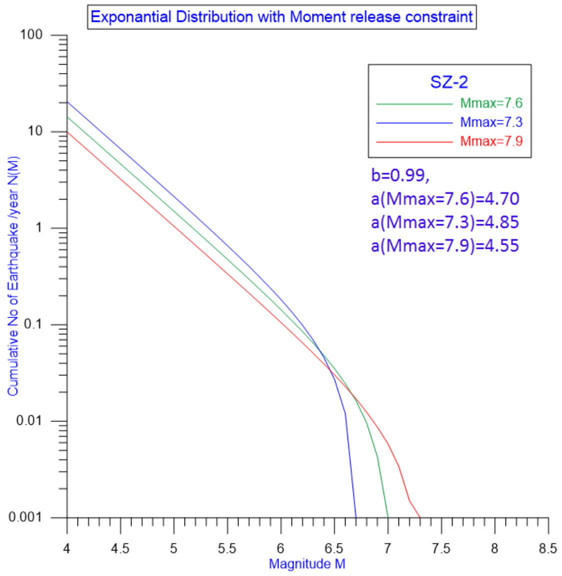
Table 8: ANNUAL OCCURANCE RATE USING SEISMIC MOMENT RELEASE *CONSTRAINT*

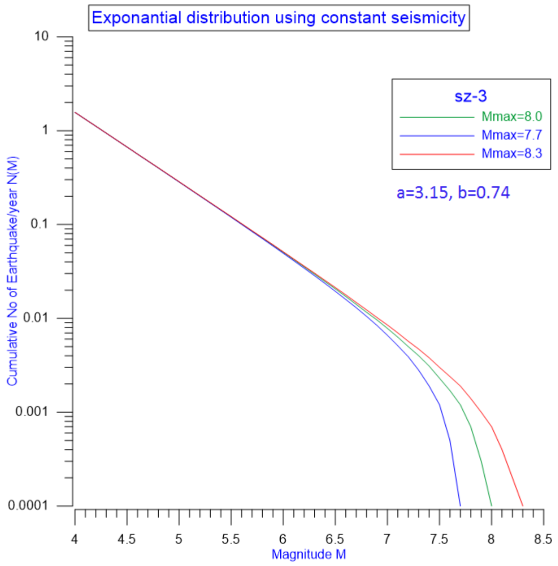
Source	Occurrence rate using constant seismicity N(Mmin)	Occurrence rate using Moment release		
		N(Mmin) for M=Mmax	N(Mmin) for M=Mmax -0.3	N(Mmin) for M=Mmax +0.3
SZ-1	2.275	-	-	-
SZ-2	1.495	5.923	8.4	4.179
SZ-3	1.570	2.718	4.6	1.607
SZ-4	5.601	14.278	20.5	9.946
SZ-5	6.528	19.570	27.1	14.109
SZ-6	2.453	7.814	11.6	5.259
SZ-7	1.023	3.439	5.4	2.181
SZ-8	4.026	7.140	10.9	4.677
SZ-9	1.940	5.317	8.6	3.283
SZ-10	1.055	-	-	-
SZ-11	1.345	-	-	-

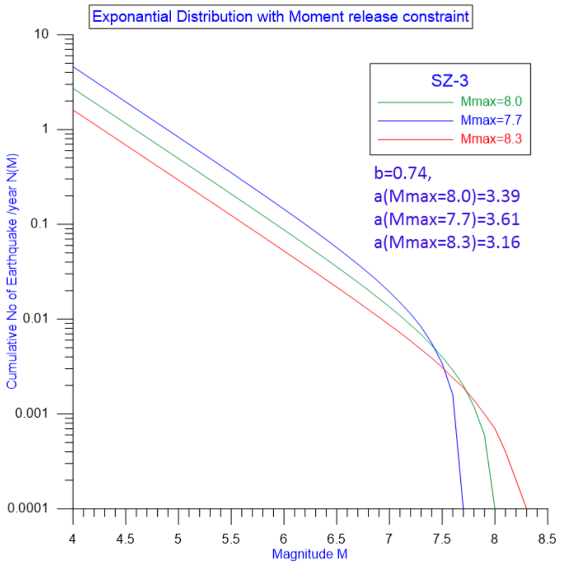
4.8 GRAPHICAL REPRESENTATION OF OCCURANCE RATE

