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Gutenberg-Richter recurrence law to seismicity analysis of Bangladesh

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ABSTRACT: Geographically, Bangladesh is situated near the border of Indian plate. The E-W boundary of the country at the top runs parallel to the active Dauki fault and which is the source of few large historic earthquakes. To the east, it follows the Chittagong-Myanmar fault. The country is qualitatively symbolized as a zone having considerable seismic risk. Earthquake information of the country (pre-historic, historic and even instrumental era) is very limited to take any convincing resolution on the seismicity of the country. Incompleteness of the earthquake catalogue and absence of instrumental data of the recent days is very apparent. This study tries to establish a seismic recurrence law for the country and represents calculation of *b*-value for Bangladesh as a whole and for near-to-fault regions like Sylhet and Chittagong. The paper compares the appropriateness of using one value for Probabilistic Seismic Hazard Analysis (PHSA) for the whole country. Incompleteness of earthquake catalogue of Bangladesh is further studied. The earthquake data from 1973 to 2013 as available from USGS database has been used in this study.

1 INTRODUCTION

Can we predict an Earthquake? Or can any other animal predict earthquakes? Strange behavior of animal before the earthquake has been reported from prehistoric time. In the 1970s, a few studies on animal prediction were done by the USGS but nothing concrete came out of it. It is learnt that the Chinese are still continuing to look at animal behavior as an aid to earthquake prediction. They have had several notable successes and also a few false alarms. It may be interesting to observe the Dogs, Ants and some type of Cat fishes to know when an earthquake is coming. Unfortunately it gives very less time to get some preparation and also one does not feel 'scientific' with animal observation for earthquakes.

Scientific prediction (at least to some level) of earthquakes starts with the observation of past earthquakes. Gutenberg and Richter (1944) plots the Frequency - Magnitude Distribution (FMD) of past earthquakes and showed that earthquakes are not randomly distributed in time, space and magnitude. Distribution of earthquakes with respect to magnitudes exhibits scale invariability, appears to be self-similar and obeys a power law. They developed an empirical relation defining distribution of earthquakes with respect to the magnitudes as,

$$log\ (\lambda m) = a - bm \qquad (1)$$

where , λm is the mean annual rate of exceedance of magnitude m, a and b are positive real constants. a, describes the seismic activity. b, usually known as *b-value* describes the relative abundance of large to smaller shocks. Equation (1) is usually referred to as the Gutenberg-Richter (G-R) earthquake recurrence law.

It can be shown also that the linear relation holds only for magnitudes m in a certain range. But still this equation is very robust and successfully describes the seismicity of a region if a complete earthquake catalogue of the area exists.

The coefficient b, supposedly a fundamental seismologic constant, varies significantly in space and time. To characterize the seismicity rate, λm and risk of a given region, one need to solve for the values of a and b.

This study is concerned with solving for the long term average values of these parameters for the entire Bangladesh and other two more seismically active zone of Sylhet and Chittagong separately and check if a single *b-value* is possible to use.

2 SEISMICITY BANGLADESH CONTEST

Bangladesh is situated between 20°34″ N ~ 26°38″N and 88°01″ E ~ 92°41″E. From the remaining of *Wari-Bottessor (a 2500 years old ancient city near Dhaka)*, it may be assumed that very ancient civilization exists in this part. However, ancient history of earthquake of the country is very limited. May be the earliest known earthquake is 1664 Bengal earthquake. A list of the historic earthquake can be found in Banglapedia but for a more realistic catalog, Global Earthquake Model (GEM) (http://www.globalquakemodel.org/what/seismic-hazard/historical-catalogue/) may be searched for.

Bangladesh has no own record of earthquake history. One analogue seismograph was installed in 1954 in Chittagong but no data is available in the public domain. Instrumentation era started by instrumentation of Jamuna Bridge. Jamuna Multipurpose Bridge Authority completed the instrumentation work in 2003. Later sixty more accelerographs were obtained from SAFER cities project of COSMOS - WSSI to deploy in the free-field at different location of Bangladesh. Thirty four (34) Strong Motion Accelerographs (SMA) are installed in different locations of PWD office and BUET campus in 2006.

Bangladesh has entered in to the instrumentation era truly in 2006. But the result is a big NO. We have no earthquake data, no strong motion recording. The instrumentation was only a PROJECT. Accelerometers are said to have configured not to record small earthquakes. But small earthquakes are necessarily needed to complete the earthquake catalogue. Hence, there are no county resources available for record and maintain earthquake data that may be required for a decision making process.

The work under the study was done using the earthquake catalog obtained from United State Geological Society (USGS) database (http://earthquake.usgs.gov/earthquakes/search/)

3 STUDY AREA

A relatively wider study area from 20^0 N-28^0 N and 86^0 E-94^0 E (area covers 722,904.41 sq.km) was chosen to get a complete earthquake catalogue.

