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Varying Rate Of Occurrence Of Earthquakes In India And Its Implication On Probabilities Of Occurrence

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Abstract: The current research revisits India's seismicity with the goal of investigating the return times of different magnitudes in distinct seismogenic zones in India. India is divided into 24 zones for this reason. The investigation took into account seismicity from prior times until 2020. The Gutenberg Richter magnitude frequency relationship was used to estimate the return times of earthquakes in specific zones. The GRT connection has been computed using several methods that take epistemic uncertainty into account. The a and b parameters are between 1.47 and 7.05 and 0.54 and 1.17, respectively. Zones 17 and 11 have the shortest return periods, indicating strong seismic activity. However, the zones 6 and 12 shows the highest return periods for magnitude 8 which shows that the great magnitude has lowest probability of occurrence in these zones. From earthquake engineering point of view the probabilities of occurrence in next 100, 225, 475, 2475, 50000 and 10000 years have been estimated. The probabilities have been calculated based on the assumptions that the earthquake occurrence follows Poisssonian distribution. It has been observed that the lowest probabilities for 100, 225, 475, 2475, 5000 and 10000 is reported in zones 17. Similarly, the highest probabilities for the return periods 100, 225, 475, 2475, 5000 and 10000 are reported in zones 24. The results are very useful for seismic hazard assessment for the regions.

Keywords: Seismicity • probability • GR parameters • earthquake occurrence • return periods

Introduction

India's increasing population and extensive unscientific constructions mushrooming all over keep India at high seismic risk. During the last 15 years, the country has experienced more than 10 major earthquakes that have resulted in over 20,000 deaths with lot of economic loss. As per the current seismic zone map of the country (IS 1893: 2002), over 59 per cent of India's land area is under threat of moderate to severe seismic hazard-; that means it is prone to shaking of MSK Intensity VII and above (BMTPC, 2006). Especially, the whole Himalayan region is prone to great earthquakes of magnitude exceeding 8.0 and in a relatively short span of about 50 years, four such earthquakes have occurred: 1897 Shillong (M8.7); 1905 Kangra (M8.0); 1934 Bihar-Nepal (M8.3); and 1950 Assam-Tibet (M8.6). Scientific publications have warned of the likelihood of the occurrence of very severe earthquakes in the Himalayan region, which could adversely affect the lives of several million people in India.

When it comes to damaging earthquakes, areas of the country that are not near the Himalayas and other inter-plate borders were once thought to be relatively safe.Even yet, albeit they were less powerful than the Himalayan earthquakes, these regions have recently been hit by deadly earthquakes. The non-seismic zone was removed from the seismic zoning map as a result of revisions made in response to the Koyna earthquake in 1967.Koyna's environs were also upgraded to Seismic Zone IV, which denotes significant risk. After the Killari earthquake in 1993, the seismic zoning map underwent further revisions. The low hazard zone, or Seismic Zone I, was combined with Seismic Zone II, and some regions of the Deccan and Peninsular India were placed in Seismic Zone III, which includes regions designated as moderate hazard zone areas. According to recent study, additional locations previously identified as low danger may end up being reclassified as higher level seismic hazard, or vice versa, as knowledge of the seismic hazard of these regions grows.The country's north-eastern region continues to periodically experience moderate to large earthquakes, including the two major quakes listed above. The area has seen a number of moderate earthquakes since 1950. Every year, on average, one earthquake of a magnitude greater than 6.0 occurs in the area. Also being on an inter-plate boundary, the Andaman and Nicobar Islands frequently experience destructive earthquakes.Due to a surge in development activities brought on by urbanisation, economic expansion, and the globalisation of India's economy, the risk of earthquakes has increased. The usage of high-tech machinery and tools in manufacturing and service sectors has increased, making them more vulnerable to interruption from relatively mild ground shaking. As a result, the risk of an earthquake no longer only depends on the death toll. After an earthquake, severe financial losses that cause the local or regional economy to collapse could have long-term negative effects on the entire nation.The probability of occurrence of a specific magnitude earthquake in finite duration of time is dependent on the past seismicity with the help of Gutenberg Richter parameters. In the present study these parameters have been studies by dividing India into 24 independent seismogenic sources. The interpretations of the variation in these parameter from source to source shows the varying probabilities of earthquake occurrence and hence in turn requirement of seismic hazard assessment for each of the zone separately.

Earthquake Occurrence in India

The earthquake data sources can be categorized as instrumental for the period after establishment of the WWSSN in 1964 early instrumental from 1900 to 1964, historical for the period from 1500 to 1900 AD paleoseismic for the period before 1500. Information about some damaging earthquakes are available in historical records in the ground caused by them. Such descriptions have been later interpreted to assign approximately the location and magnitude to these events. Isoseismal maps provide a basis for estimation of location and magnitude of even for many recent earthquakes which have not been recorded adequately by instruments.

