Investigation of Seismic Hazard in NW-Himalayas, Pakistan using Gumbel's First Asymptotic Distribution of Extreme Values

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Abstract

NW Himalayan fold and thrust belt is one of the most seismically active belt of Pakistan. The study area falls with in latitude of 32^0-35^0 $30^/$ E and longitude 71^0-75^0 $15^/$ N covering an area of 1, 40, 000 sq^2 km. It is nearly 250km wide and 560 km long irregularly shaped mountaneous belt forming very active transpersional regime which includes many active faults like MKT, MMT, MCT, and MBT etc. The on going collision between Eurassian and Indian plate resulted compresional forces in the N-W Himalayan fold and thrust belt. The documented historical and instrumental record shows that many devastating earthquakes have been stucked in this area. Among them the most prominent earthquakes are Pattan, 1974; batagram 2004 and most recently the deadly Muzafarabad earthquake of 7.6Mw are well known. The study is made to determine the probabilities for the return periods of earthquakes in this area in the future years using Annual Extreme Values Method of Gumbel (1958) by using the earthquakes equal or greater than $M \geq 4$ that occurred for the time interval 1904-2008.Also, The methodology used to estimate the magnitudes of future earthquakes is by statistical method developed by Richter and Gutenberg (1942) in which all the earthquakes of the past of any size may be taken into calculations. According to this method proposed by Gumbel, the distribution of the annual maximum earthquake magnitudes is given which yielded that the probability of an earthquake occurrence of magnitude = 7.5 in 100 years is 63 percent and its return period is 100 years

Introduction

The NW Himalayan Fold-and-Thrust Belt is one of the active Fold-and-Thrust Belt in the world. The Himalayan mountain ranges have been formed due to the continental collision between the Indo-Pak and Eurasian plates. The study area has recently been activated on 1st and 20^{th} November 2002 (Bunji Earthquakes), and 14^{th} February 2004 (Batgram Earthquake) with two devastating earthquakes of magnitudes 5.5 M_W. At the same time the most of the country consists of non-engineered structures, which are a constant threat to lives and property. And most recently the Muzafarabad Earthquake of magnitude 7.6 is warning for future construction in his area. Therefore effective engineering solutions are required to meet the challenges in this area regarding earthquakes. This study will be very helpful for future construction in the area because through this we can estimate the probable return periods of the earthquakes and there magnitudes.

Seismicity of the Area

The NW Himalayan fold and thrust belt is one of the active fold–and–thrust belt along the northwestern margin of the Indo–Pakistan Plate (Jadoon, 1992). The Panjal-Khairabad fault divides it into hinterland zone toward the north and the foreland zone into the south. The hinterland zone is also referred to as the Hazara Crystalline Zone (Bender and Raza, 1995) and Himalayan Crystalline Zone (Cornell, 1968) whereas the foreland zone lies between the Panjal-Khairabad Fault and the Salt Range Thrust along with its westward extension. (Kazmi and Abbas, 2001). The seismicity pattern in terms of magnitude of earthquakes shows concentration in N-W Himalayan zone in figure 2.