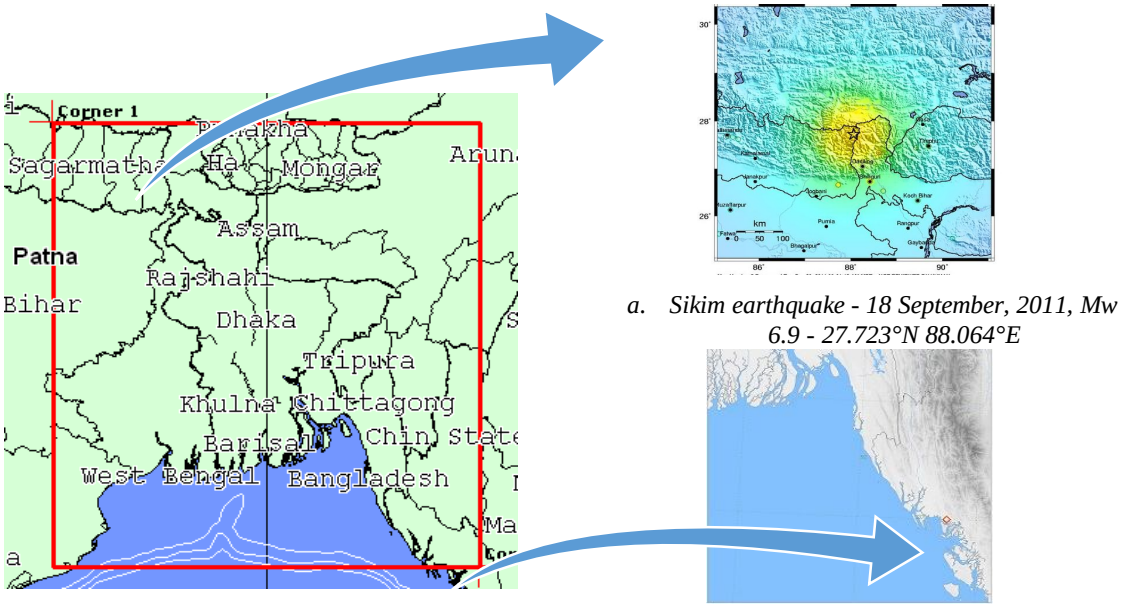

Figure 1. Study area bounded by 20N-28N to 86E-94E

a. Sikim earthquake - 18 September, 2011, Mw 6.9 - 27.723°N 88.064°E

b. Arakan earthquake – 2 April, 1762, Mw 8.8 20.00^0N 93.50^0E (Cummins, 2007)

This is because to cover the three major fault lines that encompass Bangladesh from North-East to North-South (at the east) like Dauki fault, Sylhet-Asam fault and Chittagong – Mayanmar fault. From the information of early historic earthquakes (1664 ~ 1900), only two are more reliably documented, The Great Indian earthquake of 1897 and the Arakan earthquake of 1762 (though debate is still going on the intensity and location of these two earthquakes). The study area extended below south the cover the 1762 earthquake and up to North to cover the recent Sikkim earthquake of 2011.

Two sub-regions are defined as i. Sylhet bonded by latitude 24N-26N and longitude 90E-94E(area covers 89,659 sq.km) and ii. Chittagong bonded by latitude 20N-24N and longitude 91E-94E (area 137,558 sq.km)

3.1 *Basic Data*

A search from USGS site for study area yields 796 nos. of earthquake covering from 1918 to 2013 (the work was done in 2014.). Distribution of the earthquakes over the time is plotted in Figure 2.

It can be seen from Figure 2, that the earthquake Catalogue as available from USGS website is very incomplete in the given space of time. Data are missing for small earthquakes from the beginning up to about 1970. Completeness of such Catalogue is out of question. Regular earthquake data (whatever it may be) is only available from 1973 and onward.