Since 1964, the USGS started processing the WWSSN data and making those available in the form of bulletins of earthquakes. At presents, the National Earthquake Information Center (NEIC), a part of the Department of the Interior, USGS , is an important agency providing world-wide earthquake data online **(www.ncedc.org/cnss/)** . It operates modern digital national and global seismographs networks through cooperative international agreements and determines the parameters of all significant earthquakes the world over. International Seismological Centre (ISC), UK is another important source of global data, which collects data from over 130 agencies world-wide and immediately makes these available online (www.isc.ac.uk). The ISC also scrutinize all the data manually and makes the reviewed data available with a log of about two years. The global Centroid Moment-Tensor (CMT) project, which began at Harvard University in 1982 and moved to Columbia University's Lamont-Doherty Earth Observatory (LDEO) in 2006, is a significant international source for data on the moment magnitude and fault plane solution.Moment tensors of earthquakes with magnitude greater than 5.0 are determined and provided online(www.globalcmt.org) with a delay of three to four months under this project.

The main source of data for earthquakes occurring in Indian and neighbouring areas is the India Meteorological Department (IMD), which is the modal agency for operation the Indian National Seismograph Network. Data on recent earthquakes recorded by the national network are available in the IMD’s official website (www.imd.gov.in). IMD has also compiled a catalogue of earthquakes in Indian region since historical times, with the historical Braid-Smith(1844), Milne (1911), DeBallore et al. (1911), Tuerner et al. (1911, 1912, 1913), Gutenberg and Richter (1954), Gutenberg (1956), Rothe (1972), etc. However, the historical part of the IMD catalogue has not been revisited to include additional data and improved estimates of earthquakes parameters (location and magnitude) reported in several recent studies. Some of these studies are due to Quittmeyer and Jacob(1979); Lee et al. (1976), Pacheco and Sykes(1992), Abe (1994), Iyengar et al. (1999), Ambraseys (2000), Ambraseys ad Jackson (2003), Ambraseys and Douglas(2004), Szelia et al. (2010), etc. GSI (2000) has published a seismotectonic atlas of India and its environs, which also lists the earthquakes for each 4° latitudes X 3° longitude sheets covering entire country.

For hazard analysis applications, it is necessary that a unified earthquakes catalogue be prepared by updating the IMD catalogue using other available sources. Also, to enrich the catalogue in lower magnitude earthquakes, it is necessary to include the data from local networks of seismographs operated from time to time in different parts of the country by various organizations, important among which are the Following:

- National Geophysical Research Institute (NGRI), Hyderabad
- Wadia Institute of Himalayan Geology (WIHG), Dehradun
- Regional Research Laboratory (RRL), Jorhat
- Institute of Seismological Research (ISR), Gandhinagar
- Maharashtra Engineering Research Institute (MERI), Nashik
- Gujarat Engineering Research Institute (GERI), Vadodara
- Bhabha Atomic Research Centre (BARC), Mumbai
- Many IITs and Universities

An early attempt to prepare a unified catalogue for Indian region is due to Bapat et al. (1983). Unified catalogue for India and neighboring regions have been recently prepared by Nath et al. (2010) and Raghukanth (2010). The lowest threshold magnitude in these catalogues is generally 4.0, catalogue with lower threshold magnitude around 2.5 to 3.0 have been prepared for the low seismicity Peninsular India by different investigators from time-to-time. Notable among these catalogue are due to Chandra (1977)., Rao and Rao (1984), Srivastava and Ramchandran (1985), Guha and Basu(1993) and Jaiswal and Sinha(2004). Preparation of a unified catalogue has to take care that no duplicate events are included an the most reliable location and magnitude is assigned when several differing values are reported in different sources. However, it is not an easy task to resolve these issues in a widely accepted manner.

Using Data from Paleoseimic Investigations

In addition to the above mentioned sources of earthquakes data, which generally spans a period of about 200 years, it is necessary that paleoseismic data be also included to extend the period of the catalogue to much beyond the historical period for the largest possible earthquakes. The recurrence period of the largest possible earthquakes. The recurrence period of the largest earthquakes in a given segment of Himalayas may range from 500 to 1000 years, whereas it may be one to two thousand years in a given part of the Peninsular India. Paleoseismic data are useful to constrain the occurrence rate of very large magnitude earthquakes to get realistic estimate of seismic hazard.

Paleoseismic investigations are able to identify the location, time and size of large (M≥6.5) pre-historical earthquakes from interpretation of geological evidences such as surface faulting, earthquake induced liquefaction and deformation features. Several such studies have been conducted in the areas of large historical earthquakes in different parts of Indi. But many more investigation in other parts of the country are required.

