Journal of Himalayan Earth Sciences Volume 52, No. 1, 2019 pp. 51-57

Strain energy release-based seismic hazard of Pakistan and its surrounding areas

Khaista Rehman, Muhammad Younis Khan, Syed Ali Turab and Wajid Ali
National Centre of Excellence in Geology, University of Peshawar, Khyber Pakhtunkhwa, Pakistan
**Corresponding authors email: rehmannceg@uop.edu.pk*
Submitted: 23/1/2019 Accepted:18/3/2019 Published online:29/3/2019

Abstract

The present study area is situated between the latitudes of 21°N and 39°N and the longitudes of 59°E and 77°E. The objective of this study is to estimate seismic hazard in Pakistan as a whole, northern Pakistan and southern Pakistan using cumulative frequency-magnitude distribution and strain energy release methods. The results are in the form of seismicity parameters of a and b-values (zone dependent constants), M1 (the annual mode maxima), M2 (the mean annual rate of energy release), M3 (the maximum credible earthquake), WT (the waiting time for M3 to occur and DT is the delay time. The results indicate that, in general, Pakistan and surrounding region is seismically active (e.g. north Pakistan has b < 1.0).

Keywords: Seismicity, Frequency-magnitude, Seismic hazard, Strain energy, Pakistan

1. Introduction

Modeling seismicity using statistical methods provide an insight into seismic hazard and vulnerability which is of considerable interest for researchers as well as insurers, land use planners, and emergency response agencies. Burton (1990) suggested various mathematical and statistical methods for modelling of seismicity analysis. The mathematical and the statistical approaches are the Cornell-McGuire approach, the cumulative frequency-magnitude distribution, cumulative strain energy release, part process statistics and others methods. The traditional and general approach need information regarding the input catalogue data. The advantages and disadvantages of the traditional and the statistical approaches vary in objective and study area. For example, the advantage of the strain energy released method is that it considers the whole earthquake catalogue than the part process method. The detail discussion of the advantages, disadvantages and the differences of the seismic hazard methods have been discussed by various authors (Burton, 1990; Rehman et al. 2014; Rehman et al. 2018). The first method of magnitude-frequency (Gutenberg and Richter, 1944) used in current study is is given by+

$$LogN(m)=a - b\ (m)$$

Where N(m) is the number of events per unit time with magnitude greater than or equal to m.

Parameters a and b are the constants and can be calculated from the existing earthquake catalogues for each area. N(m) is a cumulative number of earthquakes with magnitude $\geq m$. b-value depend upon of tectonic and seismic activity of the region and is inversely proportional to the stress(Olsson, 1999).

Second applied method to Pakistan is the strain energy released method which is discussed in detail in the next section. Seismic hazard studies should not be restricted by national boundaries and all important and input information for seismic hazard beyond the borders should include (Alsan et al., 1975; Giardini,1999; Bayliss and Burton, 2007). Therefore, the chosen area of interest is Pakistan and its surrounding areas (Hindu Kush of Afghanistan; Kangra, Himachal Pradesh, India and Kutch region, India near the south-east border with India). Seismic hazard parameters using strain energy release and Gutenberg-Richter methods are calculated for Pakistan as a whole, northern Pakistan and its surrounding areas and southern Pakistan and its surrounding areas.