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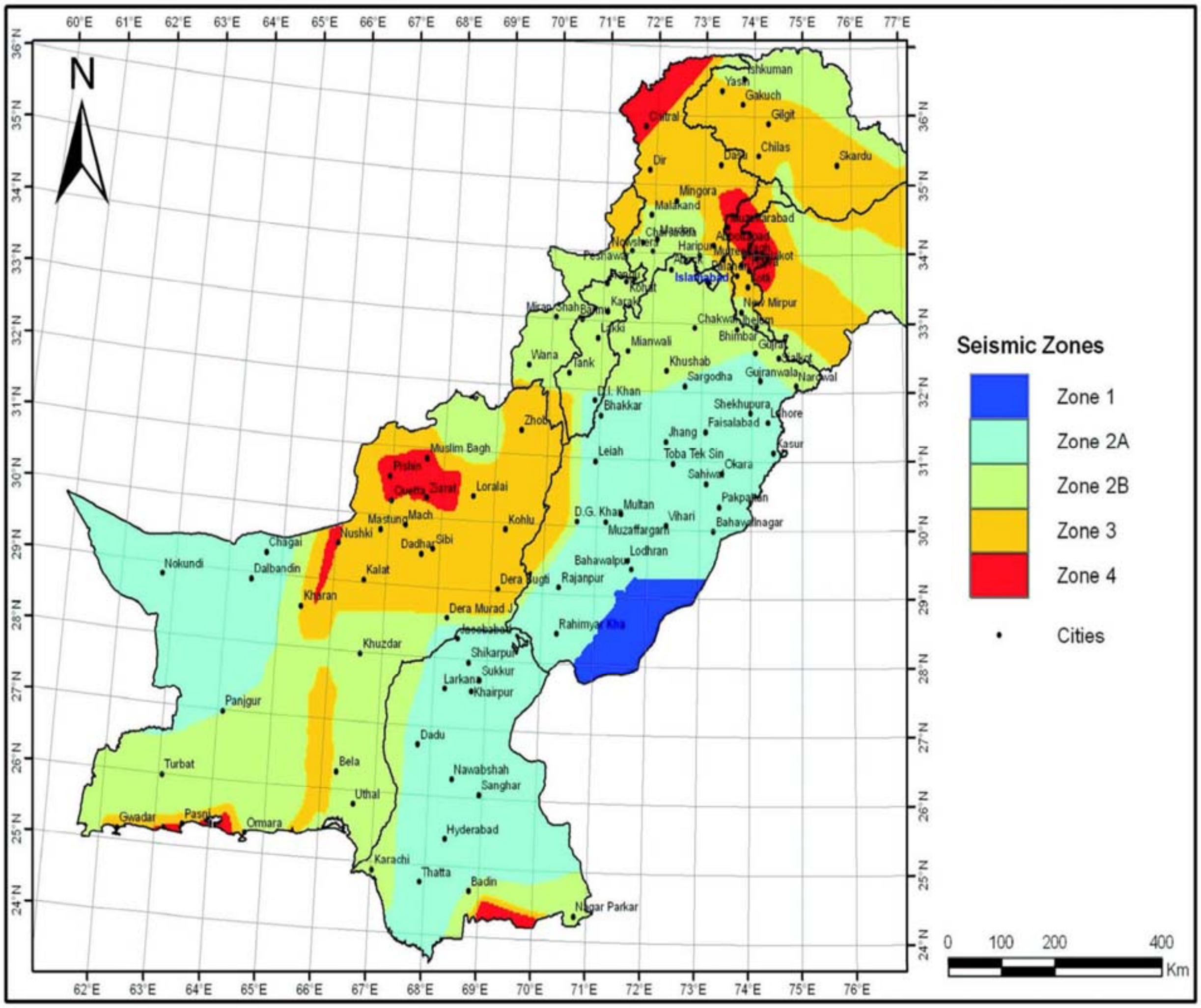

Figure 1: Seismic Zonation Map of the Area

Table 1: g values for different zones of Pakistan**.**

SEISMIC ZONE	PEAK HORIZONTAL GROUND ACCELERATION
1	0.05 to 0.08g
2A	0.08 to 0.16g
2B	0.16 to 0.24g
3	0.24 to 0.32g
4	> 0.32g