Sukhija et al. (1999) have found paleoseismic evidences for three large earthquakes (M>7.0) in the epicentral area of the great Shillong Plateau earthquake of 1897. Two of these are interpreted to be around 1450-1650 AD and 700-1050 AD, and the third one around 600-875 AD. Kumar et al. (2001) conducted paleoseimic investigations on the Himalayan Frontal Thrust (HFT) and obtained evidences for a great (M>8) earthquake in 260 AD an two large (M>7) earthquakes in 1294 AD and 1423 AD near Chandigarh. These corroborations were further confirmed by Malik et al. (2003). [Rajendran et al. (2004) have also obtained evidences for a very large earthquake (M>8.0) around 830 AD near Guwahati City] Lave et al. (2005) have reported the evidences for an earthquake of magnitude exceeding 8.5 on HFT is the far East Nepal around 1100 AD.

Sukhija et al. (2006) have interpreted the paleoseismic signature in the meizoseismal areal of 1993 Killari earthquake in Maharashtra and indicated the occurrence of even layer event (M>6.3) during 190 BC to 410 AD. From paleoseismic studies along the AllahBund fault, Rajendran et al. (2008) have interpreted two events of M>7 during 2000-3000 BC and 893 AD, respectively. They have also identified the occurrence of an event of M>7 in the area of 2001 Bhuj earthquake in the Kutch region around 325 BC.The catalogue thus prepared has been plotted on Indian map as given in Fig. 1.

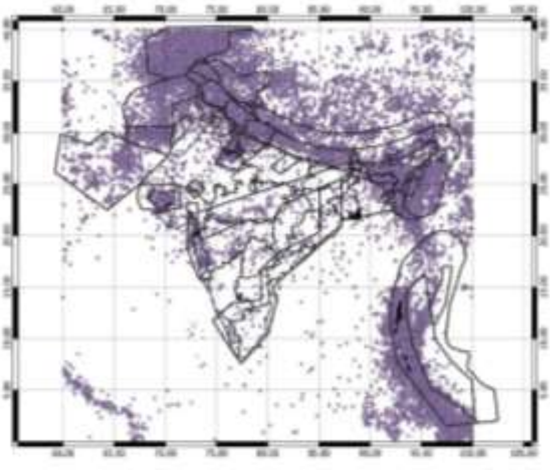

Figure 1: The catalogue thus prepared has been plotted on Indian map

Seismogenic Sources in India

Most part of the Indian continent is earthquake prone. It is necessary to understand thephysical process going on underneath before we try to assess the seismic hazard.Understanding of seismotectonics for different regions of India has gained enormousimportance in recent years as it is now recognized that no parts of India is completelyfree from earthquake and there happens to be a constant threat from both plate-marginand intraplate earthquakes. Intensification of various developmental activities inearthquake prone areas like rapid urbanization, industrial growth, installation ofcapital intensive hydel, multipurpose and nuclear power projects etc., have alsobrought in new challenges before the earth science community.Tectonic framework of the Indian subcontinent covering an area of about 3.2 millionsq. km is spatio-temporally varied and complex. As a pre requisite for the seismichazard studies, the study area has been divided into independent seismogenic sourcezones having individual characteristics. These source zones were chosen on the basisof Khattri et al. (1984) in which the whole country is divided into 24 source zones.The same zoning map has been used here for future hazard assessment. Figure 1.shows the source zones considered in the study for seismic hazard assessment.Part of the Mahanadi and Godavari grabens are included in zone I, which is made up of the eastern coastal belt. Precambrian fault systems and Archean rocks make up the majority of the zone. In this region, there is a broad east-northeast tectonic tendency. It then turns again to acquire a north-easterly alignment in the region south of Madras (80.3°E, 13.1°N), swinging in a path parallel to the curvature of the eastern boundary of the Cuddapah basin (79°E, 15°N) (Eremenko and Negi, 1968; Valdiya, 1973). Periodically, there have been light earthquakes along India's western coast, which runs from Koyna in the south to Ahmedabad in the north.The active plate boundary zones are the most active shallow-focus seismic zones, and Zone 3 includes the Kutch region. The main tectonic feature is in the west-northwest direction, and inside it, block faulting has created a series of grabens and ridges that almost have an easterly tendency. The rocks of the Archean Arravali and Delhi systems make up Zone 4, which is located in the northeast-trending Arravalirange.The Narmada-Tapi rift, a system of deeply seated faults of regional importance, is covered under Zone 5. (Naqvi et al., 1974). The Andaman-Nicobar Islands, an anticlinal welt with faults running parallel to the island formation, were created when the Indian and Burma crustal plates converged, giving rise to the Zones 6, 7, and 8. The Tertiary and substantial thickness of Mesozoic rocks that make up the extremely seismic Zone 9 of the ArakanYoma fold belt are intruded by granite and ultrabasic rocks (Krishnan, 1968). The Bramhaputra valley, one of the subcontinent's most seismically active regions, is where Zone 10 is located.Zone 11 is located to the west of Zone 10 and is made up of an alluvial geosyclinal basin. The Himalayan tectonic unit, which makes up the highest mountain chain in the world, is covered by Zones 12 and 14. This region is sparsely populated. Zone 15 is a low seismicity zone made up of a small belt with earthquake foci of low magnitude parallel to zone 12's southern boundary in the westernmost region.In the northwest of the Indian subcontinent, the Kirthar-Sulaiman mountain ranges are divided into Zones 16, 18, and 19, whereas Zone 17 is made up of an alluvial tract where shallow, occasional earthquakes occur. Zones 20, 21, and 22 are located close to the Himalaya tectonic plate near the northern end of the Indian shield. The trans-Himalayan zone, also known as Zone 24, is a huge area with shifting geotectonic provinces and seismic activity. It is located around 38° north latitude and 100° east longitude. The Pamir knot, also known as Zone 24, is widely recognised for its high shallow seismic activity. The Himalaya, the Tien-Sham, and the Kara Korum are three tectonic provinces that meet at this location and have extremely intricate geodynamic interactions.The zonation of the Indian region and the seismicity is shown in Figure 2.