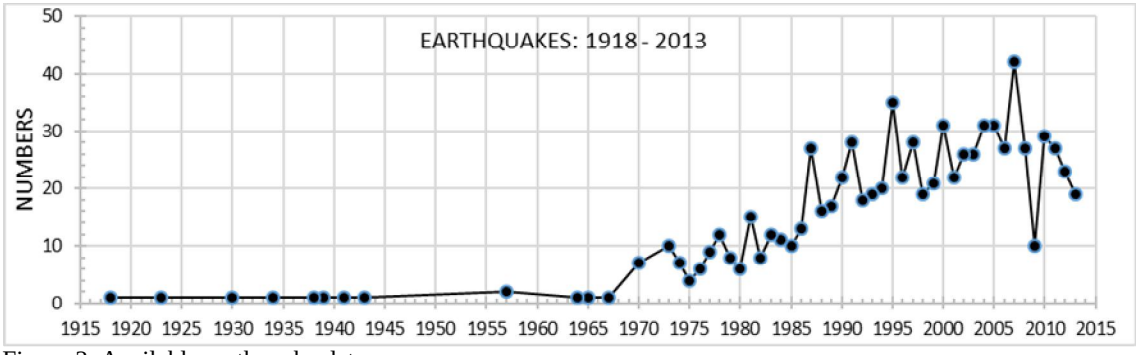

Figure 2. Available earthquake data

Distribution of earthquake intensity over this 40 years of study period is shown in Figure 3.

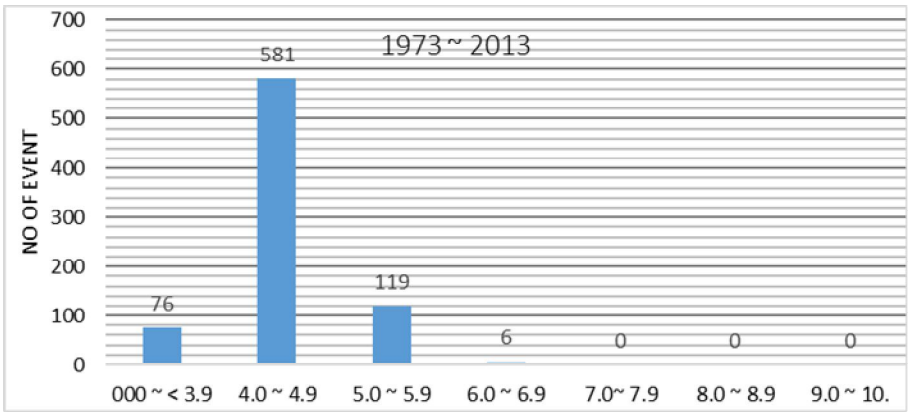

Figure 3. Magnitude distribution over the study time

This study discard data earlier 1973. Other information on basic study area and data can be found in Table 1.

Table 1. Basic information on study area and data used

Sl.	Study area	Latitude	Longitude	Area, sqm	Observation Pe-	Data	Intensity, Mw
1	Bangladesh	20N-28N	86E-94E	722,904.41	1973 ~ 2013	782	3.4 - 6.9
2	Sylhet	24N-26N	24E-26E	89,659.00	1973 ~ 2013	400	3.5 - 6.0
3	Chittagong	20N-24N	91E-94E	137,558.00	1973 ~ 2013	247	3.5 - 6.0

Average annual recurrence of earthquake $log(\lambda m)$ is plotted in Figure 4. Completeness threshold set to M_c = 4.4 from eye estimation (see Figure 4) for the full study area and the two regions.

3.2 *Analysis*

Analysis for *b-value* has been made for available data from 1973 to 2013 over the observation period of 40 years and magnitude distribution up to 6.9 (1988 Nepal-India border earthquake). Least Square data fitting method has been employed to find the '*a*' and '*b-value*'. Figure 5 represent the plot of the regression analysis.

The equations for G-R recurrence law can be summarized with the calculated '*a*' and *b-value* as calculated as :

For whole study area (Bangladesh) - $log(\lambda m) = 6.0311 - 1.1227\, m$ (2)

For region 1 (Sylhet) - $log(\lambda m) = 6.8561 - 1.3471\, m$ (3)

For region 2 (Chittagong) - $\log(\lambda m) = 6.9104 - 1.4104\, m$ (4)

