QUANTIFICATION OF FUTURE EARTHQUAKE HAZARD & RISK IN HINDUKUSH-PAMIR HIMALAYA USING IMS NETWORK DATA

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INTRODUCTION

Now days, earthquake hazard is perceived differently than one or two decades ago due to occurrence of unexpected large earthquakes.

Although there is no unique method for the estimation of earthquake risk, statistical models are popular among researchers. Among these, extreme value theory has been applied to obtained return period and probability of occurrence of the largest earthquakes

Extreme value theory was proposed by Gumbel (1958) for flood analysis and has been applied for seismic risk assessment . Nordquist (1945) attempted using this theory for the first time for earthquakes in southern California and for the largest earthquakes in the world.

In comprehensive treatment of EHE, Lomniz (1974) details a method of Gumbel Type I extreme event probability distribution to estimate design earthquake recurrence times using observed annual extreme magnitudes.

Since then several researchers have applied this method in different regions (Epstein, and Lomnitz, 1966; Knopoff and Kagan, 1977; ; Rao and Rao, 1979; Shanker and Singh, 1997)

Other various researchers of the world applied this method in different regions

Continued…..

Gayskiy and Kotak,	**(1965)**	**in Soviet Union**
Dick,	**(1965)**	**in New Zealand**
Epstein and Lomnitz,	**(1966)**	**in America**
Karnik and Hubernova &	**(1968)**	**in Europe**
Schenkova and Karnik,	**(1970)**	
Milne and Devenport,	**(1969)**	**in Canada**
Shakal and Willis,	**(1972)**	**in North Circum-Pacific seismic belt**
Rao and Rao, &	**(1979)**	**in India and adjoining region**
Goswami and Sarmah, &	**(1983)**	
Shanker and Singh	**(1997)**	

In this paper the Gumbel type I extreme value method has been used to investigate the probability of occurrence of extremes, their return periods and the seismic risk in the Hindukush-Pamir-Himalaya, USING EARTHQUAKE DATA RECORDED BY IMS NETWORK (CTBTO).

Reason for Model selection

The criteria that are required for any statistical analysis model applied to earthquake hazard estimation are that:

- it is able to emulate the known historical data, and
- it can produce suitable formulation for which the probability of the future event of interest can be inferred within a specified certainty.

As long as these criteria are met the choice of model is open, and model can be deemed suitable for the perpose.

Model characterization

- **Extreme value theory, given by Gumbel, is the most widely used seismic risk estimation method which postulate that**

➢ if earthquake magnitude is unlimited,

➢ if the number of earthquakes per year decreases with their increase in size and

➢ if individual events are unrelated,

then the probability of non-exceedance of earthquake 'm' in one year will be:

$$P(m) = \exp(-\alpha (\exp - \beta m)) \quad (1)$$

Here 'α' and 'β' are constants, which may be estimated from the least square fit of the relationship:

Lomniz (1974)

Shows that, if a homogeneous earthquake process with a cumulative magnitude distribution is assumed

$$F(m) = 1\text{-}e^{-\beta m} \quad ; (m \geq 0)$$

Where, β is the inverse of the average magnitude of earthquake in the region under consideration, and α is the average number of earthquakes per year above magnitude 0.0,

Then M, annual maximum earthquake magnitude, will be distributed as in eq (1)

Modal annual maximum magnitude

$\ln(-\ln P) = \ln\alpha - \beta m$ (2)

Above equation can be evaluated by taking double logarithms of equation (1).Then the modal annual maximum magnitude (u) can be estimated in terms of α and β as:

$u = \ln\alpha / \beta$ (3)

The modal earthquake magnitude in a year period can be written as:

$u_t = \ln(\alpha t) / \beta = u + \ln T / \beta$ (4)

The expected number of earthquakes in a given year which have magnitude exceeding 'm' can be found as:

The Average Return Period

- $\ln(N_m) = \ln\alpha - \beta m$ (5)

and the return period of earthquakes having magnitude greater than m is given by:

$$T_m = 1/ Nm = \exp(\beta m) / \alpha \quad (6)$$

Earthquake risk, R_t (m), the most important result of this theory, can be estimated in a ‘t’ year period is given by:

$$R_t (m) = 1 - \exp(\alpha t. \exp(- \beta m)) \quad (7)$$

Data treatment

For the estimation of constants of equation (1), the largest annual earthquake magnitude m_1, m_2, m_3, -------------m_n taken from N-sets are arranged in increasing size. Then the observed probability of each m_i may be written as:

$$P_i = i / (N+1) \qquad (8)$$

Where i varies from 1 to N and N is the total number of data. According to Knopoff and Kagan (1977) the above estimate is biased for larger earthquakes and they suggested another method for the estimation of observed probability:

$$P = (i-0.5) / N \qquad (9)$$

Estimation of a & b values

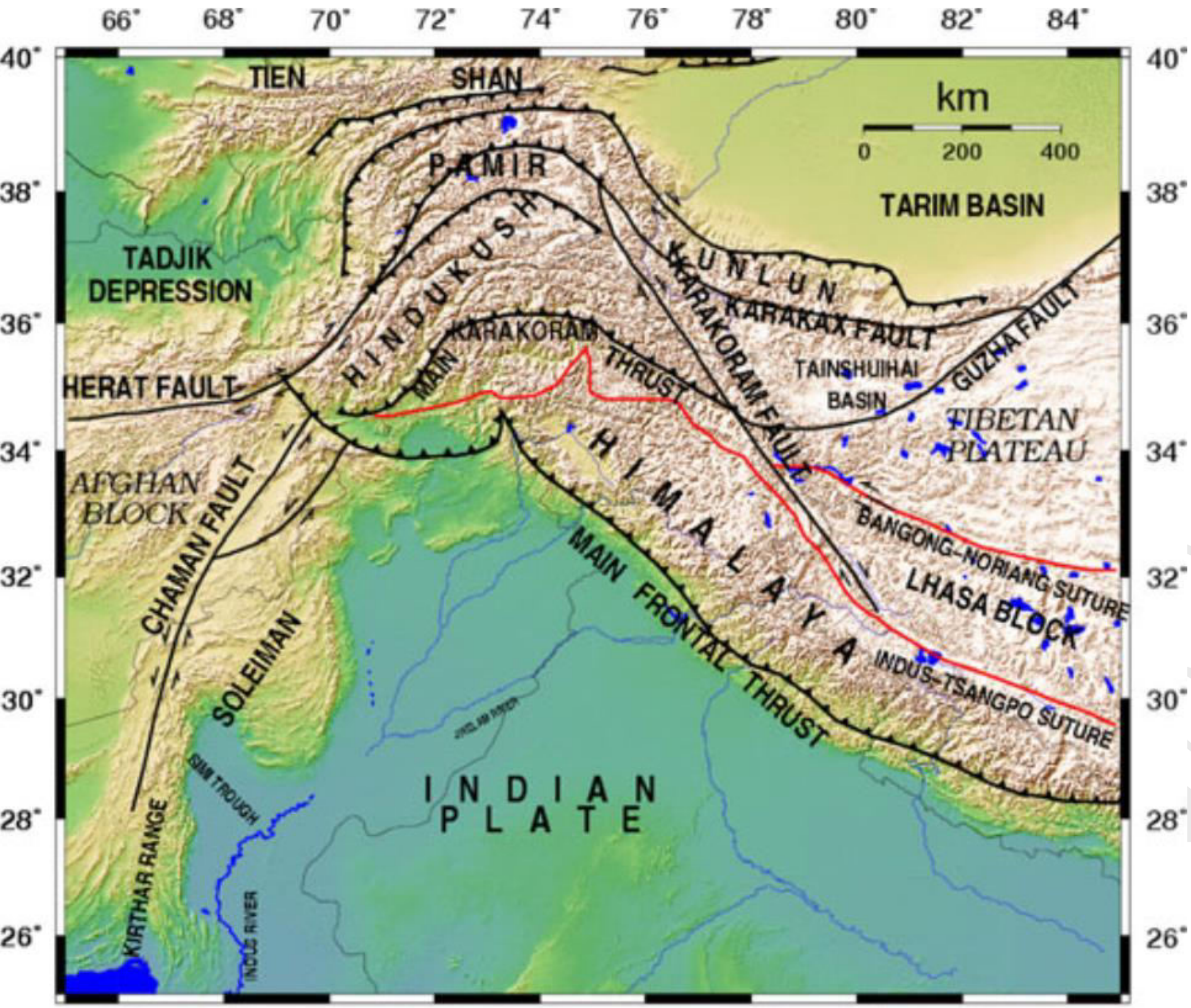
- The relationship between Gumbel parameters α and β and Gutenberg- Richter parameters a and b can be given by the expression

$$b=\beta log_{10}e \quad (10)$$

$$a=log_{10}\alpha \quad (11)$$

It must be noted that b-value is generally constant for a particular region (present case 1.54), but a-value (present case 8.5209) is **very sensitive to missing (gap) data** for considered period of investigation.

