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Earthquake Vulnerability of Bangladesh: A Probabilistic Prediction

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Abstract: *Earthquakes are impulsive turmoil in the earth's crust that causes enormous loss to life and property. The tectonic plate's movement and their overlapping are often unpredictable and can happen at any geographical location. This study was conducted for Bangladesh, bounded by specific latitudes and longitudes, to identify the earthquake vulnerability and its probabilistic prediction. The data of different parameters were taken from USGS database for the time period of 1900 to 2019. Perceived three major fault lines are located within the country. There were 44, 332, and 509 earthquakes having ML 5.6≤, 4.6 to 5.5 and 4.5≥ respectively. The average interval among major earthquakes was highest compare to moderate and minor earthquakes. The mean occurrence period of earthquakes (major, moderate, minor) in Bangladesh were calculated by applying Weibull distribution. It is expected to have another major earthquake is average three and a half years later than the preceding one. On the contrary, the moderate and minor earthquakes are expected on an average within sixty nine and thirty two days later.*

Keywords: *Earthquake, Probabilistic prediction, Bangladesh*

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I. Introduction

An earthquake is a trembling or a shaking movement of the ground, caused by the slippage or rupture of a fault within the Earth's crust. Bangladesh is positioned at the juncture of several active tectonic plate boundaries. Moreover, it sits a top of the world's largest river delta at close to sea level, facing both the risk posed by a quake and secondary risks of tsunamis and flooding in the quake's aftermath [1]. Major earthquakes generally instigate with trivial tremors but take no time in transforming into vicious shocks. An earthquake of higher magnitude is followed by quakes of low intensity and is often termed as aftershocks. The point of source at which the rocks start to crack is the focus and the point directly above the focus on the exterior is the epicenter. The extent of magnitude and intensity of an earthquake is measured by scales like Richter scale, improved Mercalli scale and the moment magnitude scale. The effects of an earthquake are most powerful in a wide zone adjoining the epicenter; most highly affected regions are those which are thickly populated urban territories where structures are not assembled to survive exceptional shaking. A tremor measuring 7 magnitudes on the Richter scale may destroy about 35 percent buildings and kill around 25,000 people [2]. At 25 April 2015, our neighboring country had been affected by a 7.8 magnitude earthquake killed more than 8,000 people and left hundreds of thousands homeless, in the worst natural disaster to strike Nepal since 1934. In some parts of the country, the quake flattens 98% of all homes in hillside villages. 5 August 2018**,** more than 460 people were killed after a 6.9 magnitude earthquake hit the Indonesian island of Lombok [3]. However, occurrences of earthquakes both inside and outside of the country and around major cities indicate that earthquake hazard exists for the country in general and the cities in particular. Bangladesh can be divided into three main earthquake zones (Zone-1: Sylhet-Mymensingh is with the possible magnitude of 7 on Richter scale; Zone-2: Chattogram-Comilla-Dhaka and Tangail are with the possible magnitude of 6 on Richter scale; Zone-3: Rest of the country is with possible magnitude of 6 on Richter scale) according to earthquake vulnerability. Seismic experts consider recent repeated earthquakes of low to medium magnitude as an advance warning for a massive, and potentially disastrous earthquake in the near future, as these tremors fail to release the majority of the stress that accumulates within fault rupture zones [4]. The country has experienced at least 360 earthquakes of minor-to-moderate magnitudes between 1971 and 2019 [5]. The time and place of earthquakes cannot be guessed accurately as most earthquakes are unpredictable, but there can be a possibility of a prediction system by which people can be informed about safety instructions, precautionary measures and important information, which can guide them to a safer place. Moreover, safety measures can be taken prior to an earthquake in order to avoid damage to life and property. However, earthquake prediction information is very inevitable for future planning and execution of any extension program. Thus, the study was taken under consideration to analyze the earthquake vulnerability of Bangladesh and its probabilistic prediction. From the different studies directed by Rahman et al., 2018 [6]; Zaman, 2017 [7]; Alam, 2017 [8]; Al-Hussain et al., 2012 [9]; Paul, 2010 [10]; Sarker et al., 2010 [11]; Sutradhar et al., 2008 [12]; Bilham, 2000 [13]; Ali, 1998 [14]; Hagiwara, 1974 [15]; Rikitake, 1974 [16]; and Ustsu, 1972 [17], the researcher was influenced in conducting this study. This might be an advancement of earthquake prediction and would be an improvement over the present prediction system apparently due to utilizing the latest data available up to the year 2019.