2. Seismicity of Pakistan

Figure 1 is an epicentre map for the earthquakes defined by earthquakes taken from Rehman et al. (2014) catalogue. The different magnitude ranges with different time periods are used in the data set. Shallow depth earthquakes and intermediate depth earthquakes are also shown by various legends in the figure. The intermediate earthquakes occurred mainly in Hindu Kush region of Afghanistan and Pakistan. This catalogue covers the north Pakistan (33-39° N and 65-77°E), south Pakistan (21-33°N and 59-77°E), Hindu Kush of Afghanistan and Pakistan and Indian-Pakistan border in northeast and southeast. The spatial variations in seismicity differentiate north Pakistan from south Pakistan. This is due to the dominated seismic activity in the region of north Pakistan and surrounding region. Seismicity increased dramatically in parts of Afghanistan and Pakistan (Hindu Kush) further to the north-east, where large number of intermediate earthquakes are occurred. Furthermore, 37 major earthquakes occurred in north Pakistan compared to the seven major earthquakes in south Pakistan. In addition, two deep focus earthquakes occurred in north Pakistan at 38.4N, 76.2 E reported by ISC and 36.63° N, 71.69° E reported by Engdahl et al. (1998). The general tectonic structures that affecting Pakistan and its surroundings is discussed in detail by Kazmi and Jan (1997). From north to south, the most prominent faults are the MKT Main Karakoram Thrust (MKT), the Main Mantle Thrust (MMT), the Main Boundary Thrust (MBT), , the Salt Range Thrust (SRT), Chaman Fault (CH), Ghazaband Fault (GF) and Makran Coastal Fault (MCF). Similarly, the structural features include the Nanga Parbat and Hazara Kashmir syntaxes, (HKS) which are located in north Pakistan. Owing to the above mentioned factors the three areas of interest are chosen to evaluate seismic hazard for Pakistan as a whole, and for the north and south Pakistan. The north Pakistan and its surrounding areas are named as NPS, while south Pakistan and its surrounding region are named as SPS.

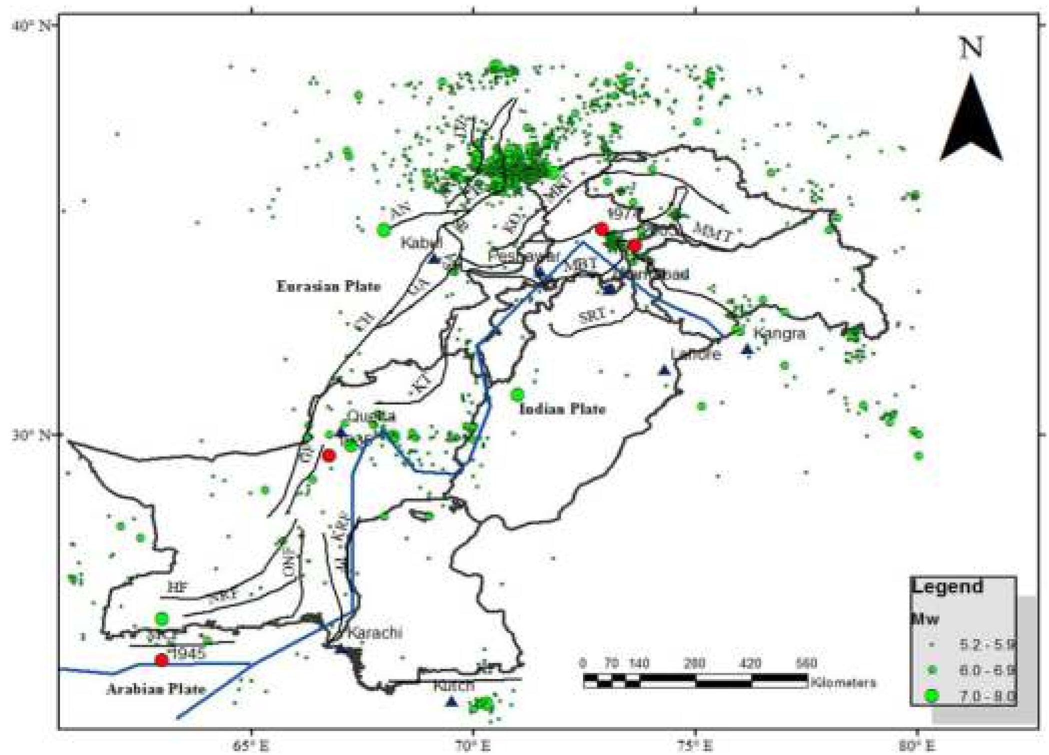

Fig. 1. Epicentral distribution of earthquakes used in the present study. Main Faults are include: MBT Main Boundary Thrust, MCF Makran Coastal Fault, MKT Main Karakoram Fault, MMT Main Mantle Thrust, RKF Runn of Kutch Fault. Thick blue lines show the location of the Indian plate, the Eurasian plate and the Arabian plate (Rehman et al. 2014).