Application of Model in Hindukush–Pamir Himalaya



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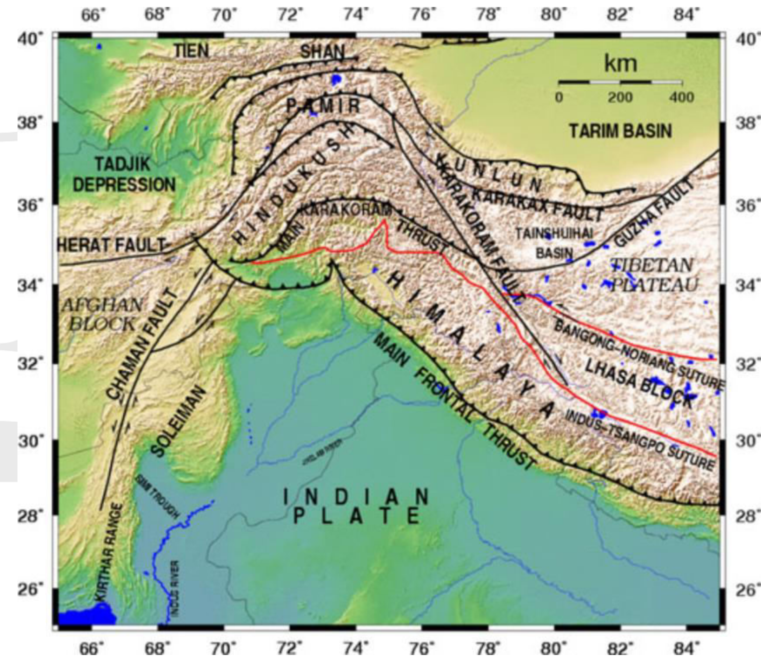
Hindukush–Pamir Himalaya and their vicinity bounded by 25–40°N and 65–85°E have been considered for future earthquake hazard (Figure 1). This region is situated on the northern boundary of the Indian Plate along its northwestern flanks.

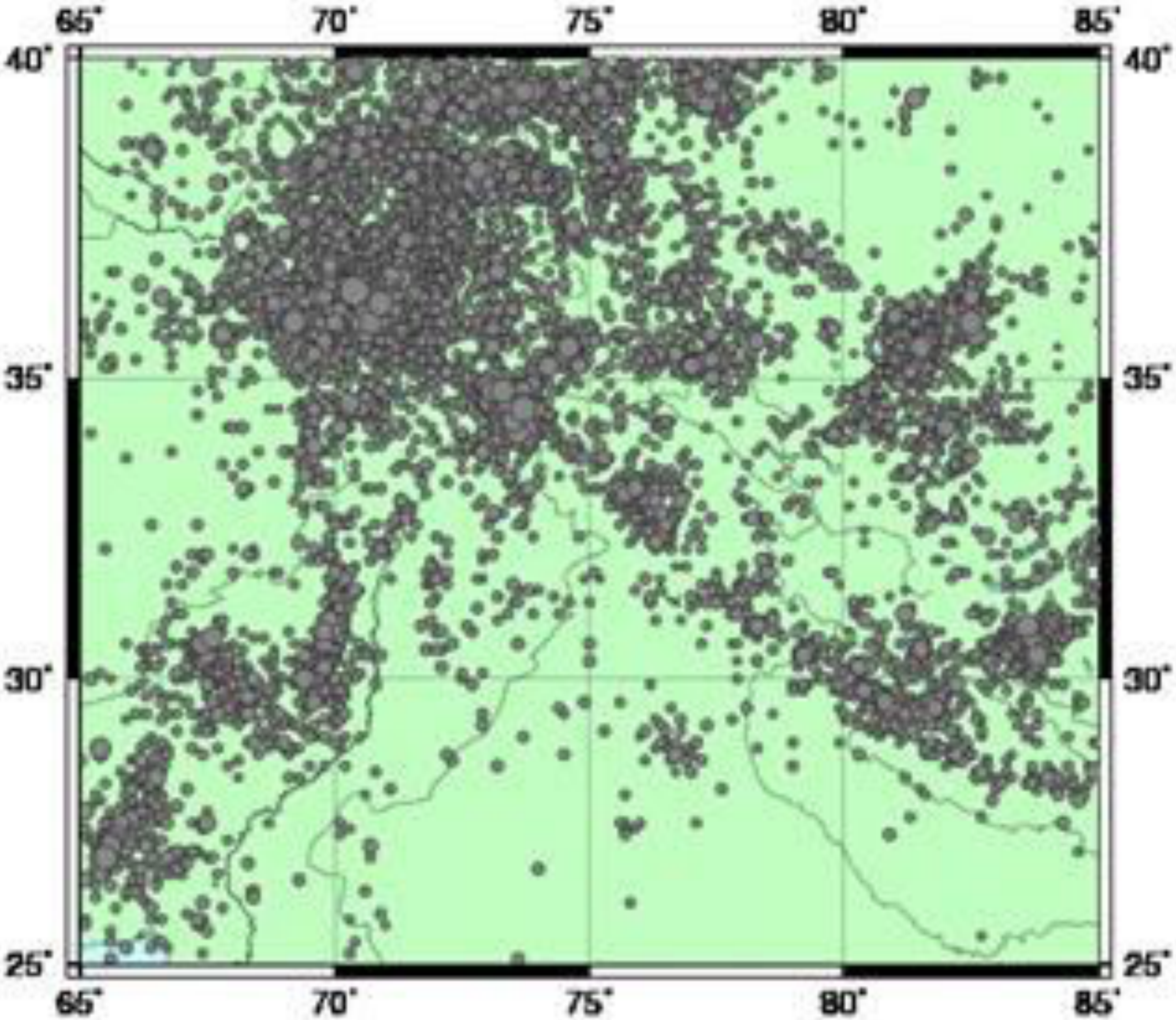
Current tectonic and seismic activity in central Asia is often considered to be the consequence of continental collision between India and Eurasia