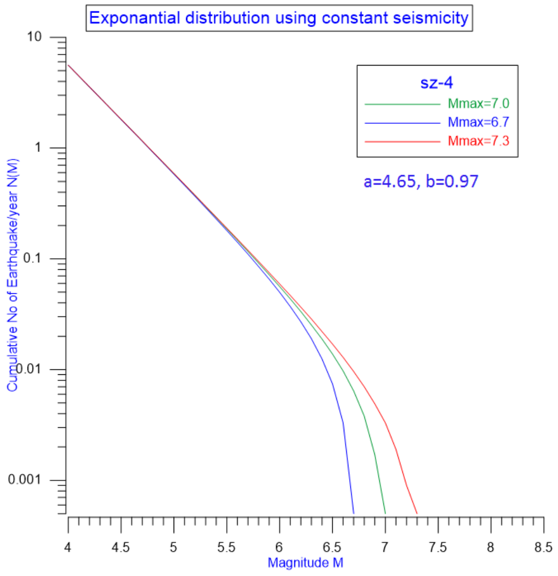


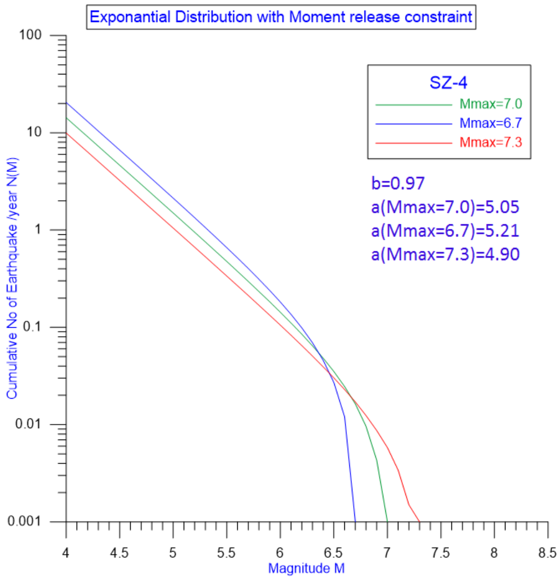


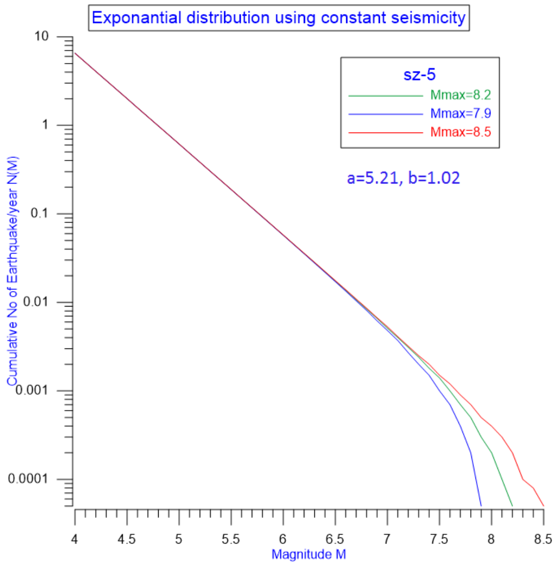


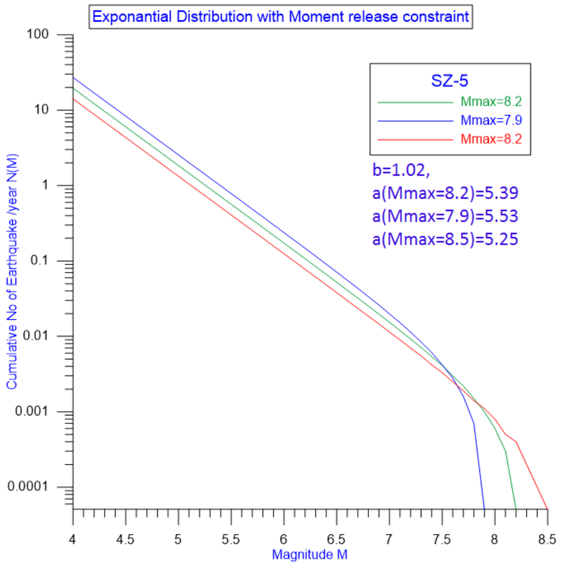


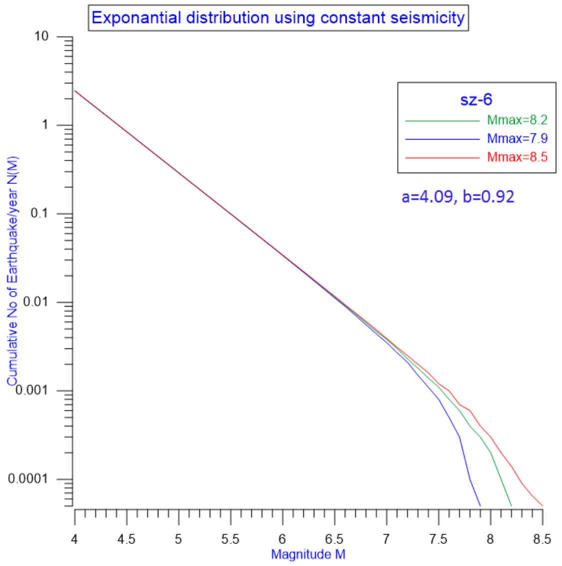


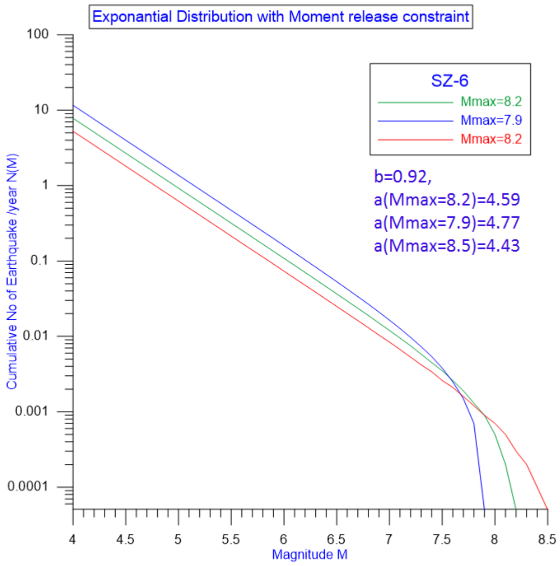

Exponantial distribution using constant seismicity
sz-4
Mmax=7.0
Mmax=6.7
Mmax=7.3
a=4.65, b=0.97
10
1
0.1
0.01
0.001
Cumulative No of Earthquake/year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

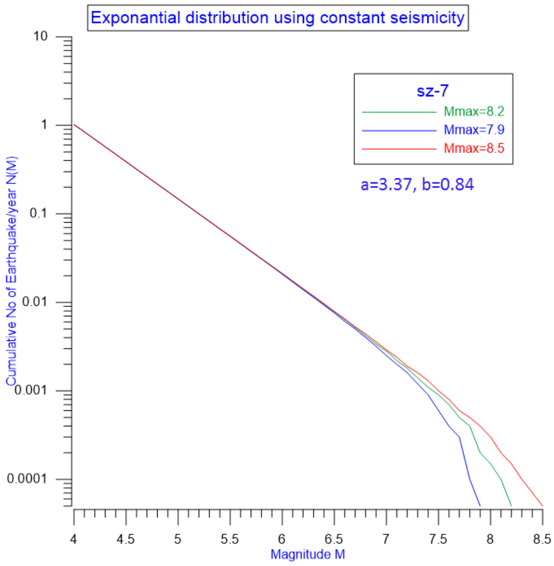

Exponantial Distribution with Moment release constraint
SZ-4
Mmax=7.0
Mmax=6.7
Mmax=7.3
b=0.97
a(Mmax=7.0)=5.05
a(Mmax=6.7)=5.21
a(Mmax=7.3)=4.90
100
10
1
0.1
0.01
0.001
Cumulative No of Earthquake /year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

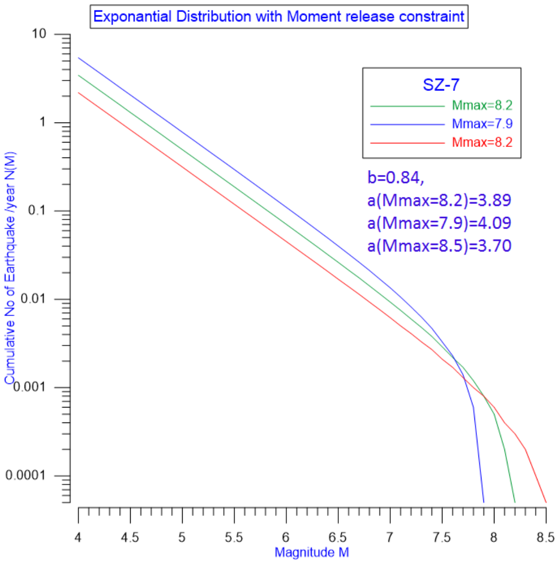

Exponantial distribution using constant seismicity
sz-5
Mmax=8.2
Mmax=7.9
Mmax=8.5
a=5.21, b=1.02
10
1
0.1
0.01
0.001
0.0001
Cumulative No of Earthquake/year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

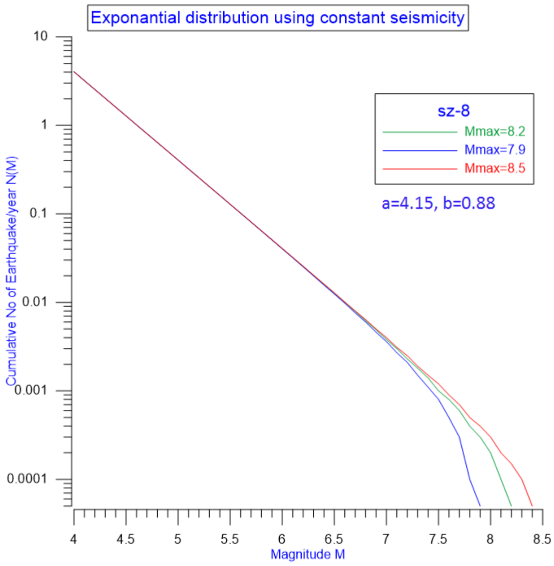

Exponantial Distribution with Moment release constraint
SZ-5
Mmax=8.2
Mmax=7.9
Mmax=8.2
b=1.02,
a(Mmax=8.2)=5.39
a(Mmax=7.9)=5.53
a(Mmax=8.5)=5.25
100
10
1
0.1
0.01
0.001
0.0001
Cumulative No of Earthquake /year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

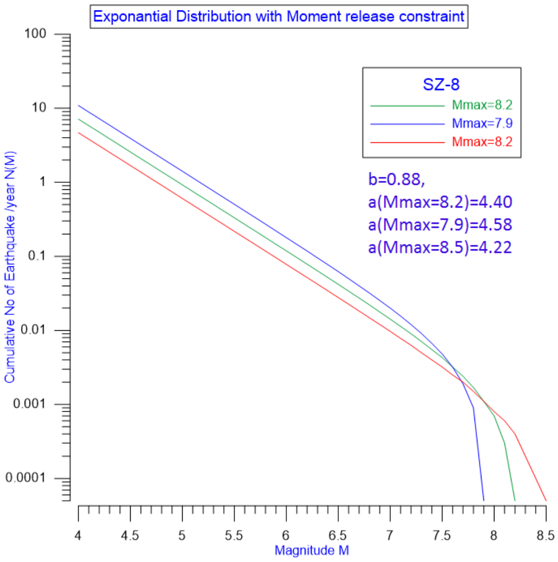

Exponantial distribution using constant seismicity
sz-6
Mmax=8.2
Mmax=7.9
Mmax=8.5
a=4.09, b=0.92
10
1
0.1
0.01
0.001
0.0001
Cumulative No of Earthquake/year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

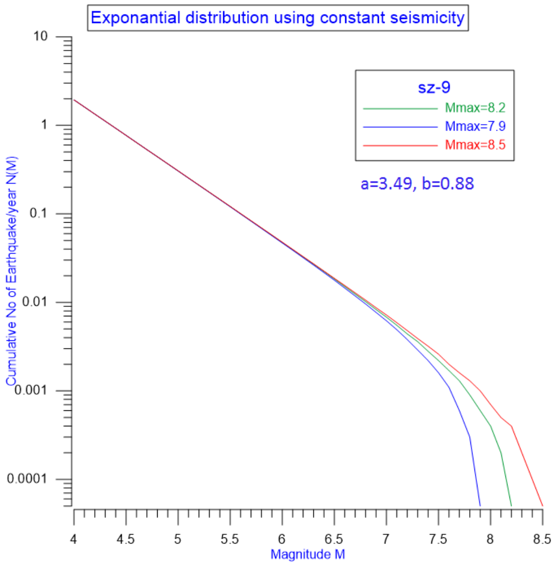

Exponantial Distribution with Moment release constraint
SZ-6
Mmax=8.2
Mmax=7.9
Mmax=8.2
b=0.92,
a(Mmax=8.2)=4.59
a(Mmax=7.9)=4.77
a(Mmax=8.5)=4.43
100
10
1
0.1
0.01
0.001
0.0001
Cumulative No of Earthquake /year N(M)
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