II. Materials and Methods

The study was conducted for Bangladesh considering the geology and tectonics. The epicenters of earthquakes of NE Indian region bounded by Latitudes 20^0N-28^0N and Longitudes 87^0E-94^0E were considered. In this study, data were collected from secondary sources. The researcher herself collected the secondary data from different published articles, website of Bangladesh Meteorological Department [18], and USGS data base [5]. Data were collected from 1900 to 2019 of different earthquakes. All earthquakes data were categorized into three strata (minor, moderate and major). After checking, the data were transferred to MS Excel for further analysis. The collected data were tabulated and analyzed in accordance with the objectives of the study. Simple tabular technique of analysis was followed. In order to interpret the findings, descriptive statistics were used.

2.1 Analytical Techniques

Different parameters of Weibull distribution were also estimated to predict the earthquake. According to Vevsel Yilmaz [19], in modeling earthquake data the most appropriate distribution was established as Weibull distribution. The Weibull distribution is one of the best-known lifetime distributions. Weibull distribution is widely used in reliability engineering and elsewhere due to its versatility and relative simplicity. It adequately describes observed failures of many different types of components and phenomena. Henceforth, Weibull distribution was considered to determine earthquakes risk. Let us consider T is a random variables defined as years elapsed between two earthquakes occurred successively on different areas in Bangladesh. The probability density function of T random variable is seen, in detail [20], [21].

$$f(t;\alpha,\beta) = \beta e^{-\beta} t^{\beta-1} \exp\left(-\alpha^{-\beta} t^{\beta}\right);\ 0<t<\alpha, \alpha > 0, \beta > 0 \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots (1)$$

and the cumulative distribution and the reliability function are

$$F(t) = 1 - \exp(-(\frac{t}{\alpha})^{\beta}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (2)$$

$$R(t) = \exp(-(\frac{t}{\alpha})^{\beta}) \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . (3)$$

and the mean of the two parameter Weibull distribution is

$$E(t) = \alpha\Gamma\left(\frac{1}{\beta} + 1\right) \ldots \ldots \ldots \ldots (4)$$

Equations (2), (3), *α* and *β* are fitting parameters of the distribution. Yilmuz [22] fits this distribution to finding out ML estimation on earthquake data. The cumulative distribution function of the Weibull distribution indicates the recurrence time *f*(*t*) and the reliability function expressed a more useful function of the probability that the earthquake times can be exceeds any given times.

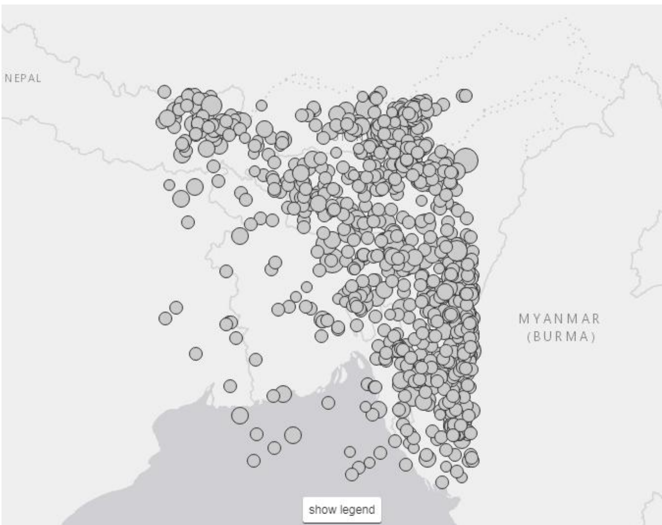

Figure 1: Earthquakes (1900 to 2019) at region bounded by Latitudes 20^0N-28^0N and Longitudes 87^0E-94^0E

III. Results

3.1 Earthquake Vulnerability in Bangladesh

In the abrupt outside of the eastern boundary of Bangladesh, Indian and Eurasian Plate boundary exist. Three major fault lines- Madhupur fault, Dauki fault and Eastern Plate boundary fault are located within the country. In the last one hundred and nineteen years, Bangladesh has experienced eight major strong ground motion (magnitude over 6.5), of which, epicenter of two earthquakes (Srimongal Earthquake of 1918, and Bengal Earthquake of 1923) were located within the country (Fig. 1). Due to the existences of geological plate boundary and fault lines, occurrences of historical damaging earthquakes in and around the country and long-term silences of happening potential earthquake (seismic-gap) across the region, possibility of occurring strong earthquake is increasing over the time period. The trend of earthquakes has been increased from 1975 in Fig 2. Sylhet, Dhaka, Chattogram, and Mymensingh districts are most vulnerable for earthquake. In Fig. 3, 4 and 5 represent that several major and moderate earthquakes have been experienced by Dhaka, Chattogram and Sylhet district recently. Since it is not possible to predict earthquake, awareness with regard to this devastating phenomena can save the live and livelihood to a great extent of the dwellers living at risk. Taking care of the structural and non-structural elements, earthquake vulnerability can be reduced a lot.