Continued----------

- However, the tectonic and seismic characteristics of the Hindukush can not be explained solely by the collision between the two plates, but thermal convection below the Indian Plate and the flow of the upper mantle in the Tibetan plateau region would affect earthquake activity and stress in the subducted lithosphere



Seismic Charateristics of the region



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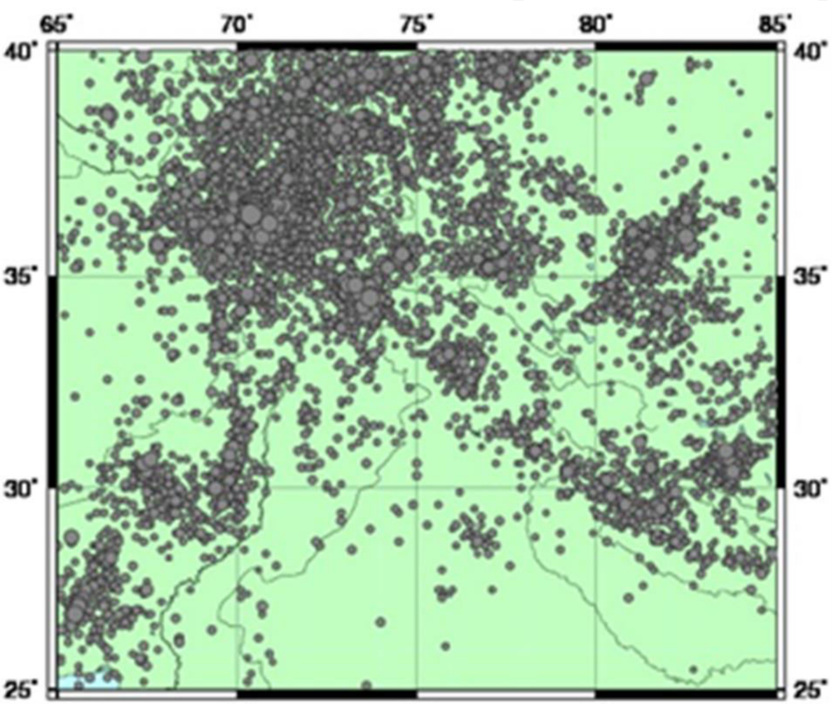
Hindukush–Pamir Himalaya and their vicinity bounded by 25–40°N and 65–85°E is one of the most seismically active regions of the world whose seismicity is mainly controlled by ongoing compressional movement of the Indian and Eurasian plates. It is the most seismically hazardous regions, which experienced large to great damaging earthquakes historically.