3. Methodology

Statistical models play an important role in understanding seismicity and seismic hazard of a region (Makropoulos and Burton 1983; Rehman et al. 2014). Several statistical models have previously been proposed to estimate seismic hazard in Pakistan (Quittmeyer, 1979, Seeber and Armbruster, 1979; Seeber et al., 1980; MonaLisa et al., 2002). Similarly, our applied method of strain energy release method have been widely used to characterise and quantify seismicity throughout the world. Makropoulos and Burton (1983) presented seismic risk using strain energy approach. Hamdache (1998) examined seismic hazard in northern Algeria using physical strain energy release. The parameters of strain energy in Egypt have been calculated by Soheir and El-Hemamy (2004). Cole et al. (2006) have analyzed seismic hazard of north China using coseismic strain energy release.

Bath's (1958) relate strain energy release with earthquake magnitude through the following expression:

$$\text{Log } E = 1.44\ M + 12.24 \quad (2)$$

Where E is energy and M is magnitude. The graphical application of strain energy release method is easy to apply and illustrates important model in seismic hazard analysis (Makropoulos and Burton, 1983; Figure 2). M1 can be obtained from the parameters of a and b-values of the frequency-magnitude relation. Line-slope connecting the start and end energy values, and therefore denotes the mean strain energy released annually. This is defined as M2 using a convention introduced by Makropoulos and Burton (1983). Differences in the results are enclosed by two parallel positions to M2, shows the total amount of energy that may stored and released in a region. This maximum strain energy release in a region is called the large earthquake magnitude, termed as M3, if no other earthquake occurs during this time period. This is shown in figure 2b by perpendicular departure of the inclosing lines. The minimum waiting time (WT) indicated by the time difference between two enveloping lines shows the time period required to store the maximum energy. A fourth strain energy released method parameter is delay time, DT, which is the shortest possible time difference in years from the point of the last seismic activity to cross the lower parallel line.

4. Results and discussion

Figure 2, 3 and 4 are created to discuss the results for Pakistan as whole, NPS, SPS respectively using frequency-magnitude distribution (FMD) and cumulative strain energy release (CSER). For each area of interest the FMD and CSER is graphically displayed for time period of 1900-2007. We start by discussing figure 2 showing seismic hazard in Pakistan as a whole. The a and b values of 8.28 and 0.969 (Fig. 2a) calculated using whole process statistics of cumulative frequency-magnitude distribution.

The large earthquake magnitude found by strain energy release to be M3= 8.17 (Fig. 2b). 8.1 of November 27 1945, is the maximum earthquake magnitude in the post-1900 dataset. Gutenberg and Richter (1954) have given surface wave magnitude of 8.08 to this great earthquake, while Geller and Kanamori (1977) assigned Ms 8.0. 45 years is determined for the waiting time and 8.54 is the most probable magnitude. The mean annual earthquake magnitude, M2, is 7.26 with the delay time, DT, is 5.20 years. All these values are shown in Table 1.

Figure 3 shows the distribution of parameters M2, M3, WT and DT for a catalogue period of 1900-2007 for NPS using CSER, along with parameters of FMD (M1, a-value, b-value). The values of a and b from frequency-magnitude distribution method results in 8.1 and 0.953 respectively, while the annual mode magnitude is 8.49. 1905 Kangra earthquake, 1974 Pattan earthquake and 2005 Kashmir earthquake are the examples of large to major earthquakes which generally indicate seismic activity in this region. The seismic hazard parameters from strain energy release are M2=7.16, M3=8.03, WT=22 years and DT=4.87 years. If the results of seismic hazard parameters for NPS are compared with that of whole Pakistan then both indicates comparable values. The difference between the values of M3 is 0.14. This is because NPS is characterized by dominant seismic activity throughout Pakistan and the existing of intense seismic zone of shallow and intermediate earthquakes in the Hindukush region (NW Pakistan and NE Afghanistan).