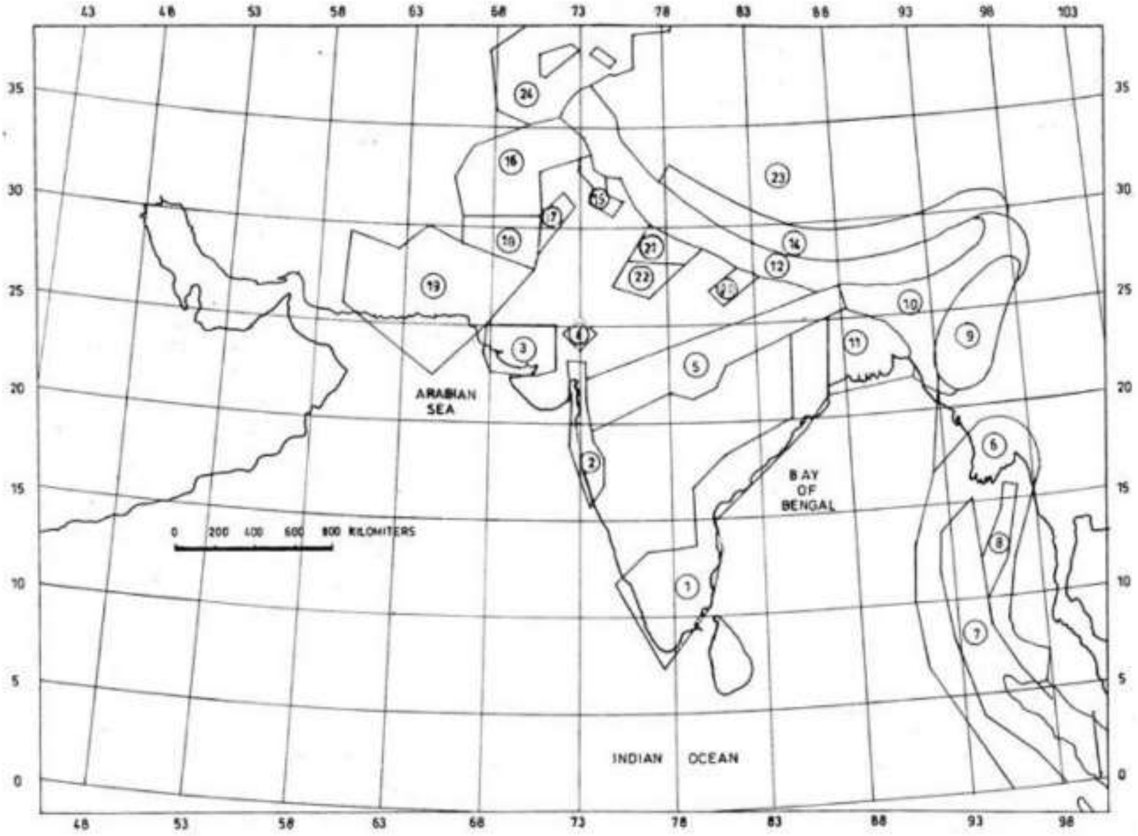

Figure 2: The zonation of the Indian region

Gutenberg Richter Relationship

Distributions of earthquakes in any region of the Earth typically satisfy the Gutenberg and Richter (1956) relationship (GR) as given below:

$$\mathbf{Log10[N(>M)]=a–bM} \qquad \mathbf{(1)}$$

where N is the total number of earthquakes with a magnitude larger than M, a represents the seismic activity, and b is normally close to 1. (Richter, 1958). Higher values of b denote a greater proportion of minor earthquakes, whereas lower values of b denote a lesser proportion of small earthquakes. As GR is a power law and roughly linear, M is proportional to the logarithm of energy.As a result, GR shows that earthquake physics is not completely elastic, which may not come as a surprise. Initially defined (with remarkable insight about 60 years ago) as an empirical magnitude-frequency relationship, the general relativity (GR) is now recognised as one of a wide variety of natural phenomena that exhibit self-organized criticality (Bak, 1996; Bak and Tang, 1989); fractal scaling (Turcotte, 1992; Main et al., 1990); statistical physics (Rundle et al., 2003); critical-point theory (Chen et al., 2006); and critical systems“It is one of the universal miracles of nature that huge assemblages of particles subject only to the blind forces of nature, are nevertheless capable of organising themselves into patterns of cooperative activity” (Davies, 1989). Such critical occurrences impose on conventional sub-critical geophysics a variety of fundamentally novel critical features, some of which are mentioned in Table 1. (after Crampin and Gao, 2013). These unusual characteristics are a result of a fundamental rethinking of numerous physics (and geophysics) concepts (Davies, 1989), in which well-known theories from traditional sub-critical physics are no longer entirely valid and require revision. We propose a New Geophysics in response to Davies (1989) who refers to these phenomena as a New Physics (reviewed by Crampin and Gao, 2013). To calculate the parameters for each of the 24 zones, this relationship was employed. These variables will be used to calculate the destructive earthquake's return period and determine the level of seismic risk in the area.

GR Parameters for Seismogenic Sources in India

The seismic hazard is estimated using the GR parameters along with magnitude of completeness, cut off magnitude, maximum magnitude a, and b values. Therefore, it is necessary that the a and b values of GR relationship are estimated realistic from the data. Ofcourse the cut off magnitude and maximum magnitudes are iteratively used to estimate a and b values and vice versa. For looking into the seismic hazard of any area the a and b values gives the idea quite a bit for the relative seismicity vis a vis the seismic hazard in that region. With the objective to compare the independent seismogeic source as marked in the earlier section an endeavor is made to estimate the a and b values foe ach of the seismogenic sources. Various methods are available to estimate these parameters which are discussed in earlier section. Thus estimated a and b values along with their cut off magnitude. Since parameter b is very important for the relative seismicity interpretation and is represented by the slope of the curve, its error is also reported for each of the seismogenic sources in Table I. One of the important and easiest way to interpret the GR relationship is the estimation of return periods of various magnitudes. The mean return periods thus estimated from GR relationship are given in Table 2. The minimum return period for magnitude 6, 7 and 8 are 1, 14 and 144in seismogenic sources zone 24, zone 24 and zone 19.Similarly, the maximum return periods for magnitude 6, 7 and 8 are 150, 1024 and 15489in seismogenic sources zone 17, zone 11 and zone 7 respectively.