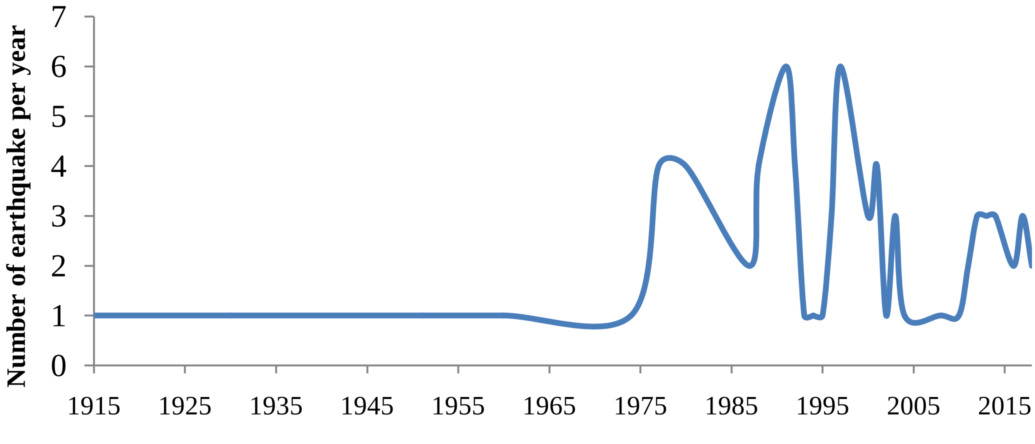

Figure 2: number of major earthquake each year (1915 to 2018) at region bounded by Latitudes 20^0N-28^0N and Longitudes 87^0E-94^0E

3.2 Earthquake Prediction for Bangladesh

Many methods for earthquake prediction have been suggested and some of these methods may be reliable. Statistical analysis is one of interesting method for predicting earthquake. Statistical methods are useful for characterizing seismic hazard because earthquakes are, for all practical purposes, random phenomena. They provide additional insights to the seismic hazard or risk problem. Seismic risk and earthquake occurrence probabilities can be estimated by using probability distributions. Statistical analysis is when you look at the history of earthquakes in a given region and see if there is a recurrent or cyclical pattern of the earthquakes. If earthquakes in a given region have a recurrent pattern, then a long-term prediction can be made based on the recurrent pattern, see in Fig 2. In order to illustrate the statistical analysis, we considered a region bounded by Latitudes 20^0N-28^0N and Longitudes 87^0E-94^0E. There were 44, 332, and 509 earthquakes having ML 5.6≤ (major earthquake), 4.6 to 5.5 (moderate earthquake) and 4.5≥ (minor earthquake) respectively during 1900 to 2019. Three of them (ML 7.0 and above) were powerful enough to cause serious devastation. Using statistical analysis of earthquake, the average interval among major, moderate and minor earthquakes is 2.364, 0.189 and 0.088 years respectively.