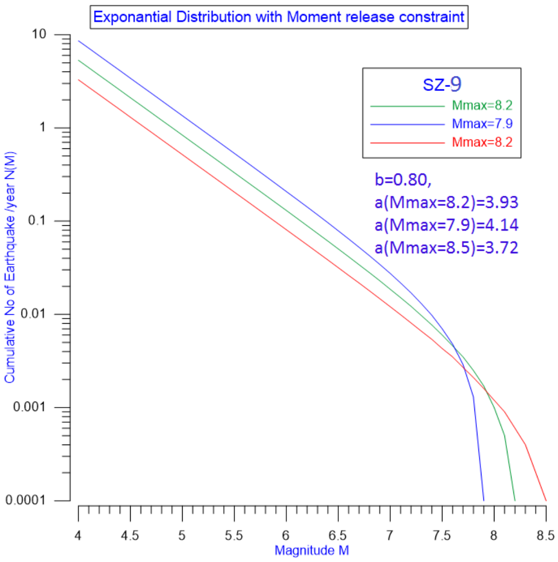

Exponantial distribution using constant seismicity
sz-7
Mmax=8.2
Mmax=7.9
Mmax=8.5
a=3.37, b=0.84
Cumulative No of Earthquake/year N(M)
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M


Exponantial Distribution with Moment release constraint
SZ-7
Mmax=8.2
Mmax=7.9
Mmax=8.2
b=0.84,
a(Mmax=8.2)=3.89
a(Mmax=7.9)=4.09
a(Mmax=8.5)=3.70
Cumulative No of Earthquake /year N(M)
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M


Exponantial distribution using constant seismicity
sz-8
Mmax=8.2
Mmax=7.9
Mmax=8.5
a=4.15, b=0.88
Cumulative No of Earthquake/year N(M)
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M


Exponantial Distribution with Moment release constraint
SZ-8
Mmax=8.2
Mmax=7.9
Mmax=8.2
b=0.88,
a(Mmax=8.2)=4.40
a(Mmax=7.9)=4.58
a(Mmax=8.5)=4.22
Cumulative No of Earthquake /year N(M)
100
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M


Exponantial distribution using constant seismicity
sz-9
Mmax=8.2
Mmax=7.9
Mmax=8.5
a=3.49, b=0.88
Cumulative No of Earthquake/year N(M)
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M


Exponantial Distribution with Moment release constraint
SZ-9
Mmax=8.2
Mmax=7.9
Mmax=8.2
b=0.80,
a(Mmax=8.2)=3.93
a(Mmax=7.9)=4.14
a(Mmax=8.5)=3.72
Cumulative No of Earthquake /year N(M)
10
1
0.1
0.01
0.001
0.0001
4
4.5
5
5.5
6
6.5
7
7.5
8
8.5
Magnitude M

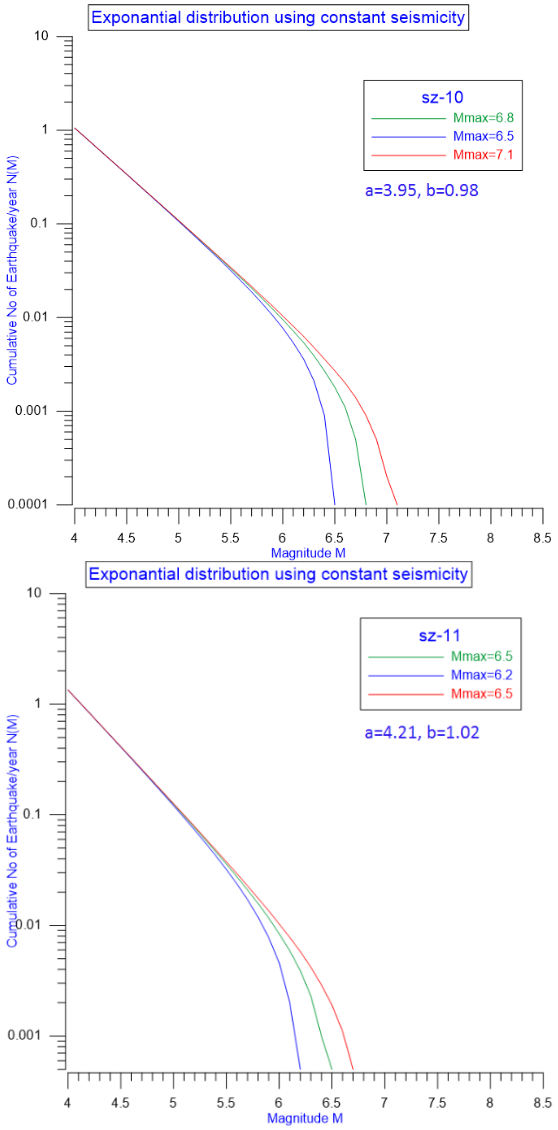


Figure 5: Comparison of exponential recurrence model with constant seismicity (left) and constant seismic moment release constraints (right).

CHAPTER 5

HAZARD ESTIMATION

5.1 INTRODUCTION

Seismic hazard can be represented in different ways but most frequently in terms of probability distributions of acceleration velocity, or Displacements of either bedrock or the ground surface. For the estimation of the maximum expected effects of earthquake on the Earth's surface estimation of seismic hazard is necessary. For the quantitative estimation of hazard at different sites we have to first define the occurrence rate and attenuation relations associated to the sites. Zoning maps can then be prepared by contouring the hazard values at all the sites. Using the recurrence relations developed in the previous chapter and by selecting a suitable attenuation relationship, zoning Maps in terms of PGA are prepared for Uttarakhand state. Constant occurrence rate and constant moment release rate are used for this purpose

5.2 COMPUTATION OF OCCURANCE RATE υ $\left(\boldsymbol{M_j}\,,\boldsymbol{R_i}\right)$

In the previous Chapter we have defined the recurrence relationship for the 11 seismic sources which can be used to get the annual occurrence rate N(M) in different magnitude bins $(M_j - \delta M_j,\ M_j + \delta M_j)$ between minimum and maximum magnitude $M_{min}\ and\ M_{max}$. For the estimation of occurrence rate of magnitude M_j at a site at distance R_i, the entire source zone is divided into large no of locations for earthquake occurrence and the number $N(M_j)$ is divided equally among all the locations. The distance from a selected site is then estimated from all the locations in the source zone to get the occurrence rate υ $\left(M_j\,,R_i\right)$. The occurrence rate υ $\left(M_j\,,R_i\right)$ are estimated for 498 sites in which the entire Uttarakhand state is discretized with 0.2°×0.2° grid. This occurrence rate is further used in estimating the Hazard.

5.3 ATTENUATION RELATIONSHIP

In addition to the occurrence rates υ $\left(M_j\,,R_i\right)$, the computation of hazard needs to define the probability $q(Z > z|M_j\,,R_i)$ of exceeding value z of ground motion parameter Z (say PGA) due to each pair $(M_j \,, R_i)$ of magnitude and distance. This probability is commonly estimated using a Gaussian distribution for the logarithm of z with the mean value and standard deviation obtained for $(M_j \,, R_i)$ pair using a suitable ground motion attenuation relationship. Various attenuation relationships are given in literature for different source-site characteristics and geologic conditions. An attenuation model given by Abrahamson and Silva, 1997 has been used to determine Peak Ground Acceleration (PGA) for shallow crustal earthquake. The basic form of attenuation is given as:

$$\ln Sa(g) = F_1\left(M, R_{rup}\right) + F * F_3(M) + HW * F_4(M, R_{rup}) + S * F_5(PGA_{rock}) \quad (18)$$

Where $Sa(g)$ is the spectral acceleration in g, M is the magnitude and R_{rup} is the closest rupture distances to the rupture plane in km. F is the fault type (1 for reverse fault, 0.5 for reverse or oblique fault, 0 for otherwise), HW is the hanging wall factor (1 for the site on hanging wall, 0 for otherwise), and S is the variable for site (1 for deep soil, 0 for rock or shallow soil). The $Sa(g)$ for period of 0.01s has been taken as the PGA value

The function $F_1\left(M, R_{rup}\right)$ is the basic form of attenuation for strike slip event at rock site. It can be express as

$$F_1\left(M, R_{rup}\right) = \begin{cases} a_1 + a_2(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]lnR \,, & for\; M \le c_1 \\ a_1 + a_4(M - c_1) + a_{12}(8.5 - M)^n + [a_3 + a_{13}(M - c_1)]lnR \,, & for\; M \ge c_1 \end{cases} \quad (19)$$