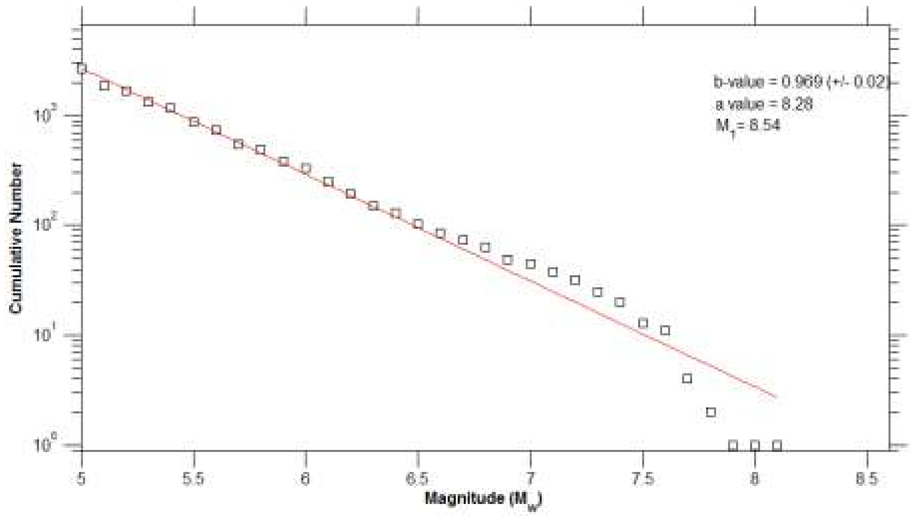

Fig. 2a. Plot of the cumulative number of earthquakes for the region of whole Pakistan.

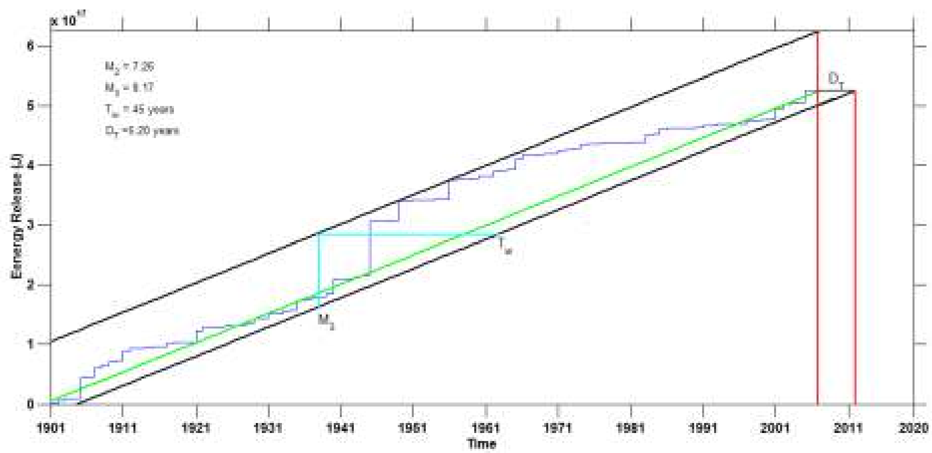

Fig. 2b. The cumulative strain energy released model for whole Pakistan

Table 1. Calculated cumulative strain energy release parameters, along with FMD parameters

Area of Interest	a	b	M1	M2	M3	Wt (years)	Dt (years)
Whole Pakistan	8.28	0.969	8.54	7.26	8.17	45	5.20
NPS	8.1	0.953	8.49	7.16	8.03	22	4.87
SPS	7.93	1.04	7.6	6.99	8.11	65	23.10