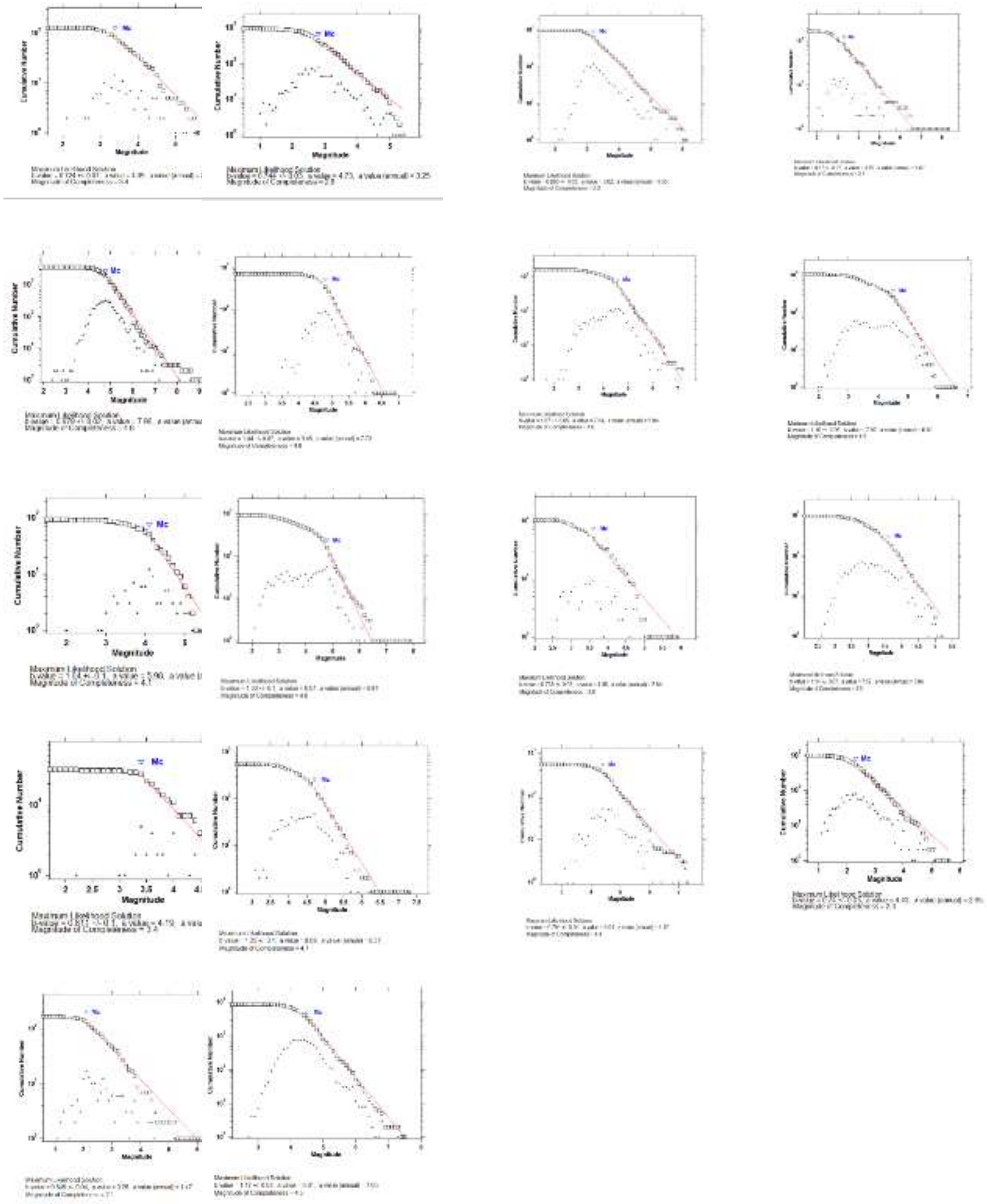

Figure 3. Shows the estimation of a and b values for various seismic sources

There are some of the seismogenic sources viz., IV, VIII, XIII, XX and XXIII for which the values could not be estimated due to lesser number of data points as evident from low seismicity in these zones.

Table 1: The GR Parameters for different zones

Source Name	Value of a	Value of b	Value of Mc	Error in b
I	2.61	0.724	3.4	0.07
II	3.25	0.744	2.8	0.03
III	3.55	0.886	3.2	0.03
IV	-	-	-	-
V	1.82	0.57	3.3	0.07
VI	5.93	0.979	4.8	0.02
VII	7.73	1.44	4.8	0.07
VIII	-	-	-	-
IX	5.84	1.07	4.6	0.05
X	6.01	1.16	4.5	0.06
XI	4.27	1.04	4.1	0.1
XII	2.99	0.409	2.9	0.005
XIII	-	-	-	-
XIV	6.91	1.33	4.8	0.1
XV	2.64	0.738	3.6	0.08
XVI	5.84	1.14	4.6	0.07
XVII	2.69	0.811	3.4	0.1
XVIII	6.37	1.25	4.7	0.1
XIX	4.17	0.791	4.4	0.04
XX	-	-	-	-
XXI	2.65	0.74	2.3	0.03
XXII	1.47	0.549	2.1	0.04
XXIII	-	-	-	-
XXIV	7.05	1.17	4.5	0.02

Table 2: Return periods of magnitudes 6, 7 and 8 based on the GR parameters estimated in Table 1. For various seismogenic sources in India

Sources	a	b	Return Periods		
			6	7	8
1	2.61	0.724	54.20009	287.0781	1520.548
2	3.25	0.744	16.36817	90.78205	503.5006
3	3.55	0.886	58.34451	448.7454	3451.437
4	-	-	-	-	-
5	1.82	0.57	39.81072	147.9108	549.5409
7	7.33	1.44	20.41738	562.3413	15488.17
8	-	-	-	-	-
9	5.84	1.07	3.801894	44.66836	524.8075
10	6.01	1.16	8.912509	128.825	1862.087
11	4.27	1.04	93.32543	1023.293	11220.18
14	6.91	1.33	11.74898	251.1886	5370.318
15	2.64	0.738	61.3762	335.7376	1836.538

Sources	a	b	Return Periods		
			6	7	8
16	5.84	1.14	10	138.0384	1905.461
17	2.69	0.811	149.9685	970.51	6280.584
18	6.37	1.25	13.48963	239.8833	4265.795
19	4.17	0.791	3.767038	23.28091	143.8799
20	-	-	-	-	-
21	2.65	0.74	61.6595	338.8442	1862.087
22	1.47	0.549	66.68068	236.0478	835.603
24	7.05	1.17	0.933254	13.80384	204.1738

Similarly, the magnitudes for various return periods can be estimated using GR relationship. The GR relationship may be written as

$$M=(a-Log(N))/b \quad (2)$$

The return period is reciprocal of N. The various magnitudes for the return periods 100, 225, 475, 2475, 5000 and 10000 years are estimated and tabulated in Table 3.