Where $R = \sqrt{{R_{rup}}^2 + {C_4}^2}$

The function $F_3(M)$ for type of faulting is used in the following form

$$F_3(M) = \begin{cases} a_5 & for\; M < 5.8 \\ a_5 + \dfrac{a_6 - a_5}{c_1 - 5.8} & for\; 5.8 < M < c_1 \\ a_6 & for\; M > c_1 \end{cases} \quad 20$$

The magnitude and distance dependence form $F_4(M, R_{rup})$ for the hanging wall effect is defined as:

$$F_4\left(M, R_{rup}\right) = f_{HW}(M) \times f_{HW}(R_{rup}) \quad (21)$$

Where

$$f_{HW}(M) = \begin{cases} 0 & for\ M \leq 5.5 \\ M - 5.5 & for\ 5.5 < M < 6.5 \\ 1 & forM \geq 6.5 \end{cases} \quad (22)$$

And

$$f_{HW}(R_{rup}) = \begin{cases} 0 & for\ \ R_{rup} < 4 \\ a_9 \dfrac{R_{rup} - 4}{4} & for\ 4 < R_{rup} < 8 \\ a_9 & for\ 8 < R_{rup} < 18 \\ a_9 \left(1 - \dfrac{R_{rup} - 18}{7}\right) & for\ 18 < R_{rup} < 24 \\ 0 & for\ R_{rup} > 24 \end{cases} \quad (23)$$

The function $F_5(PGA_{rock})$ for the nonlinear rock soil is modelled by

$$F_5(PGA_{rock}) = a_{10} + a_{11}\ln(PGA_{rock} + c_5) \quad (24)$$

Where PGA_{rock} is the expected peak acceleration on rock in g. The standard error is defined in terms of magnitude and is modelled as follows:

$$\sigma(M) = \begin{cases} b_5 & for\ \ \ M \leq 5 \\ b_5 - b_6(M - 5) & for\ 5 < M > 7 \\ b_5 - 2b_6 & for\ \ \ M \geq 7 \end{cases} \quad (25)$$

The various coefficients for the estimation of PGA are taken for 0.01 sec period which are C_1 =6.4, C_4=5.6, a_1=1.64, a_2=0.512, a_3=-1.145, a_4 =-0.144, a_5=0.610, a_6=0.260, a_9=0.370, a_{10}=-0.417, a_{11}=-0.230, a_{12}=0, a_{13}=0.17, b_5=0.7, b_6=0.135.

5.4 ESTIMATION AND REPRESENTATION OF SEISMIC HAZARD

In the seismic hazard analysis we have estimated the peak ground acceleration (PGA) at a closely spaced grid of sites covering an Uttarakhand state. These PGA values are used to draw hazard zoning map in the form of contour. The hazard zoning maps are prepared for 90% and 98% probability of not occurrence (10% and 2% probability of exceeding) in next 50 years. For the quantitative estimation of the hazard attenuation relation is used for finding out the probability $q(Z > z|M_j\ , R_i)$ using log normal distribution with mean and standard deviation for all magnitude M_j and at distance R_i obtained from equation (18) and (19) respectively. The occurrence rate for desire probability of exceeding the PGA>z is determine by the summation of all recurrence rate υ $(M_j\ , R_i)$ multiplied with their individual probability $q(Z > z|M_j\ , R_i)$ over the j magnitude range and i distances for each magnitude. For the computation purpose the parameters a, b, $M_{\max}$, $N(M_{min})$ and attenuation models are used for input in the programme developed by Dr. I.D. Gupta and PGA is estimated by using attenuation model (Abrahamson and Silva, 1997). PGA ordinates are calculated for 475 and 2475 year return period.

The estimated PGA values are used in SURFER programme to draw hazard zoning maps. Hazard map has been drawn for both the constant seismicity and seismic moment release constraint models for different $M_{\max}$ values.

5.5 RESULTS AND DISCUSSION

For the estimation of hazard (PGA) the Kumaun-Gargwal is divided into 498 small grids of size 0.2°×0.2° (Figure : 6). PGA has been estimated at the centre point of all the grid for 90% and 98% probability of not occurrence in 50 years (return period of 475 years and 2475 years). The resulting PGA distribution of Kumaun Garhwal Himalaya is shown in contour Maps (Figure 7-12) considering constant seismicity (case-I) and using moment release constraints (case-2) for different values of $M_{\max}$.

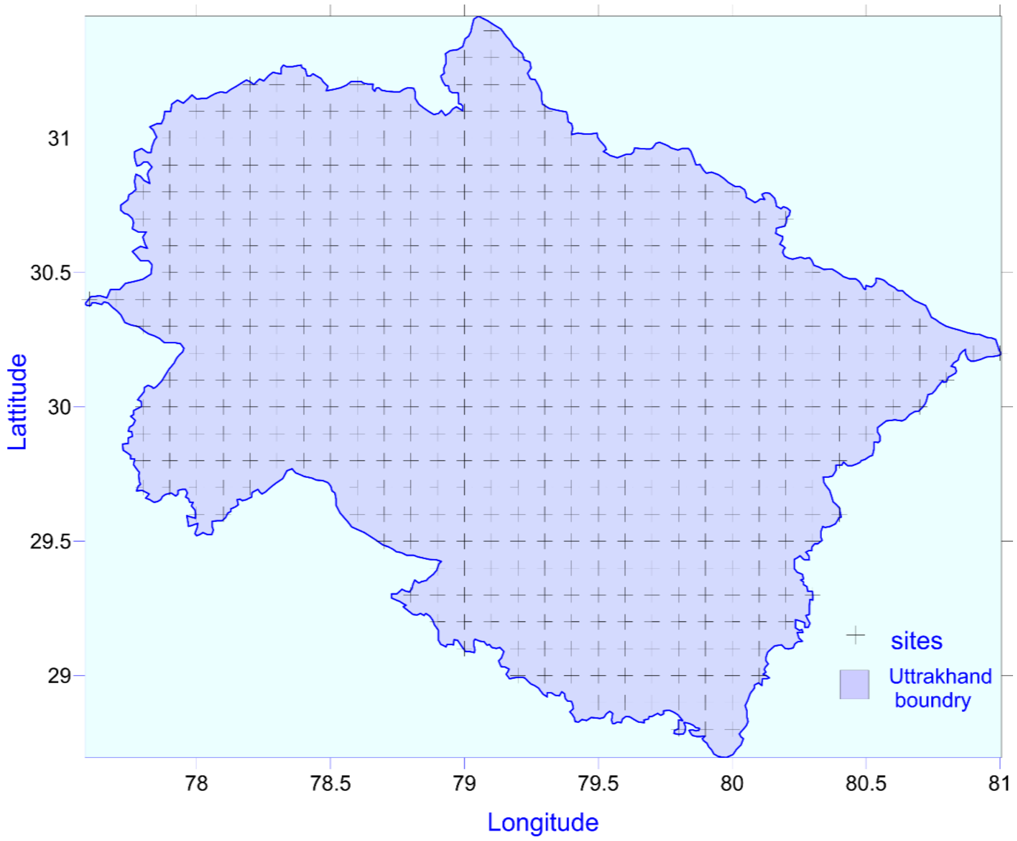


Figure 6: "The State Boundary of Uttarakhand and 498 boundary made inside it for seismic Hazard analysis"

5.5.1 CASE-I (Hazard using ‘Constant seismicity’)

For the return period of 475 years and 2475 years, the study has been carried out for three different $M_{\max}$ taken as the expected value for each source zone given in table and by lowering and raising it by 0.3 magnitude unit. For the return period 475 PGA in the major part of kumaun and Garhwal of Uttarkashi and chamoli district lies between 0.27 to 0.3g (for magnitude $M_{\max}$), 0.26 to 0.3g (for magnitude $M_{\max}$ -0.3), 0.28 to 0.32g (for magnitude $M_{\max}$ +0.3) and for the return period of 2475 years these PGA values lies between, 0.45g to 0.5g, 0.43g to 0.48g, 0.47g to 0.52g for their respective$M_{\max}$. The area of northeast attached to Tibet have high PGA value while southern region have less hazard level. In general, for the Kumaun and Garhwal Himalaya, PGA varies from 0.1 to 0.45 g for 475 years return period while for the return period 2475 years PGA varies between 0.2 to 0.72 g corresponding to all $M_{\max}$.