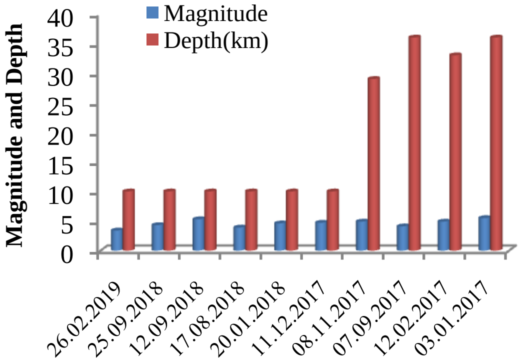

Figure 3: Recent Earthquake near Dhaka

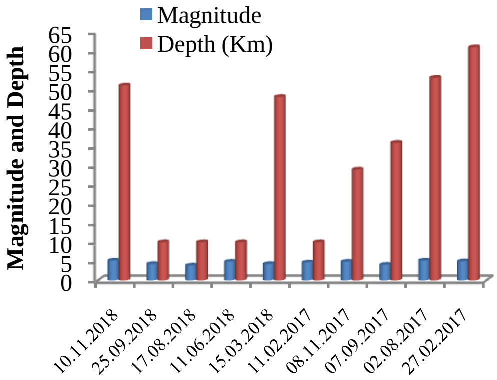

Figure 4: Recent Earthquake near Sylhet

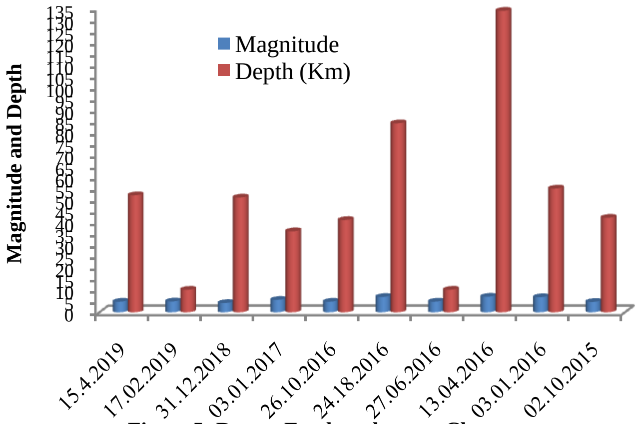

Figure 5: Recent Earthquake near Chattogram

Parameter estimation values and means occurrence period found by using Maximum Likelihood Estimation technique are given in Table 1. By putting these values in Equation (1) we got,

$$f(t;\alpha,\beta) = \beta e^{-0.753} t^{0.753-1} \exp(-2.897^{-0.753} t^{0.753}); (for\ ML\ 5.6 \leq)$$

$$f(t;\alpha,\beta) = \beta e^{-0.933} t^{0.933-1} \exp(-0.148^{-0.933} t^{0.933}); (for\ ML\ 4.6 \text{ to } 5.5)$$

$$f(t;\alpha,\beta) = \beta e^{-0.988} t^{0.988-1} \exp(-0.073^{-0.988} t^{0.988}); (for\ ML\ 4.5 \geq)$$

Earthquake data were well modeled by Weibull distribution in Equation (4). The mean occurrence period of earthquakes in Bangladesh which have magnitude equal to 5.6 or above was calculated approximately 3.438 years. So it is expected to have another earthquake having magnitude equal to 5.6 or above in Bangladesh is average 3.438 years later than the preceding one. On the other hand, the mean occurrence period of moderate earthquake and minor earthquakes was calculated approximately 0.153 and 0.074 years respectively. So it is expected to have another moderate and minor earthquake is average 0.153 and 0.074 years later than the preceding one respectively. Cumulative distribution function graph, that shows occurrence risk of an earthquake (major, moderate and minor) having a specific magnitude range in *t* years after an earthquake occurred in region of Bangladesh with that specific magnitude was given in Fig. 6, 7 and 8. The graph of reliability function that gives the probability of having another earthquake (major, moderate and minor) with specific magnitude range in *t* years after the preceding one with the same magnitude in Bangladesh is given in Fig. 9, 10 and 11.

Table 1: Parameter estimation values and mean occurrence period

Earthquake	β (*shape parameter*)	α (*scale parameter*)	$E(t)$
ML 5.6≤ (major)	0.753	2.897	3.438
ML 4.6 to 5.5 (moderate)	0.933	0.148	0.153
ML 4.5≥ (minor)	0.988	0.073	0.074

N.B: ML=Magnitude level

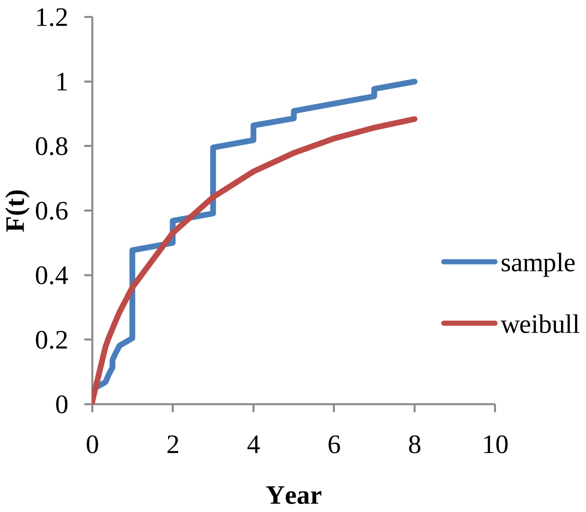

Figure 6: The graph of cumulative function F(t) (for ML 5.6≤)