Table 3:Probabilities for the return periods of 100, 225, 475 and 2475 based on the GR parameters

Source	a	b	Magnitudes for various return periods			
			100	225	475	2475
1	2.61	0.724	6.367403	6.853843	7.302063	8.292231
2	3.25	0.744	7.056452	7.529815	7.965986	8.929537
3	3.55	0.886	6.264108	6.661606	7.027871	7.836992
4	-	-	-	-	-	-
5	1.82	0.57	6.701754	7.319618	7.888936	9.146623
7	7.33	1.44	6.479167	6.723738	6.949093	7.446927
8	-	-	-	-	-	-
9	5.84	1.07	7.327103	7.656245	7.959527	8.62951
10	6.01	1.16	6.905172	7.208778	7.488529	8.10653
11	4.27	1.04	6.028846	6.367483	6.679513	7.368822
14	6.91	1.33	6.699248	6.964047	7.20804	7.747049
15	2.64	0.738	6.287263	6.764475	7.204192	8.175576
16	5.84	1.14	6.877193	7.186125	7.470784	8.099627
17	2.69	0.811	5.782984	6.217241	6.617378	7.501326
18	6.37	1.25	6.696	6.977746	7.237355	7.81086
19	4.17	0.791	7.800253	8.24549	8.655744	9.562042
20	-	-	-	-	-	-
21	2.65	0.74	6.283784	6.759706	7.198235	8.166994
22	1.47	0.549	6.320583	6.962081	7.553176	8.858971
24	7.05	1.17	7.735043	8.036053	8.313413	8.926133

The probabilities of earthquake occurrence is generally assumed to be Poissonian. The poisson distribution is used to estimate the probability of occurrence in finite time period. The standard Poisson seismic hazard model requires only an average arrival rate, to provide a complete statistical description of seismic occurrences (Cornell 1968; Der Kiureghian and Ang 1977). Poisson processes having following assumptions: The number of occurrences in one time interval is independent of the number that occurs in any time interval. The probability of more than one occurrence during a very short time interval is negligible. The probability of occurrence during a very short time interval is proportional to the length of the time interval. These assumptions show that the events of a Poisson process occur randomly, with no memory of time, size, or location of any preceding event. According to poisson process the probability of having exactly *n* number ofearthquakes of a given size in any given time interval *t* in an area can be defined by

$$p(n)=\frac{(\lambda t)^{n}}{n!}e^{-\lambda t} \qquad \textbf{(3)}$$

where λ is the mean occurrence rate per unit time. Thus, the probability of no event (*n*=0) in time *t* can be written as

$$p(n=0)=e^{-\lambda t} \qquad \textbf{(4)}$$

This can be interpreted as the probability that time lapse since one event to the next (inter-event times) is greater than *t*.

The GR parameters have been used to estimate the mean rate of occurrence which is further used to estimate the probability of occurrence in next T years using equation (4).

Table 4:Probabilities for the magnitudes of 6, 7 and 8 based on the GR parameters for different return periods

Source	**Prob of 6 in**				**Prob of 7 in**				**Prob of 8 in**			
	100	**225**	**475**	**2475**	**100**	**225**	**475**	**2475**	**100**	**225**	**475**	**2475**
1	84.20	98.43	99.98	100.00	29.41	54.33	80.88	99.98	6.36	13.75	26.83	80.36
2	99.78	100.00	100.00	100.00	66.76	91.61	99.47	100.00	18.01	36.04	61.07	99.27
3	81.98	97.89	99.97	100.00	19.98	39.43	65.30	99.60	2.86	6.31	12.86	51.18
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	91.89	99.65	100.00	100.00	49.14	78.15	95.97	100.00	16.64	33.60	57.87	98.89
7	99.25	100.00	100.00	100.00	16.29	32.98	57.03	98.77	0.64	1.44	3.02	14.77
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	100.00	100.00	100.00	100.00	89.34	99.35	100.00	100.00	17.35	34.87	59.55	99.10
10	100.00	100.00	100.00	100.00	53.99	82.56	97.50	100.00	5.23	11.38	22.52	73.53
11	65.75	91.03	99.38	100.00	9.31	19.74	37.14	91.10	0.89	1.99	4.15	19.80
14	99.98	100.00	100.00	100.00	32.84	59.17	84.91	99.99	1.84	4.10	8.47	36.93
15	80.39	97.44	99.96	100.00	25.76	48.84	75.70	99.94	5.30	11.53	22.79	74.01
16	100.00	100.00	100.00	100.00	51.54	80.41	96.80	100.00	5.11	11.14	22.06	72.72
17	48.67	77.69	95.79	100.00	9.79	20.69	38.70	92.19	1.58	3.52	7.28	32.57
18	99.94	100.0	100.0	100.0	34.0	60.86	86.19	100.0	2.32	5.14	10.5	44.02