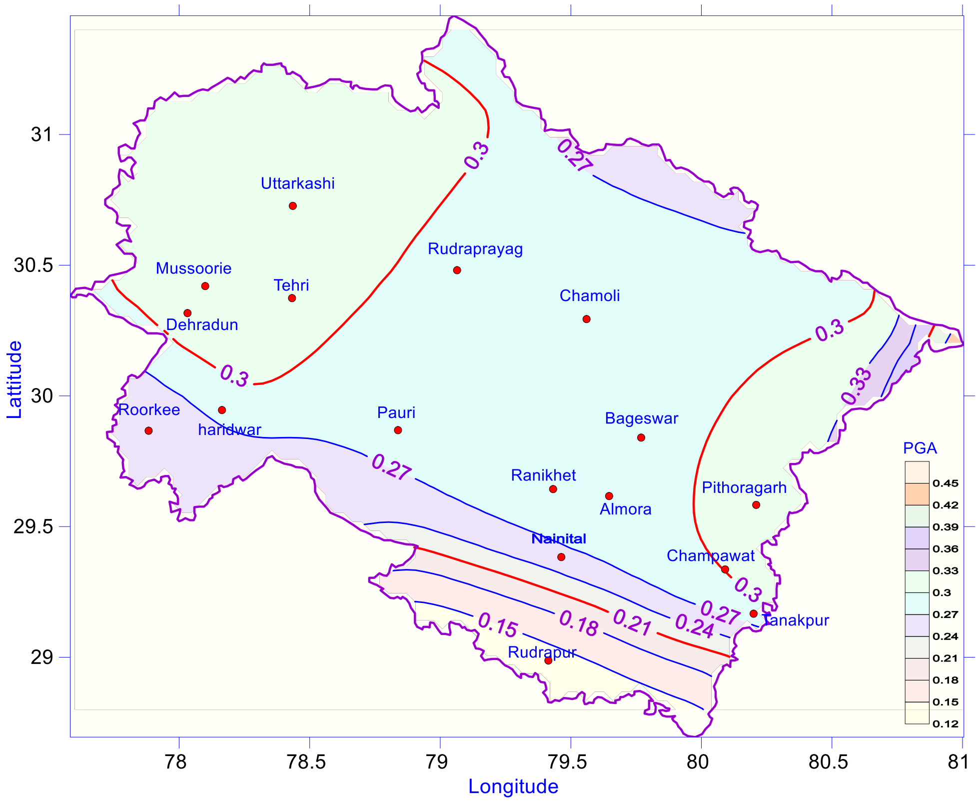
5.5.2 CASE 2 (Hazard Using ‘Seismic Moment Release Constraint’)

Considering ‘seismic moment release constraint’, it is found that PGA varies between 0.39 to 0.44g, 0.44 to 0.49g, 0.34 to 0.38g in major parts of Kumaun and Garhwal Himalaya for return period of 475 years and corresponding selected three $M_{\max}$ respectively. However for the return period 2475 years these values found to be 0.60 to 0.66g, 0.68 to 0.76g and 0.54 to 0.6g. In general PGA varies 0.14 to 0.54g for 475 years return period while for the return period 2475 years PGA varies between 0.2 to 0.84g corresponding all selected $M_{\max}$. The PGA value for different Parts of Kumaun and Garhwal are given Table: 9

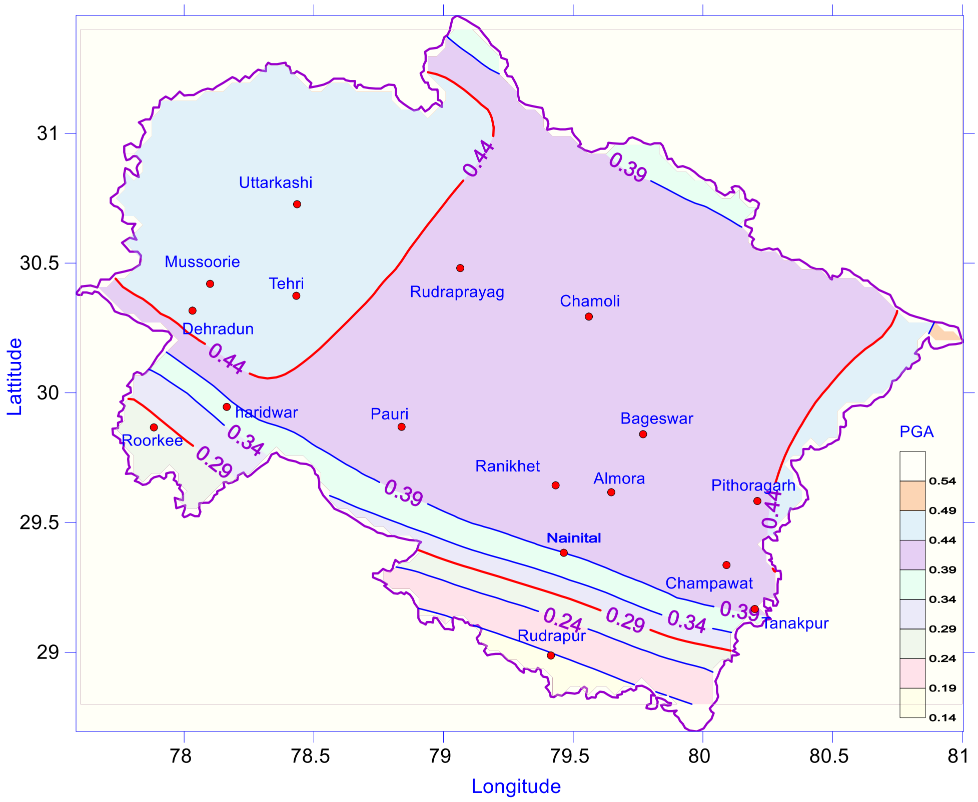
Table 9: IMPORTANT PGA VALUES

Maximum Magnitude/ Return period	Used Model	PGA in terms of g				
		North	West	South	East	Central region
$M_{\max}$ 475 years	constant seismicity	0.24-0.27	0.30-0.33	0.12-0.24	0.30-0.45	0.27-0.30
	moment release	0.34-0.39	0.44-0.49	0.14-0.34	0.44-0.54	0.39-0.44
$M_{\max}$ 2475 years	constant seismicity	0.4-0.45	0.50-0.55	0.20-0.40	0.50-0.70	0.45-0.50
	moment release	0.54-0.6	0.66-0.72	0.24-0.54	0.66-0.78	0.60-0.66
$M_{\max}$-0.3 475 years	constant seismicity	0.22-o.26	0.30-0.34	0.10-0.22	0.30-0.42	0.26-0.30
	moment release	0.39-0.44	0.49-0.54	0.14-0.39	0.49-0.59	0.44-0.49
$M_{\max}$-0.3 2475 years	constant seismicity	0.43-0.48	0.48-0.53	0.18-0.38	0.48-0.68	0.43-0.48
	moment release	0.6-0.68	0.76-0.84	0.20-0.60	0.76-0.84	0.68-0.76
$M_{\max}$ +0.3 475 years	constant seismicity	0.24-0.28	0.32-0.36	0.12-0.24	0.32-0.44	0.28-0.32
	moment release	0.3-0.34	0.38-0.42	0.14-0.30	0.38-0.42	0.34-0.38
$M_{\max}$ +0.3 2475 years	constant seismicity	0.42-0.47	0.52-0.57	0.22-0.42	0.52-0.72	0.47-0.52
	moment release	0.48-0.54	0.60-0.66	0.24-0.48	0.60-0.72	0.54-0.60

It has been observed that the value of PGA obtained from Seismic Moment Release Constraint method are higher than the PGA from constant seismicity. One more important point is that for the constant seismicity as the $M_{\max}$ increases the PGA value increases but for the moment release constraint method as the $M_{\max}$ increases the PGA values decreases. This unexpected behaviour is due to decrease in the number of lower magnitude earthquakes with increase in the value of $M_{\max}$. It is also seen that the PGA of the southern part of Kumaun Garhwal have less destructive potential while the eastern part adjoining to Nepal have the high seismicity and high PGA value.