Seismicity Data

To understand an earthquake phenomenon and its associated risk in a region, a good database is important. **We have used a very precisely located dataset taken by the International Monitoring System (IMS)**



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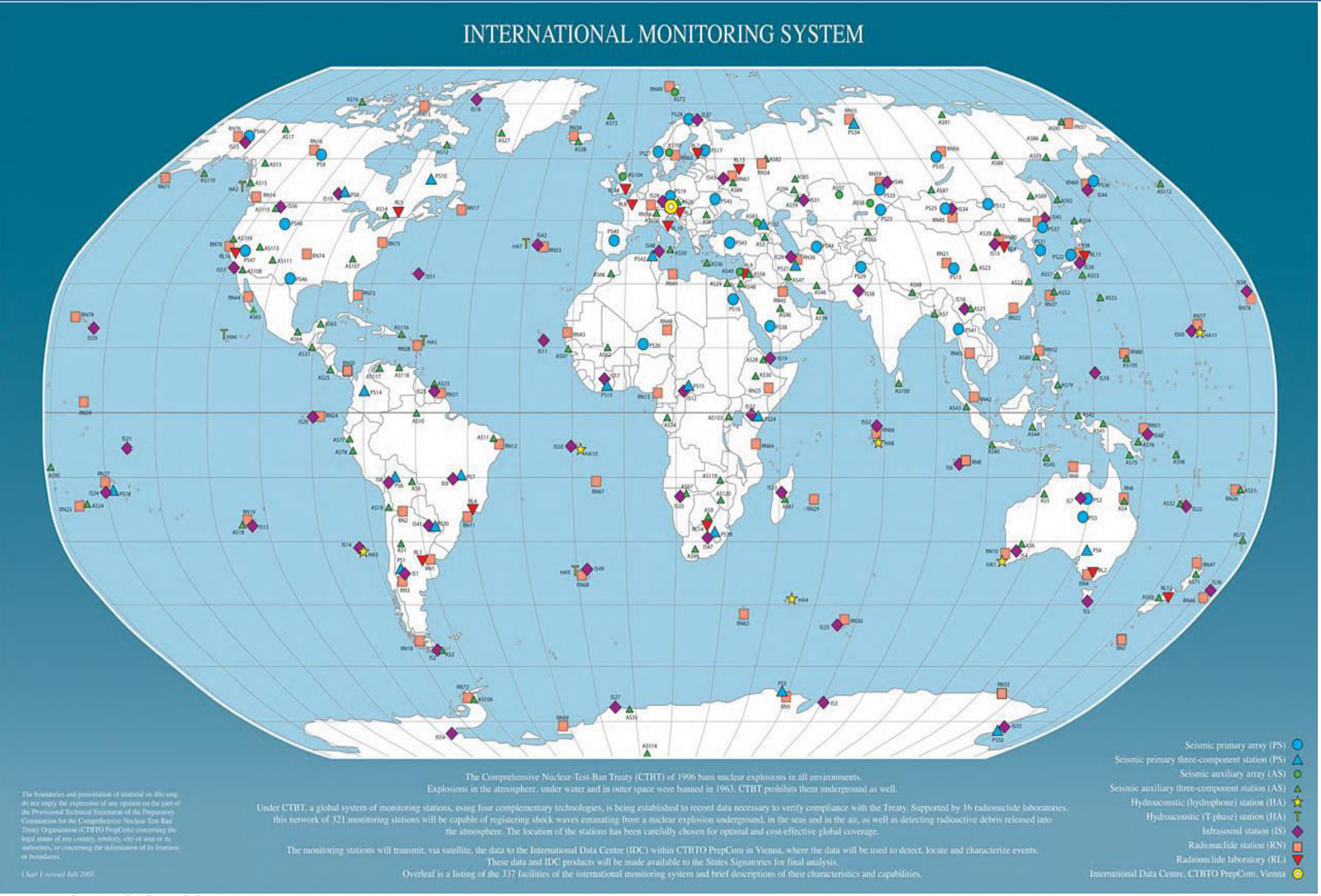
Study investigates 17- years earthquake data from June 13, 1999 to March 12, 2015 with M ≥ 5.0 for the considered region (25–40°N and 65–85°E) taken from International Monitoring System (IMS) Network setup by Comprehensive Nuclear-Test-Ban Treaty Or-ganization (CTBTO), Vienna Austria; which ensures a more reliable analysis

IMS Network



The International Monitoring System (IMS) consisting of 337 monitoring facilities around the globe.