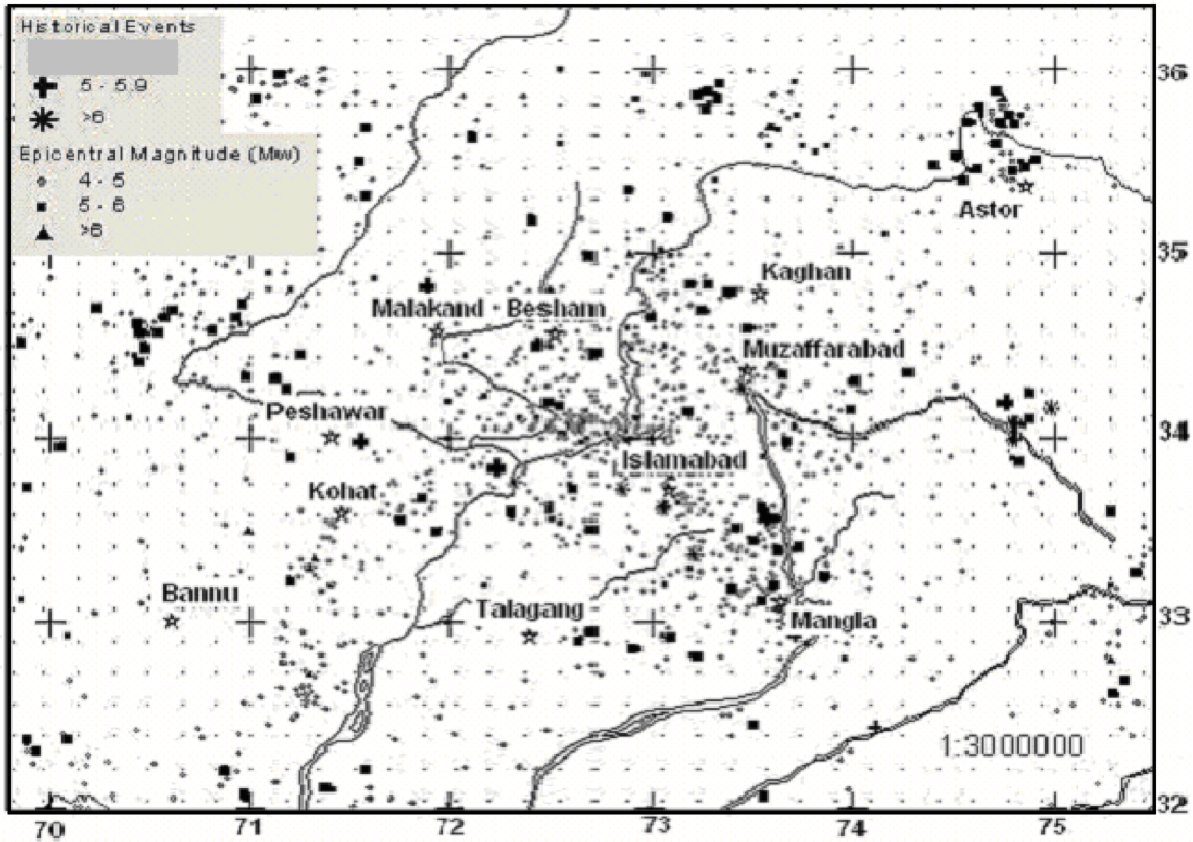

Figure 2: Seismicity map of the NW Himalayas, Pakistan

Methodology

The methodology used in this study is a statistical approach. The main purpose is to estimate the future return periods of earthquake and magnitudes. The earthquake catalog used for this study is made by PMD, Nespak, GSP and IRIS. The data used is of interval 1904 to 2008. And years without documented earthquakes are considered of magnitude 4. The methodology used in this study is developed by Gumbel and Gutenberg and Richter.

Application of Gumbel's Annual Extreme values method for NW Himalayas City

The methodology used to estimate the magnitudes of future earthquakes is by statistical method developed by Richter and Gutenberg (1942) in which all the earthquakes of the past of any size may be taken into calculations. It is very hard to find all values. That's why Gumbel's Annual Extreme Values Method is interested with only largest past earthquakes may be very useful and effective (Nurlu, 1999). The extreme value methodology is given by

$$G(M) = e^{-\alpha e^{-\beta M}} \quad \text{.............................. (1)}$$

M: Magnitude of earthquake

α,β: Regression coefficient

G (M): Probability of not exceeding the earthquakes having magnitudes more than M in one year. In 1956 Gutenberg-Richter have proposed the following relationship which relates the earthquake magnitude to the total number of earthquakes in one year. (Gutenberg-Richter, 1956)

$$\mathbf{LogN = a - b\ (M)} \ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (2)$$

a, b: Regressions coefficients

N: The number of earthquakes in one year whose magnitude is M or greater

There are as following the correlations between Gumbel and Richter formulations (Tezcan, 1996).

$$\alpha = 10^{a}, \quad a = \mathrm{Log}\alpha \ \ldots\ldots\ldots\ldots\ldots\ldots\ (3)$$

$$\beta = b / \mathrm{Log}e, \quad b = \beta \mathrm{Log}e \ldots\ldots\ldots\ldots\ldots\ldots (4)$$

$$N = \alpha\, e^{-\beta M =} -\mathrm{Ln}G \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (5)$$

The regression constants mentioned in Gumbel's equation are found by selecting maximum earthquake of the year from 1800 to 2008 from different catalogs given by USGS, ISC, IMD,PMD etc in table 1.We assumed Mmax = 4 for years with no earthquakes. And the number of this earthquake (j) and relative frequency (f = j / (n+1)) have been determined (n: seismic history period being investigated). Then G (M), N and LogN values calculated using (1) and (5) equations as in Table 3.