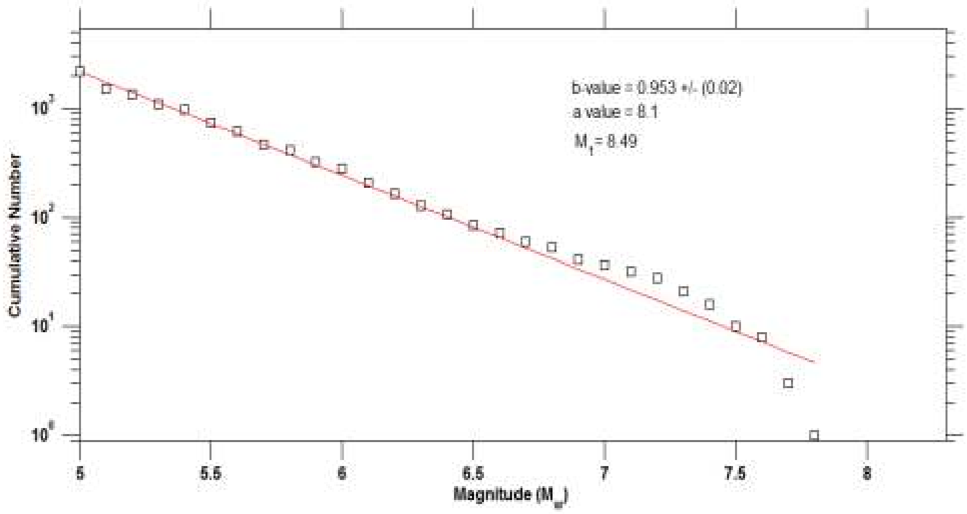

Fig. 3a. The FMD method applied to north Pakistan.

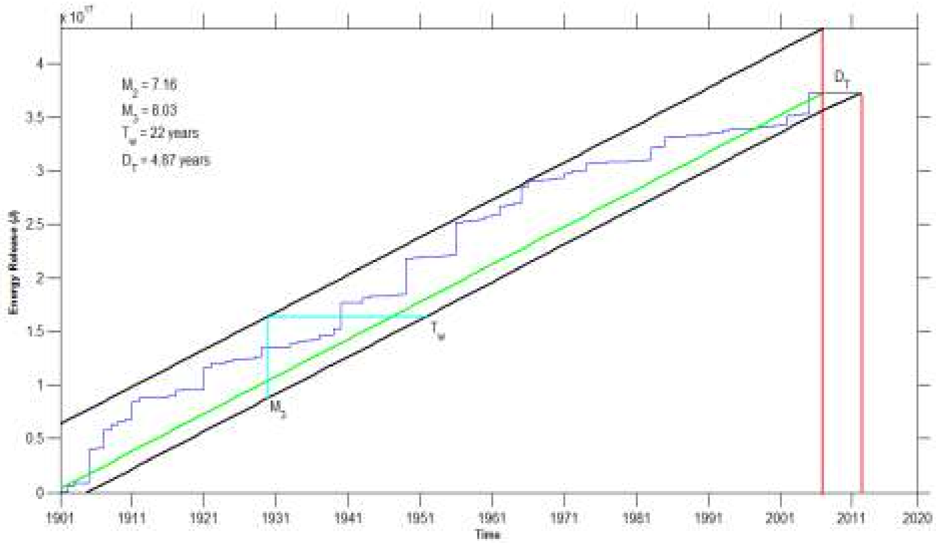

Fig. 3b. CSER plot and the results for north Pakistan.

Finally, Figure 4 shows the seismic hazard parameters for SPS using FMD and CSER. The calculated values of a and b are 7.93 and 1.04 using FMD method for SPS , while the annual mode magnitude is 7.6 which is different from whole Pakistan and NPS values. Similarly the obtained results of seismic hazard are M2=6.99, M3=8.11, WT =65 years and DT =23.10 years for SPS using CSER. 1935 Quetta earthquake, 1945 Makran earthquake and 2001 Kutch earthquake are the important earthquakes which characterise this region. This region has higher value of M3 compared to NPS. The 1945 earthquake dictates overall seismic hazard within this region resulting in a maximum credible magnitude of 8.11. In addition the energy release of eight earthquakes greater than or equal to magnitude 7 after the 1905 event give general impression that strain energy is constructing again (the energy line close to upper enveloping line compared with whole Pakistan and NPS) and this corresponds to a waiting time of 65 years and delay time of 23.10 years. If the results of waiting time and delay time are compared with the CSER in NPS then the SPS is seen as higher values. This is because more earthquakes are found in NPS than SPS.