Source	Prob of 6 in				Prob of 7 in				Prob of 8 in			
	100	225	475	2475	100	225	475	2475	100	225	475	2475
		0	0	0	9			0			4	
19	100.00	100.00	100.00	100.00	98.64	99.99	100.00	100.00	50.09	79.07	96.32	100.00
20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	80.25	97.40	99.95	100.00	25.56	48.52	75.39	99.93	5.23	11.38	22.52	73.53
22	77.68	96.58	99.92	100.00	34.53	61.45	86.63	100.00	11.28	23.61	43.36	94.83
24	100.00	100.00	100.00	100.00	99.93	100.00	100.00	100.00	38.72	66.78	90.24	100.00

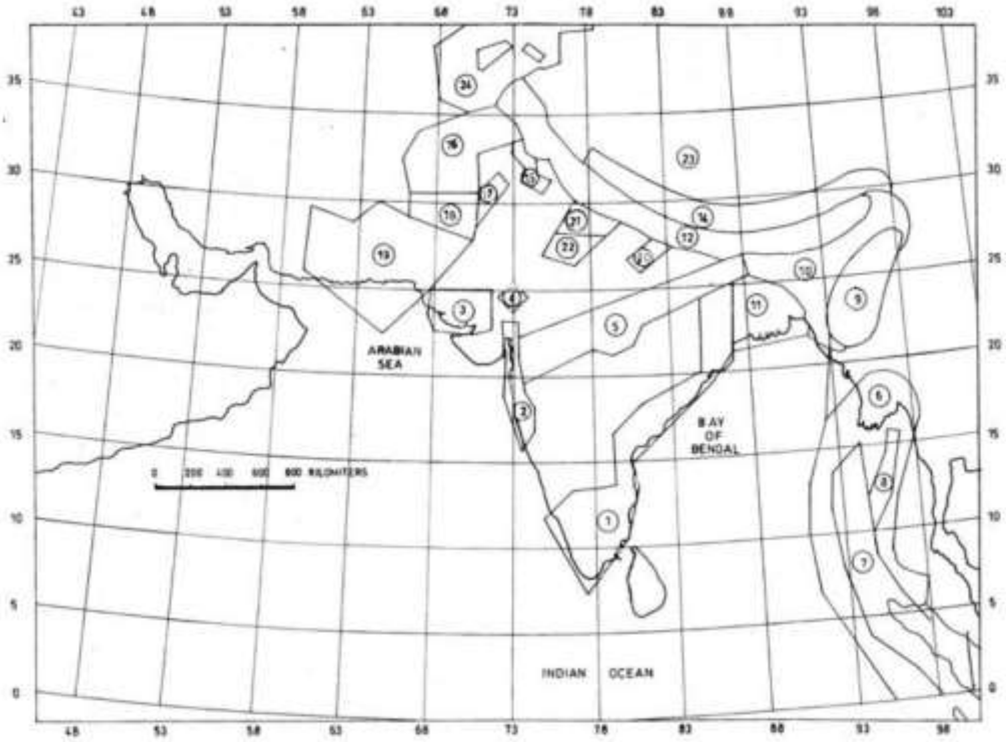

Figure 4: Seismogenic source considered for the probabilistic seismic hazard analysis based on Khattri *et al. (1984)*

Conclusion

The seismicity of India has been revisited to look into the return periods of different magnitudes in various seismogenic zones. There are 24 zones with seismogenic sources over the entire nation.The seismicity from earlier times to 2020 has been considered and return periods in specific zones have been estimated using the Gutenberg Richter magnitude frequency relationship. The GR parameters has been estimated as a and b parameters in the ranges from 1.96 to 7.0 and 0.393 to 1.79, respectively. The results are provided in terms of the return periods of the earthquakes in each zone which gives the mean annual rate of occurrence. This can be further used by seismologists and earthquake engineers for seismic hazard assessment. Most of the time these mean annual rate of occurrence along with the Ground motion prediction equations are used along with the Poissonian occurrence to estimate the seismic hazard for an engineering site. The results are very useful for seismic hazard assessment for the regions.

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