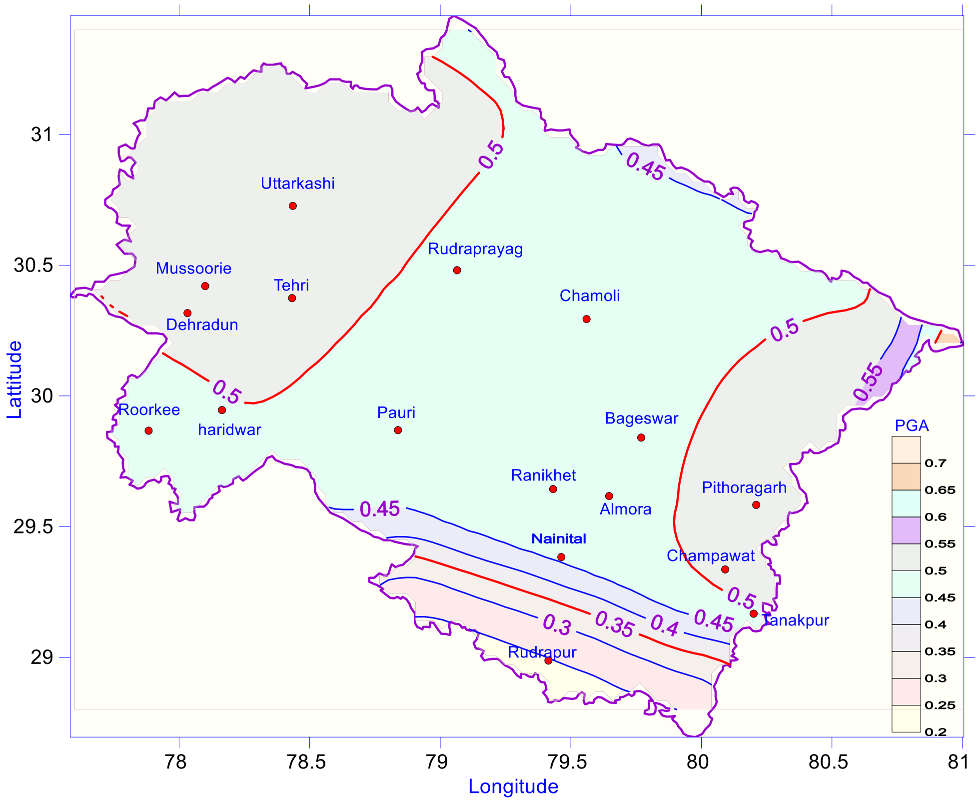


Constant seismicity (a)

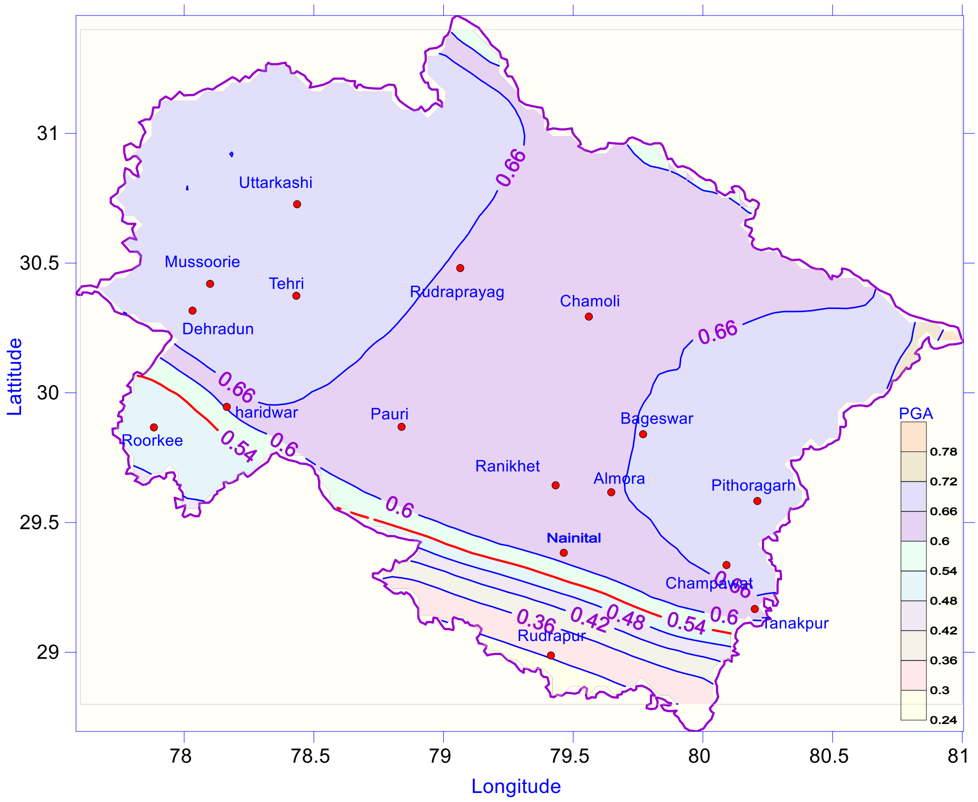


PGA using Seismic Moment Release Constraint (b)

Figure 7: “Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 475 years Return Period for selected magnitude $M_{\max}$”

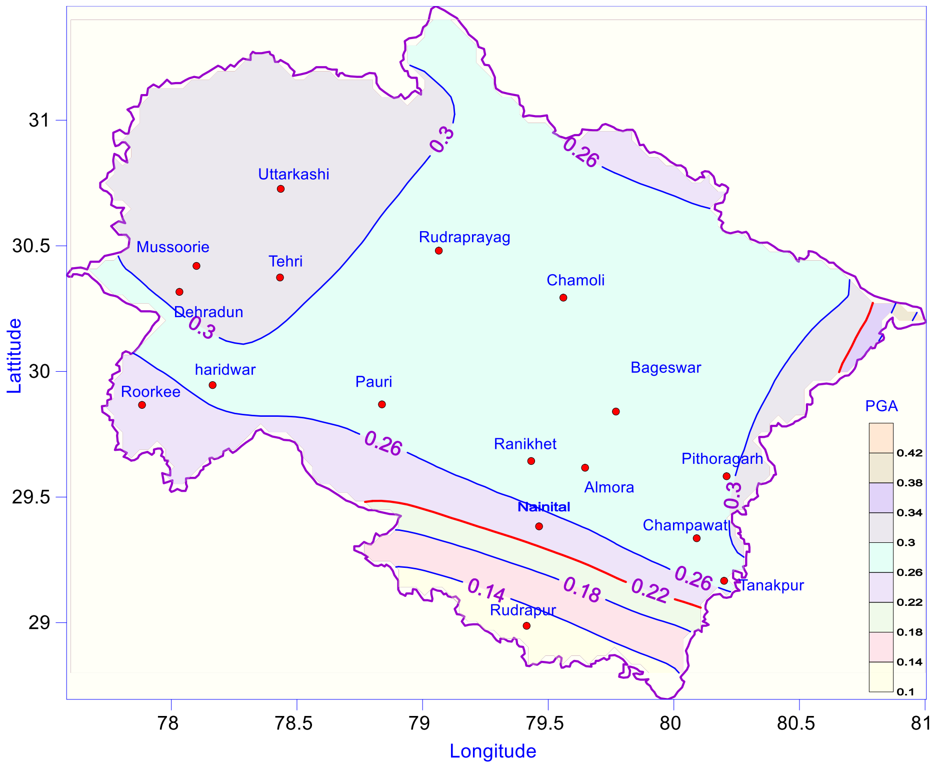


Constant seismicity (a)

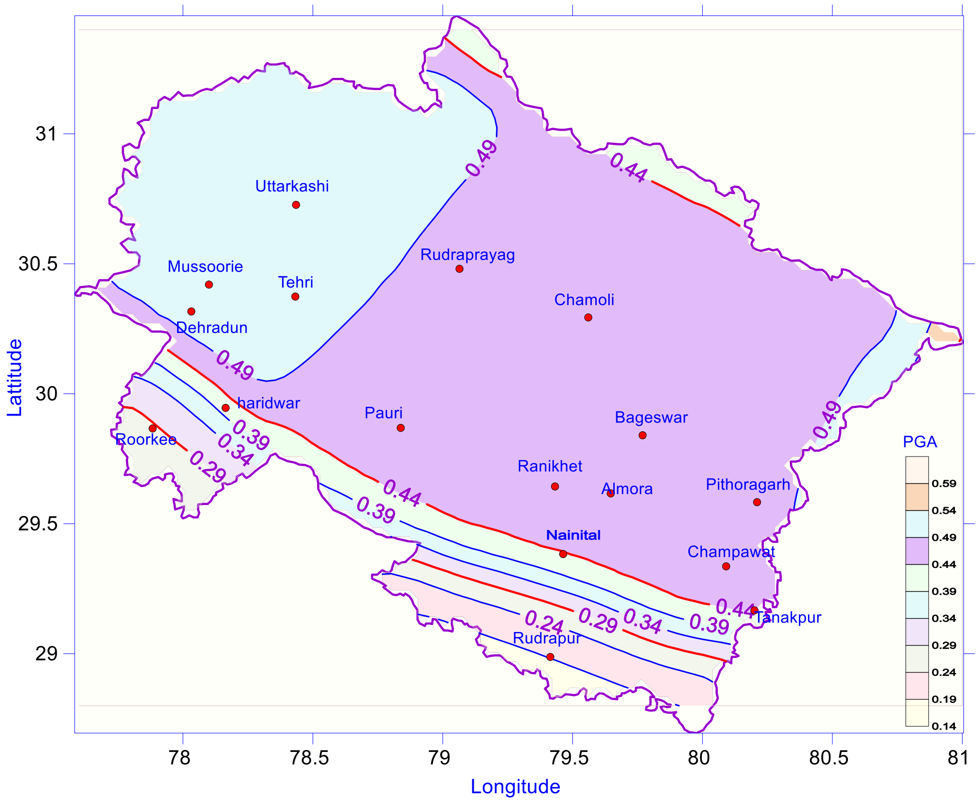


PGA using Seismic Moment Release Constraint (b)