Table 2: Annual Maximum Earthquake magnitudes for Time Interval 1904-2008.

year	Mmax	year	Mmax	year	Mmax
1904	5.9	1973	5	1992	5
1914	6.3	1974	5.9	1993	5
1915	5.6	1975	5.3	1994	4.5
1919	5.9	1976	5	1995	5.2
1924	5.2	1977	5.5	1996	5.6
1927	5.4	1978	5.4	1997	5
1928	5.4	1979	5.3	1998	5.3
1953	5.5	1980	5	1999	5.4
1962	5.1	1981	5.1	2000	5.5
1963	5.4	1982	5.4	2001	5.3
1964	5	1983	5.1	2002	6.8
1965	4.8	1984	5.2	2003	6.4
1966	5.2	1985	5.2	2004	6.1
1967	4.3	1986	5.3	2005	7.6
1968	4.1	1987	5.1	2006	6.7
1969	4.4	1988	5.1	2007	6.3
1970	5.1	1989	4.6	2008	6.5
1971	5.2	1990	4.7		
1972	5.4	1991	4.4		

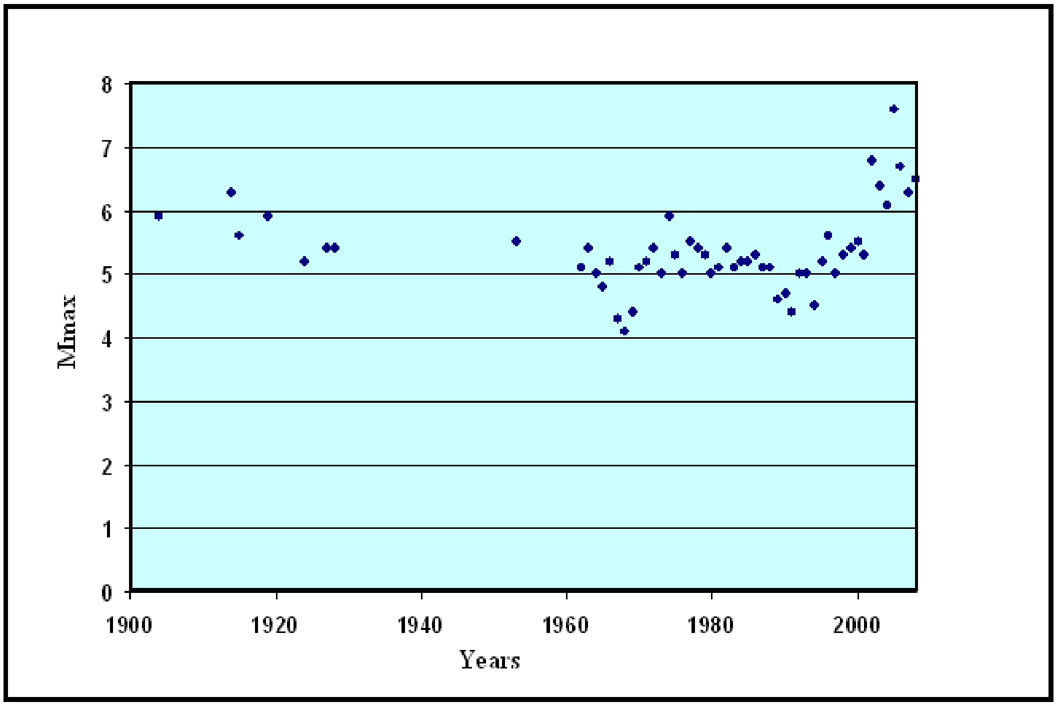

Figure 3; Variation of Earthquakes of Maximum Magnitude during time Interval (1904 - 2008)