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IMS Network

The International Monitoring System (IMS) consisting of 337 monitoring facilities around the globe. It is being established in order to monitor the entire globe using four different sensor technologies. When complete, the **seismic network will consist of 50 primary and 120 auxiliary seismological stations to monitor the solid earth**. Data from IMS stations are transmitted to the International Data Center (IDC) using a purpose communications infrastructure. Since June 1999, the IDC began routine automatic and interactive processing of seismic data; the detected and located events are systematically included in the Reviewed Event Bulletin (REB). The seismicity catalog of IDC constitutes a major product of seismological research, while simultaneously providing a beneficial tool for a wide range of seismic data analyses. For this reason, the focal parameters, origin time, and magnitude of the events are determined as precisely as possible. The state of IMS seismic networks over time and the associated spatial and instrumental heterogeneity are additional factors of paramount importance, as they considerably affect the level of earthquake detection.

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Analyses and Results

TABLE 1: Calculation for Gumbel's Annual Maximum Distribution & Estimation of α and β

Extremes m	Year	Rank(j)	Plotting Position G(m) = i / (N+1)	Reduced Statics Ln(-ln (G(m)))
5.1	1999	1	0.0555556	1.061385
5.2	2000	2	0.1111111	0.787195
5.4	2001	3	0.1666667	0.583198
5.5	2002	4	0.2222222	0.40818
5.5	2003	5	0.2777778	0.247589
5.6	2004	6	0.3333333	0.094048
5.6	2005	7	0.3888889	-0.05714
5.6	2006	8	0.4444444	-0.20957
5.7	2007	9	0.5	-0.36651
5.8	2008	10	0.5555556	-0.53139
5.8	2009	11	0.6111111	-0.70831
5.8	2010	12	0.6666667	-0.90272
5.8	2011	13	0.7222222	-1.12263
5.8	2012	14	0.7777778	-1.38105
5.9	2013	15	0.8333333	-1.70198
6	2014	16	0.8888889	-2.13891
6.3	2015	17	0.9444444	-2.86193

Table 2: Estimated Gumbel's Parameters α and β

Statistics	Value
Slope(-β)	-3.551
β	3.55
Intercept(ln(α))	19.62
α	331785754.23

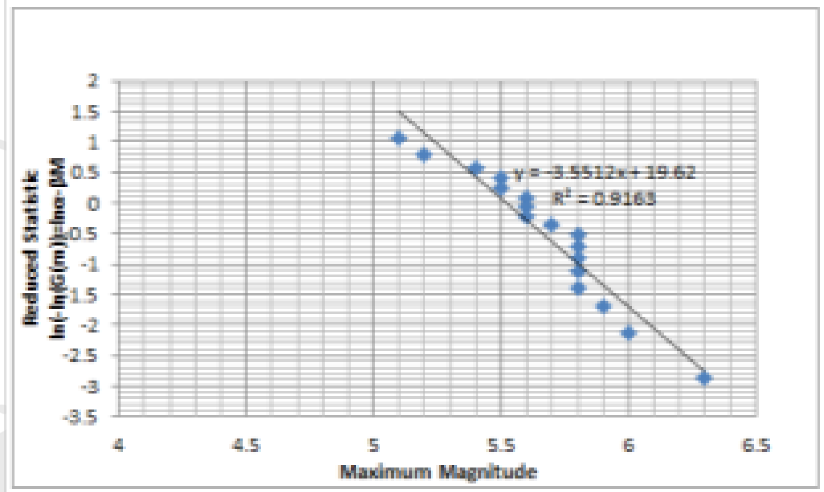

Figure 4. Display the reduced Variate versus maximum magnitude and to calculate α and β using linear regression of data

Earthquake Hazard

Lomniz (1974) provides number of equations that use of α and β to determine statistical quantities frequently used in analyses, we call it "**Earthquake Risk"** can be understandable in different ways:

-the odds of EQ occurrence (Time, Region); Rann et.al, 1987)

- The probability of damages (McCue, 1996)

"Seismic Hazard"

- the probability of EQ occurrence (Time, Region)

The equation provided by Lomnitz (1974) can used for determine Hazard of the region.

Earthquake Hazard $H_t(m)$ is a probability of occurrence of an earthquake of magnitude m within a period of t years and is given by