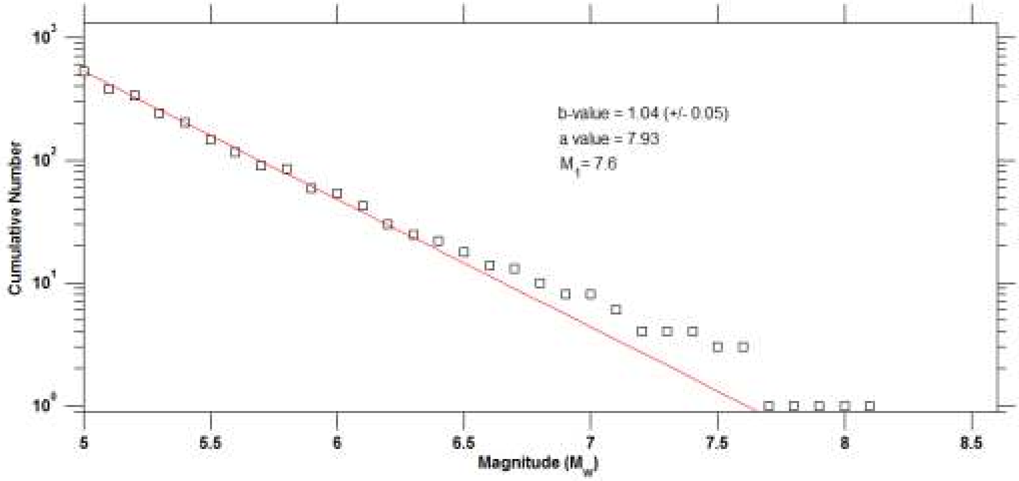

Fig. 4a. Plot of the cumulative number of earthquakes for SPS.

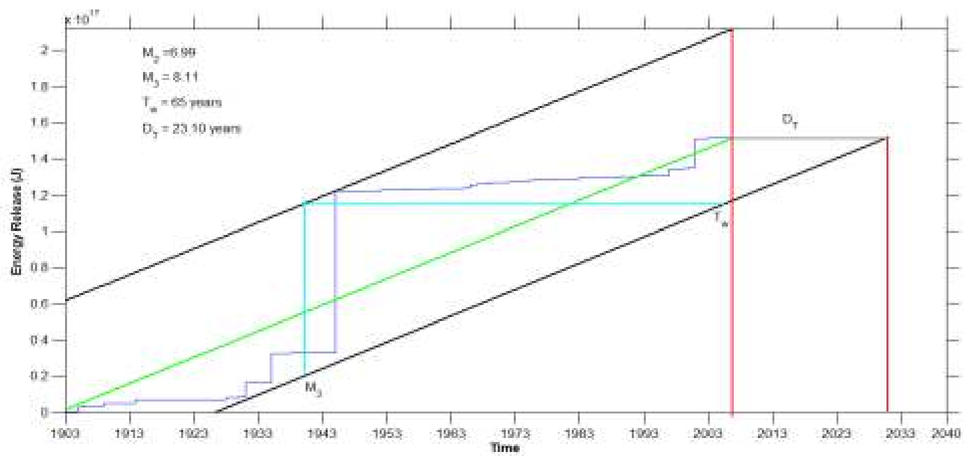

Fig. 4b. CSER model for south Pakistan.

5. Conclusions

In the present study, seismic hazard in Pakistan and the surrounding areas has been assessed using both the method of cumulative frequency-magnitude distribution and cumulative strain energy release. The parameters of seismicity has been used to derive seismic hazard in terms of a value, b value, M1, M2, M3, WT and DT for the time period 1900-2007, and are tabulated in Table 1. The results are estimated and displayed for Pakistan as whole, north Pakistan and its adjoining areas and south Pakistan and its adjoining areas. The most important results is that the difference between the NPS and SPS in seismic hazard values exist due to the spatio-temporal distribution of earthquakes in two both different tectonic regions. Similarly, similarity exist between the NPS and whole Pakistan seismic hazard values as the earthquakes occurred mostly in north Pakistan. The results obtained, particularly M3, show that south Pakistan has higher values than north Pakistan and that the NPS has similar values with whole Pakistan. In general, the seismic activity of whole Pakistan, north Pakistan and south Pakistan is high as demonstrated from the various seismic hazard models for the investigated region.