Table 3: Calculations for Gumbel's Annual Maximum Distribution

M	j	f	G(M)	N=-LnG	LOGN
4	49	0.460	0.460	0.776529	-0.10984
4.1	1	0.010	0.470	0.756087	-0.12143
4.3	1	0.010	0.479	0.736005	-0.13312
4.4	2	0.019	0.498	0.697012	-0.15676
4.5	1	0.010	0.508	0.678071	-0.16872
4.6	1	0.010	0.517	0.659482	-0.1808
4.7	1	0.010	0.527	0.641233	-0.19298
4.8	1	0.010	0.536	0.62331	-0.2053
5	7	0.067	0.603	0.506115	-0.29575
5.1	6	0.057	0.660	0.415552	-0.38138
5.2	6	0.057	0.717	0.332513	-0.47819
5.3	5	0.048	0.765	0.268222	-0.57151
5.4	7	0.067	0.831	0.184639	-0.73368
5.5	3	0.029	0.860	0.150851	-0.82145
5.6	2	0.019	0.879	0.128943	-0.8896
5.9	3	0.029	0.908	0.096957	-1.01342
6.1	1	0.010	0.917	0.086518	-1.06289
6.3	2	0.019	0.936	0.065962	-1.18071

M	j	f	G(M)	N=-LnG	LOGN
6.4	1	0.010	0.946	0.05584	-1.25305
6.5	1	0.010	0.955	0.04582	-1.33895
6.7	1	0.010	0.965	0.035899	-1.44492
6.8	1	0.010	0.974	0.026075	-1.58377
7.6	1	0.010	0.984	0.016347	-1.78656

Regression constants a, b are found by using least squares method in fig below.

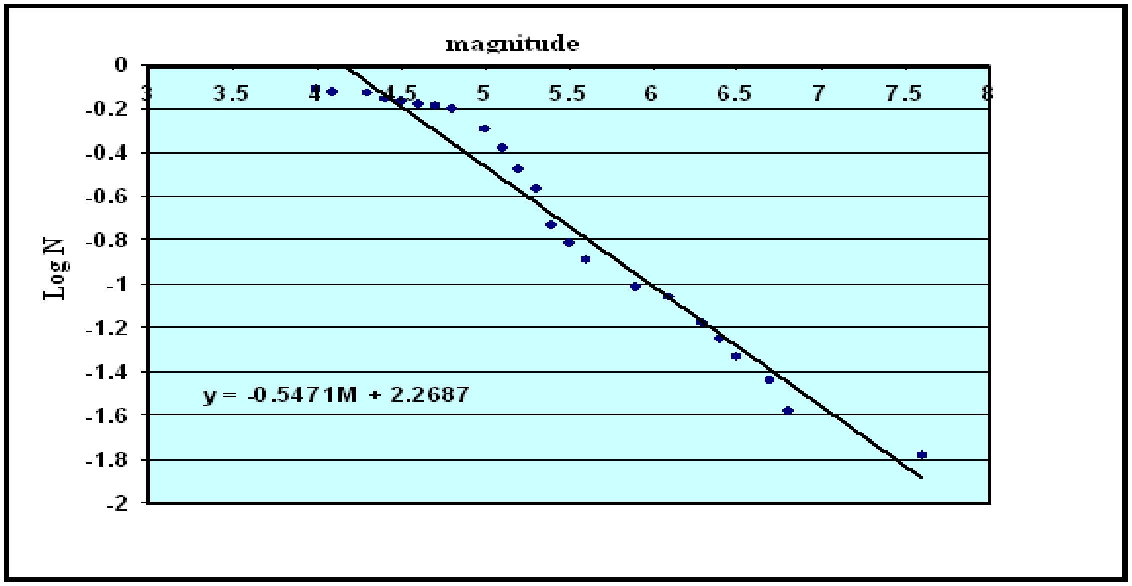

Figure 4: Relation between Magnitude and logN

Magnitude – Frequency Relation

Magnitude – frequency relation have been found for this area as following:

$$\text{LogN} = 2.268 - 0.5471M$$

Gumbel's regressions coefficients (α, β) have been calculated using the magnitude-frequency relation as follows:

$$\alpha = 10^{a} = 10^{2.268} = 185.35$$

$$\beta = b / \log e = 1.26$$

Calculation of Annual Risk (Probability) for different Return Periods

The earthquake number greater than a certain magnitude M for one year N(M), return period (Tr), risk for one year (R_1) and for D year have been calculated using the following formulas (Tezcan,1996):

$$N(M) = \alpha \exp^{-\beta M}$$

$$Tr = 1 / N(M)$$

$$R1(M) = 1 - e^{-N(M)}$$

$$RD(M) = 1 - e^{-DN(M)}$$

The probabilities of earthquake occurrence for the seismic source are calculated for periods of T = 1, 50, 100 years and magnitudes of M = 4.5, 5, 5.5, 6.0, 6.5,7, 7.5 and they are presented in Table 4.