$$H_t(m) = 1 - \exp(-\alpha t e^{-\beta y})$$

Earthquake Hazard

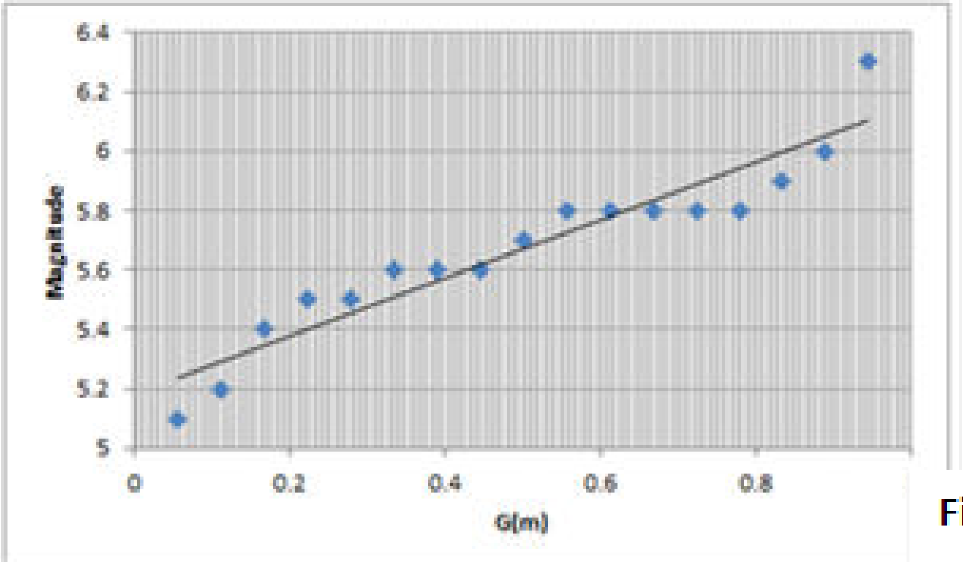

Figure 3. Variation of extremes magnitude with probability

The figure 3 shows the mean Line of Expected Extreme (LEE) to study the probability of largest extreme.

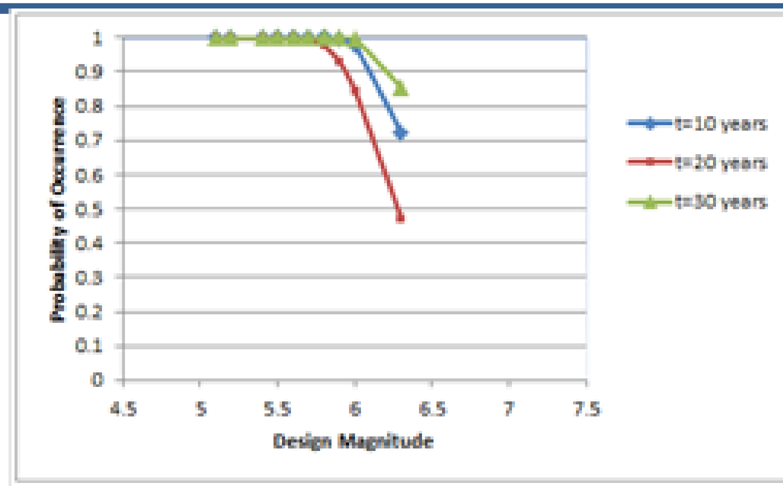

Figure 5: Earthquake Hazard in Hindukush-Pamir-Himalaya for different period

It should be note that in interpreting Hazard probabilities, there **is non-zero probability of no event occurring over any given period of time**, and probability of any particular event occurring never reaches 1.0 (probability of any particular event is never absolutely certain). For example M=5.5, P=1; e.i. it is most certain than atleast one event will occur within that period (10 yr) of time.

Earthquake Hazard

Table3: Predicted Annual number of earthquakes and its return periods

Magnitude	N_m	T_m
5.1	4.549421127	0.219808
5.2	3.189933276	0.313486
5.4	1.568312185	0.637628
5.5	1.099658855	0.909373
5.5	1.099658855	0.909373
5.6	0.771051586	1.29693
5.6	0.771051586	1.29693
5.6	0.771051586	1.29693
5.7	0.540640895	1.849657
5.8	0.379083038	2.637944
5.8	0.379083038	2.637944
5.8	0.379083038	2.637944
5.8	0.379083038	2.637944
5.8	0.379083038	2.637944
5.9	0.265802959	3.762185
6	0.186373976	5.365556
6.3	0.064248301	15.56461
6.5	0.031587304	31.65829
7	0.005353525	186.7928
7.5	0.000907334	1102.13
8	0.000153778	6502.877
8.5	2.60628E-05	38368.8

Table 4: Most probable largest earthquake hazard H_t (m) for Different Magnitude and Time Periods (t=10, 20, 30) years