Figure 8: “Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 2475 years Return Period for selected magnitude M_{max}”

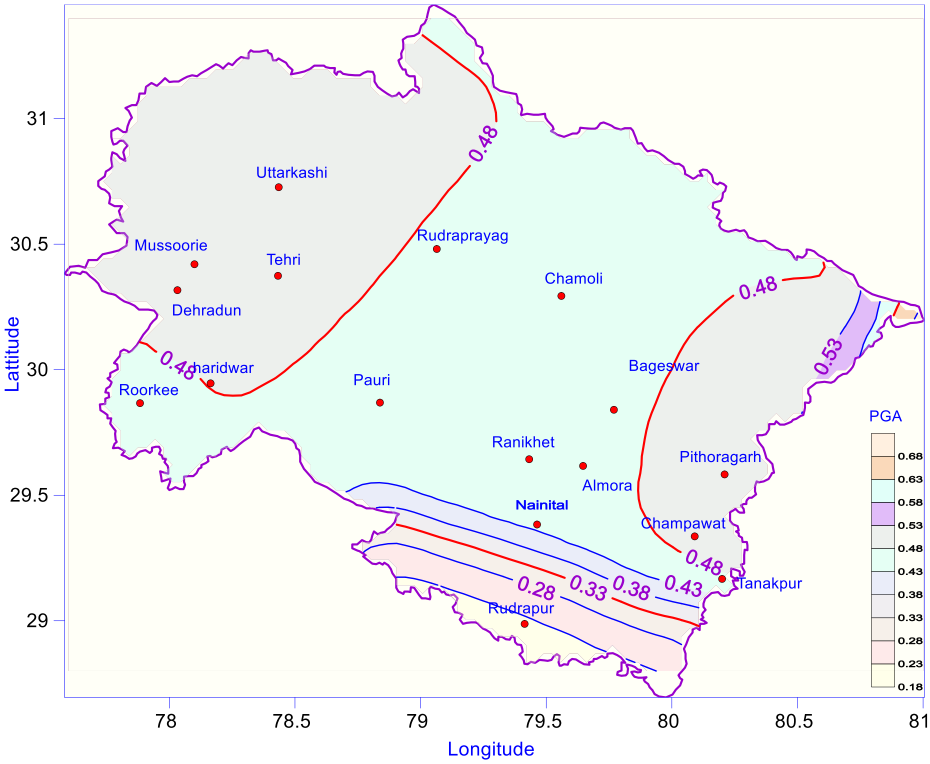


Constant seismicity (a)

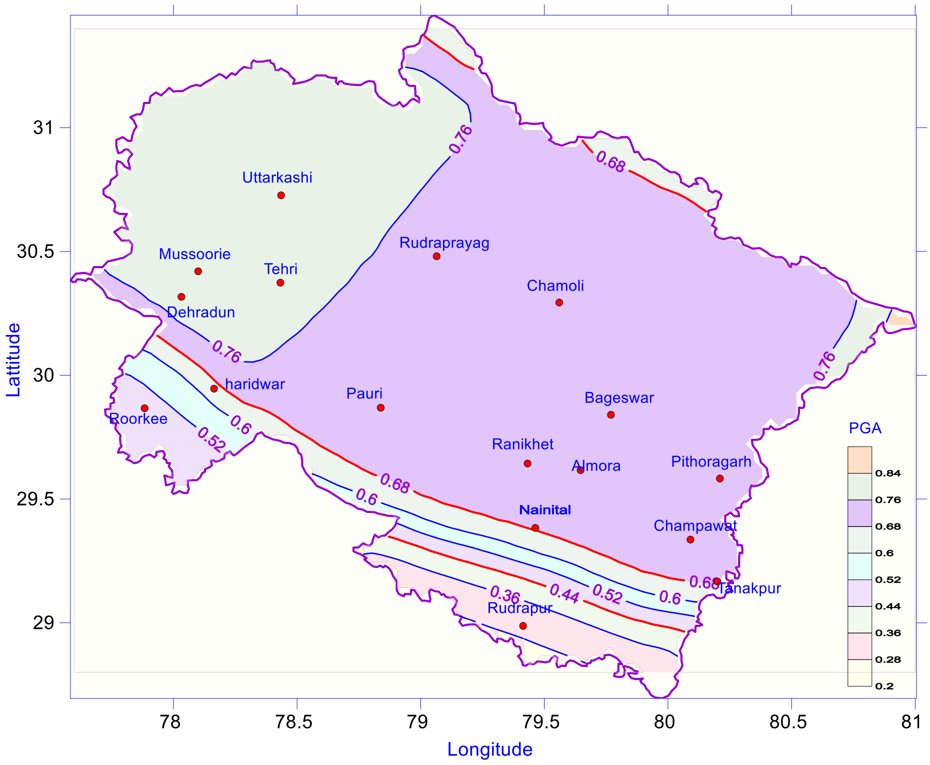


PGA using Seismic Moment Release Constraint (b)

Figure 9: "Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 475 years Return Period for magnitude M_{max} - 0.3"

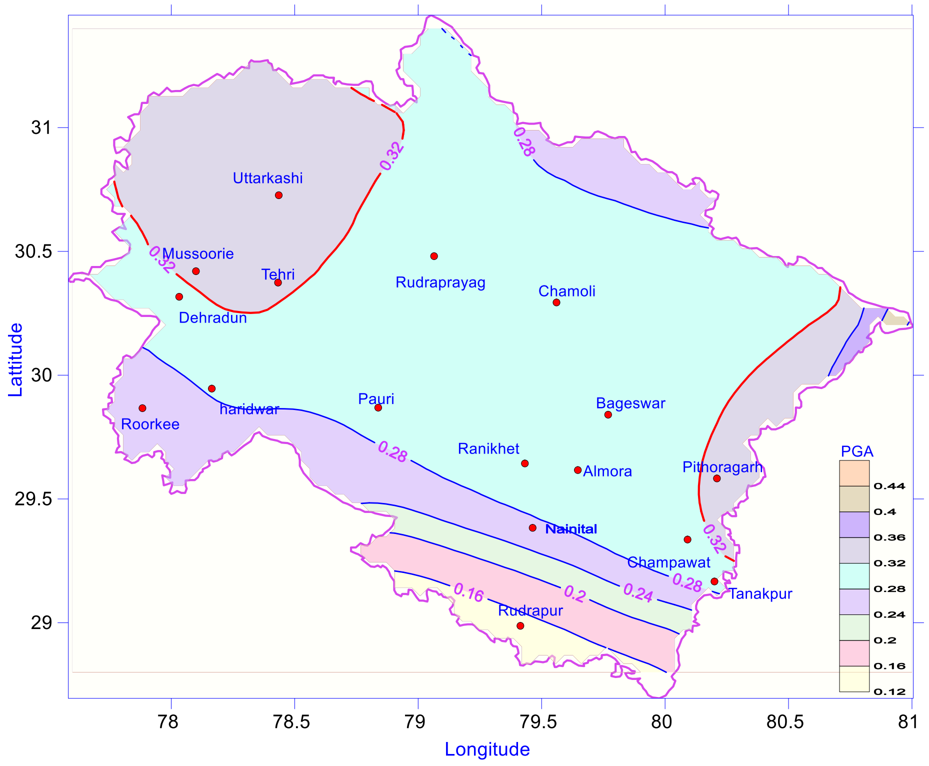


Constant seismicity (a)