Table 4: Probabilities of Earthquake for Different Periods.

M	N(M)	R1	50N	R50	100N	R100	Tr
4.5	0.63	0.462	31.5	1	63	1	1.58
5	0.34	0.283	17	1	34	1	2.94
5.5	0.18	0.165	9	0.99	18	1	5.55
6	0.09	0.082	4.5	0.98	9	0.99	11.11
6.5	0.05	0.047	2.5	0.91	5	0.99	20
7	0.02	0.019	1	0.63	2	0.86	50
7.5	0.01	0.009	0.5	0.39	1	0.63	100

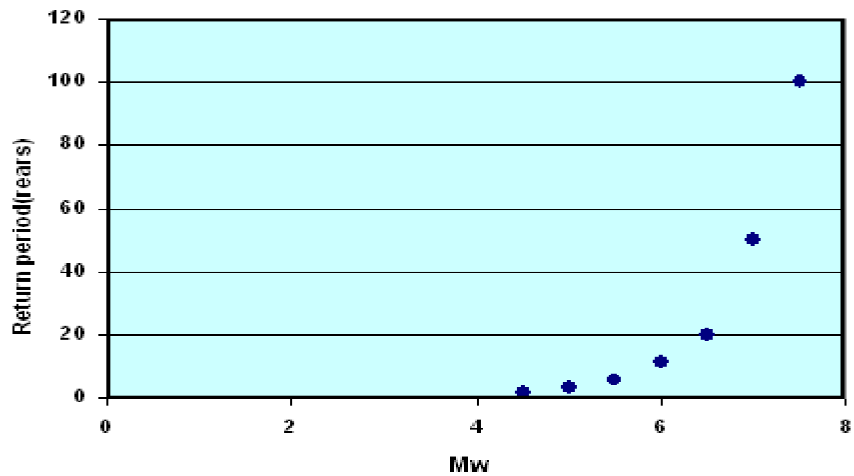

Figure 5: Magnitude Distribution with respect to Return Period.

The above calculations clearly shows that the probability of an earthquake occurrence of equal or greater than magnitude = 7.5 in 100 years within this area is calculated about 63 percent and its return period is 100 years. Now for given annual risk, we can calculate the maximum magnitude and the risk (Rd) for given structure life (Td) using the following formulas and vulnerability analysis in this area can be done in light of above calculated risk. (Tezcan, 1996).

$$M = Ln [-\alpha / Ln (1-R_1)] / \beta$$

$$Rd = 1 - (1-R_1)^{T_d}$$

Need for appropriate Seismicity Risk Studies for this Area

Simplified regional seismic hazard maps as shown in fig 1 are adequate for designing a majority structures and for zoning and planning purpose. But after the muzafarabad earthquake there is need to update all the data like isoseismal maps, seismic hazard zonation maps and probabilistic hazard analysis studies etc, according to latest information and observations. However in earthquake prone country, much more specific seismic site evaluation should be carried out for different structures like dams, bridges, freeways, high rise buildings, nuclear power plants and reactors etc (Bolt, 2006). The estimates in this study can be very helpful in analyzing further this area regarding earthquakes.

Conclusions

Literature review shown that this area one most seismically active region of Pakistan. The historical earthquake data shows that any major earthquake can stuck the area. The Gumbel's extreme value method is considered to be very helpful to estimate the future earthquake return periods because it uses the maximum magnitude of each year and also it is very helpful with respect to construction because it estimates the return periods if earthquakes of maximum magnitudes. In this study the return period calculated for 7.5 magnitude earthquake is 100 years and its probability of occurrence is about 63%. And the Gutenberg-Richter methodology is considered to be very important for magnitude –frequency analysis, regression analysis and to calculate the magnitude of earthquakes.

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