Acknowledgment

We acknowledge the research facilities provided by the National Centre of Excellence in Geology, University of Peshawar, Pakistan. The authors wish to thanks the anonymous reviewers for their insightful comments.

Author's Contribution

Khaista Rehman, proposed the main concept and involved in write up. M. Younis Khan assisted in collection and preparation of the seismic catalogue data. Syed Ali Turab helped in geological faults related work. Wajid Ali was involved in review and proof read of the manuscript before submission.

References

Alsan, E., T`ezucan, L., Bath, M, 1975. An earthquake catalogue for Turkey for the interval 1913–1970, Common Rep. 75 Kandilli Turkey Obs., Seism. Inst. Uppsala, Sweden.

Bathh, M., 1958. The energies of seismic body waves and surface waves. In: Benioff, M., Ewing, B.F., Howell Jr., F. Press (Eds.), Contributions in Geophysics. Pergamon, London, 1, l-16.

Bayliss, T, J., Burton, P. W., 2007. A new earthquake catalogue for Bulgaria and the conterminous Balkan high hazard region, Nat. Hazards Earth Syst. Sci, 7, 345–359,

Burton, P. W., 1990. Pathways to seismic hazard evaluation: extreme and characteristic earthquakes in areas of low and high seismicity. Natural Hazards, 3, 275-291.

Cole, S, Xu, Y., Burton, P, W., 2006. Seismic Hazard of the North South seismic zone, China, First European Conference on Earthquake Engineering and Seismology, Geneva, Switzerland, Paper Number, 582.

Gutenberg, B., Richter, C.F., 1944. Frequency of earthquakes in California. Bulletin of the Seismological Society of America, 34, 1985-1988.

Hamdache, M., 1998. Seismic Hazard Estimation in Northern Algeria, Natural Hazards, 18, 119–144.

Kazmi, A, H., Jan, M. Q., 1997. Geology and tectonics of Pakistan. Graphic Publishers, Huntsville

Lisa, M., Khwaja, A. A., Qaiser, M., 2002. Focal Mechanism studies of Kohat and northern Potwar deformed zone (NPDZ), Pakistan, Geological Bulletin University of Peshawar, 35, 85-95.

Makropoulos, K. C., Burton, P. W., 1983. Seismic risk of circum-Pacific earthquakes, I. Strain energy release, Pageoph, 121, 247- 267.

Olsson, R., 1999. An estimation of the maximum b-value in the Gutenberg-Richter relation, Geodynamics, 27, 547-552.

Quittmeyer, R. C., 1979. Seismicity Variations in the Makran Region of Pakistan and Iran: Relation to Great Earthquakest., Pageoph, 117, 1212- 1228.

Rehman, K., Burton, P.W., Weatherill, G., 2014. K-means cluster analysis and seismicity partitioning for Pakistan. Journal of Seismology, 18(3), 401–419.

Rehman, K., Burton, P. W., Weatherill, G. A., 2018. Application of Gumbel I and Monte Carlo methods to assess seismic hazard in and around Pakistan. Journal of Seismology. 22, 575-588

Seeber, L., Armbruster, J., 1979. Seismicity of the Hazara arc in northern Pakistan: Decollement vs. basement faulting. In: Farah, A., DeJong, K. (Eds.), Geodynamics of Pakistan: Quetta, Geological Survey of Pakistan, 131-142.

Seeber, L., Armbruster, J., Farhatullah, S., 1980. Seismic activity at Terbela Dam site. Geological Bulleton, University of Peshawar, 13.

Soheir, T., Hemamy, E., 2004. Seismic hazard evaluation using strain energy release in Egypt, 13th World Conference on Earthquake Engineering Vancouver, B.C., Canada, Paper No. 2255.