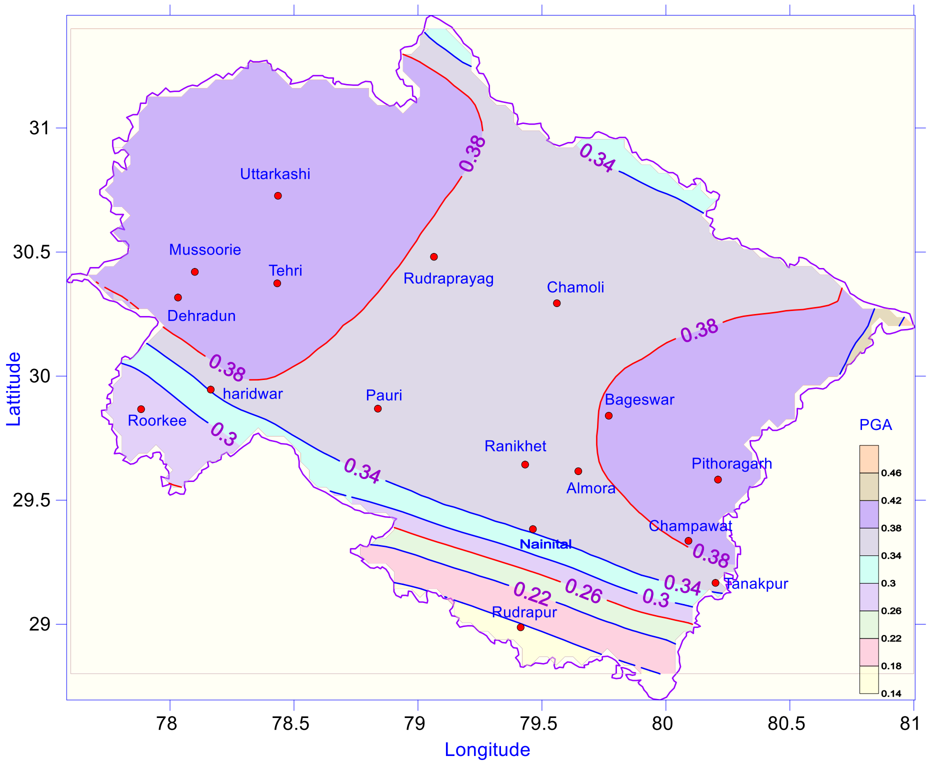


PGA using Seismic Moment Release Constraint (b)

Figure 10: “Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 2475 years Return Period for magnitude $M_{max} - 0.3$”

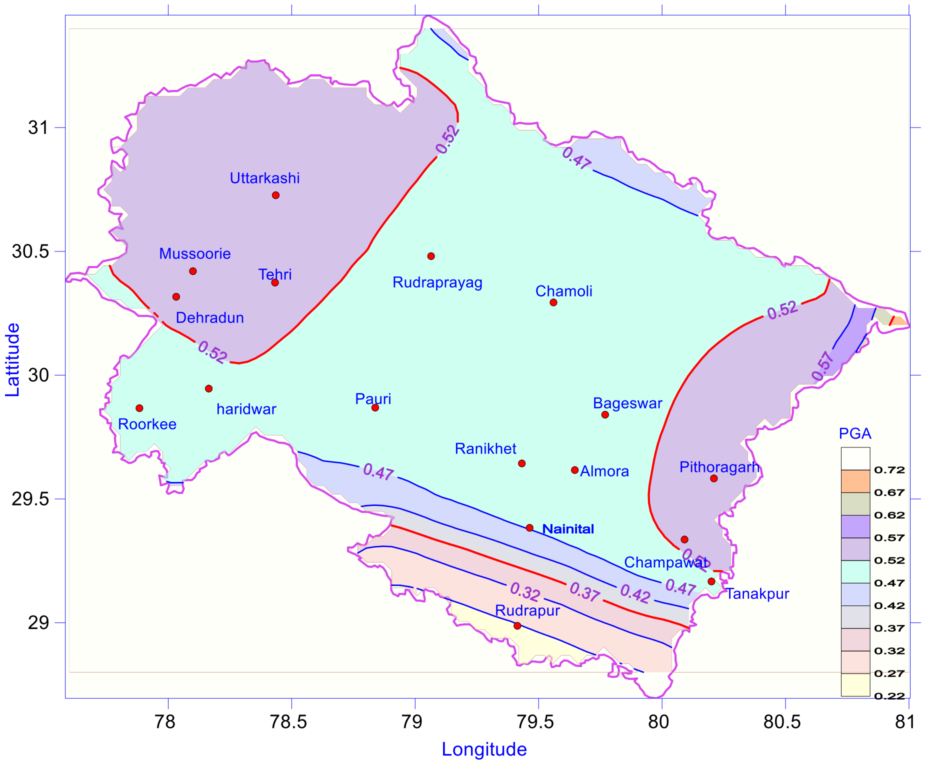


Constant seismicity (a)

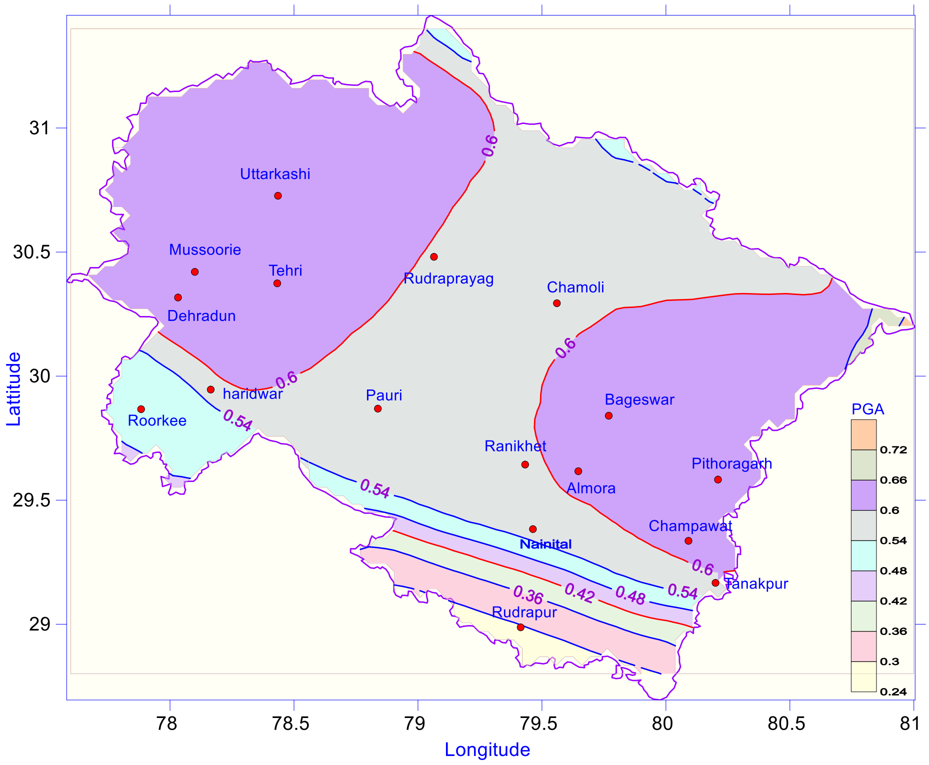


PGA using Seismic Moment Release Constraint (b)

Figure 11: Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 475 years Return Period for magnitude $M_{max} + 0.3$



Constant seismicity (a)



PGA using Seismic Moment Release Constraint (b)

Figure 12: “Comparison between PGA value from constant seismicity (a), and Seismic moment release Constraint (b) for 2475 years Return Period for magnitude M_{max} + 0.3”

CHAPTER 6

SUMMERY AND CONCLUSION

In the study of Kumaun and Garhwal Himalaya, Probabilistic Seismic Hazard Analysis (PSHA) method is used to estimate the PGA using the constant seismicity and Seismic Moment release constraint by the analysis on the earthquake catalogue and slip rates data. The current literature on PSHA approach are used to prepare the hazard zoning maps for ground motion parameter PGA. The hazard has been estimated for the 90% and 98% probability of not occurrence (475 year and 2475 year return period) in exposure period 50 year.

The value of PGA, obtained from the constant seismicity varies between 0.1 to 0.45g for 475 year return period and 0.2 to 0.72g for the 2475 year return period. These PGA values is increases with increase in the upper bound magnitude $M_{\max}$while these PGA values lies between 0.15 to 0.54g for 475 year return period and 0.2 to 0.84g for 2475 year return period with Constant Seismic Moment Release Constraint and this peak ground acceleration decreases with increase in the maximum magnitude $M_{\max}$.

The hazard maps indicates that the ground motion pattern remains same for the method constant seismicity as well as moment release constraint but the values of PGA from constant seismicity are less as comparable to obtain from seismic moment release constraint. The distribution of PGA also reflect that the region along the MCT and MFT have the more seismicity while in the direction of north and south of these range the PGA values are decrease.

The hazard (PGA) obtain from the constant seismicity is similar to the past recorded ground motion at various site but the hazard obtain from the Seismic Moment release method is very high that reflect the greater seismicity which may release in future.

To explain the application of PSHA method the hazard map has been prepared for different maximum magnitude $M_{\max}$and for different confidence level. These maps are able to exhibit the effect of the special distribution of seismicity in a realistic way. Various hazard maps, presented in this study have the practical application to estimate the earthquake effect on structures.

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