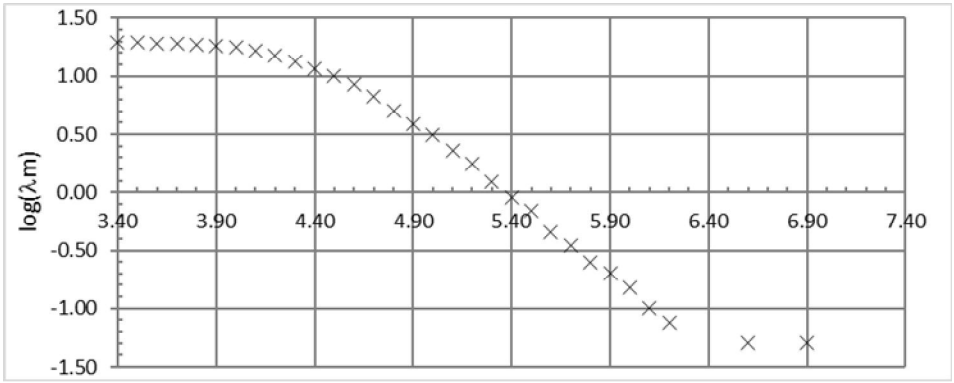

Figure 4. Frequency Magnitude Distribution of the available data

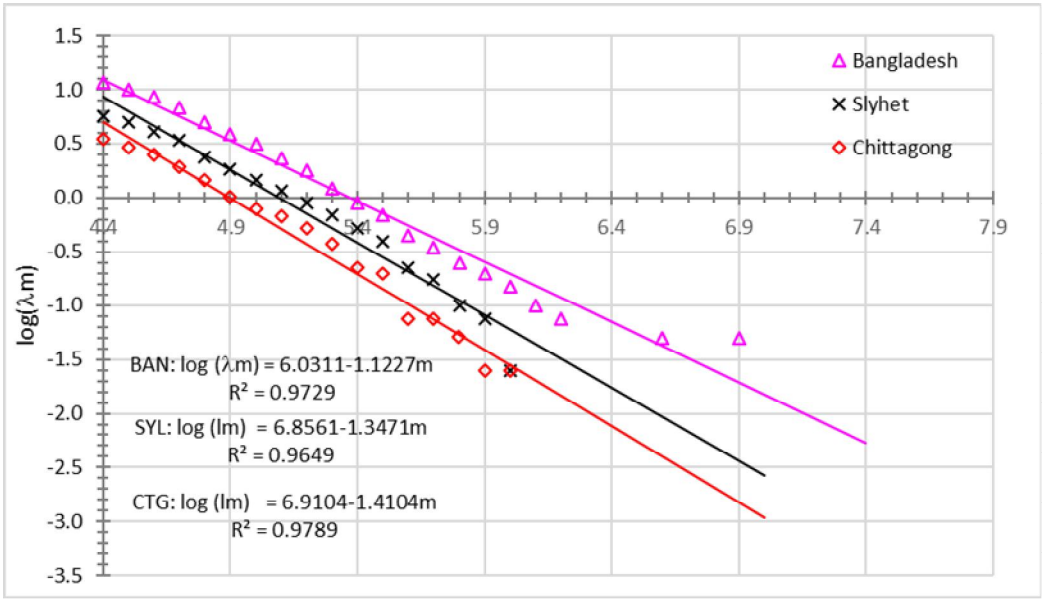

Figure 5. a and b-values and G-R earthquake recurrence law

It can be seen that same *b-value* cannot be used for both Sylhet and Chittagong region. Seismic risk assessment for Bangladesh needs to be done carefully with appropriate *b-value* of the regions. One *b-value* may not be rightly applicable for the whole country. However, it may be noted that for the observation period (1973 to 2013), the equation fits quite well with the observed earthquakes (calculated R^2 value is more than 97%) and may be used to predict future earthquakes up to magnitude 6.5 or less with confidence and for higher earthquake with caution.

4 CONCLUSIONS

The *b-value* represents the relative abundance of large earthquakes over small earthquakes. With the increase of *b-value*, the number of large magnitude earthquakes decreases in comparison to those of small earthquakes. Calculated *b-value* estimates recurrence period of large earthquake is relatively more spaced over the time for Bangladesh. This agrees with the idea of Roger Bilham (2004) *"….The strain rate within the Indian plate is observed to be less than 3 ns/yr (Bilham and Gaur, 2000) and the renewal time for earthquakes in the subcontinent may exceed many thousands of years, rendering it unlikely that earthquakes will have repeated during the time of written records."*

And also same conclusion made by Roger Bilham and Philip England in their article "Plateau 'pop-up' in the great 1897 Assam earthquake".

"….. Our conclusions also raise important issues concerning the seismic hazard potential of the Shillong Plateau. The >300-km length of the Dauki fault has not slipped recently, but were it to slip in a single earth-

quake its potential maximum magnitude (M 8) would constitute a significant seismic threat to nearby densely populated regions of Bangladesh, and to the megacity of Dhaka less than 150 km to the south. The interval between these giant plateau-building earthquakes fortunately exceeds 3000 years."

Probabilistic Seismic Hazard Analysis (PHSA) has been used for seismic hazard estimation of Bangladesh. A basic assumption of PSHA is that the earthquake recurrence law obtained from past earthquakes is appropriate for the prediction of future earthquakes. Establishing the earthquake recurrence law requires a complete earthquake catalogue. Bangladesh lacks a complete earthquake catalogue – this need to be keep in mind in calculation of seismic risk.

With the existing data as available – occurrence of large earthquake in the study area is quite spaced in time. Nevertheless, by this time, enough instruments have been placed in different parts of the country but only needing immediate data collection for better estimation of earthquake risk for the Country in the near future.

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