Mag. (m)	$H_{10}(m)$	$H_{20}(m)$	$H_{30}(m)$
5.1	1	1	1
5.2	1	1	1
5.4	0.999999846	1	1
5.5	0.999983241	1	1
5.5	0.999983241	1	1
5.6	0.99955191	0.999999799	1
5.6	0.99955191	0.999999799	1
5.6	0.99955191	0.999999799	1
5.7	0.995512273	0.99997986	0.99999991
5.8	0.977423153	0.999490286	0.999988492
5.8	0.977423153	0.999490286	0.999988492
5.8	0.977423153	0.999490286	0.999988492
5.8	0.977423153	0.999490286	0.999988492
5.8	0.977423153	0.999490286	0.999988492
5.9	0.929913816	0.995087927	0.999655732
6	0.844908461	0.975946614	0.996269523
6.3	0.474015224	0.723340015	0.85448106

Design Earthquake Magnitude

- Hazard is referred to a design magnitude. A design magnitude is the magnitude that an earthquake of interest is likely to equal or exceed. An earthquake that fits this design criteria is referred to as a design earthquake of magnitude m
- For earthquake engineering purposes, the design magnitude is commonly chosen as that magnitude, above which the probability of an earthquake occurring during a given time period is considered to be negligibly small, depending on what is considered to be an acceptable risk.
- In order to make such engineering decisions, statistics providing the **average recurrence period for earthquakes**, of any given magnitude, and probabilities of single and multiple earthquake occurrences over any given period, need to be available

Confidence of Recurrence Period

The probability P (t=≥T) that the recurrence period of design earthquake of magnitude m **exceeds the arbitrary recurrence period of T** years is given by (Lomniz, 1974)

$$P\ (t \geq T) = \exp\ (-T/T_m)$$

This is fundamental relationship derivable from the Poisson Model. It can be used here because of the fact that the **Gumbel extreme value method is based on the lognormal relationship** of which Poisson model is an example,.

Therefore, the probability of the recurrence period **being less than an arbitrary time T** is given by

$$P\ (t \leq T) = 1 - \exp\ (-T/T_m)$$

From which it can be deduced that the **period within which at least one earthquake** of magnitude m will occur with a probability P is given by

$$T = T_m \ln(1-P)$$

For **example recurrence period for at least one earthquake** of magnitude m within a probability of 89% is given by

$$T_{89} = T_m \ln(1-0.89)$$

The 89% of Prob. has been chosen, because it is at that level of probability that the calculated return periods conforms to the observed recurrence periods.

Design earthquake Recurrence Period with 89% probability

Table 5: Most probable largest earthquake hazard H_t (m) for Different Magnitude and Time Periods (**t=50, 75, 100**) years

Mag. (m)	$H_{50(m)}$	$H_{75(m)}$	$H_{100(m)}$
5.1	1	1	1
5.2	1	1	1
5.4	1	1	1
5.5	1	1	1
5.5	1	1	1
5.6	1	1	1
5.6	1	1	1
5.6	1	1	1
5.7	1	1	1
5.8	0.999999994	1	1
5.8	0.999999994	1	1
5.8	0.999999994	1	1
5.8	0.999999994	1	1
5.8	0.999999994	1	1
5.9	0.999998309	0.999999998	1
6	0.999910269	0.99999915	0.999999992
6.3	0.959740732	0.991922094	0.998379191

Table 6: Design earthquake Recurrence Period with 89% probability

Magnitude (m)	Return Period (Years)	Recurrence Periods (years)
5.5	0.90	1.986547422
6	5.37	11.85306628
6.5	31.65828868	69.8785464
7	186.7928035	412.3030692
7.5	1102.130055	2432.704022
8	6502.877173	14353.63765
8.5	38368.80352	84690.49745

Conclusions

- **CTBTO, IMS Network data** is used because it represent a continuous and complete set of annual maximum magnitude events

- The results are potentially useful and can be used to determine a **variety of statistics** including **average recurrence periods** of annual maximum magnitude earthquakes, **probabilistic seismic hazard** assessment in the region

- Results are informative for **seismic threat and related earthquake engineering determinations**, usually require estimation of return periods or probabilities of exceedance of specific levels of design load criteria or extremal safety conditions.

Conclusions

- The most probable annual maximum magnitude is equal to 5.5 and most probable 50-years maximum magnitude equal to 6.6. Thus the derived return periods may be used as quantitative measure of seismicity. However, this model don't tell anything about the earthquake characteristics.

- The predicted values are also useful for engineering application and decision making for planning human settlement or societal infrastructure development in the region.

- The estimates can be considered to be **two ways reliable** because on **one way**, the value of α and β which have been used to estimate the earthquake hazard and return periods do not change much for the short or long duration of data used and **other**, complete and reliable IMS data recording.


Thank you
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