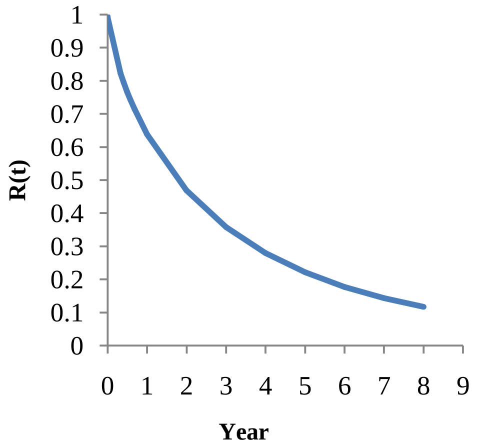

Figure 9: The graph of reliability function R(t) (for for ML 5.6≤)

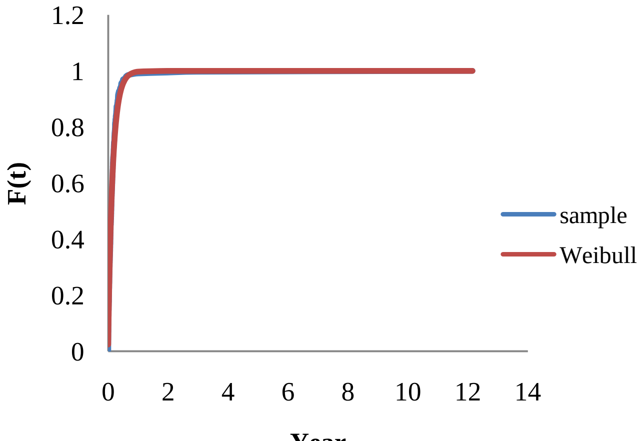

Figure 7: The graph of cumulative function F(t) (for ML 4.6 to 5.5)

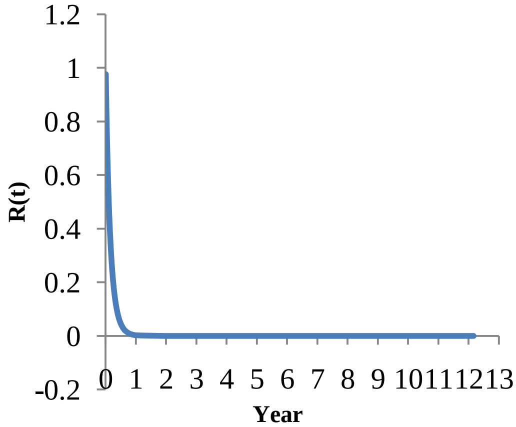

Figure 10: The graph of reliability function R(t) (for ML 4.6 to 5.5)

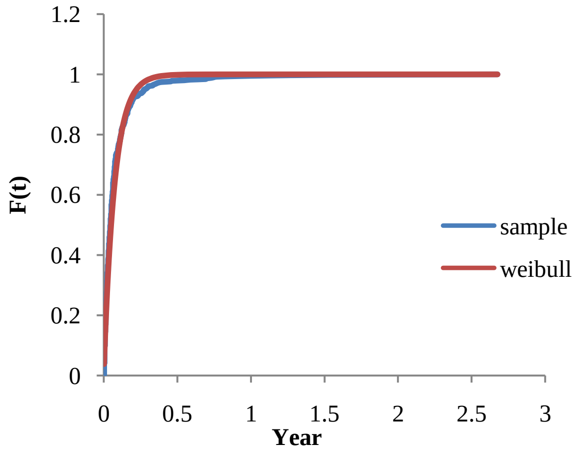

Figure 8: The graph of cumulative function F(t) (for ML 4.5≥)

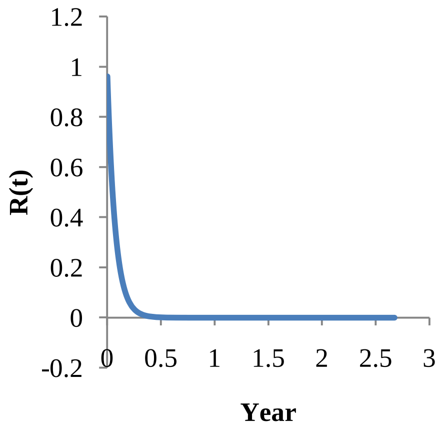

Figure 11: The graph of reliability function R(t) (for ML 4.5≥)

IV. Conclusion

Bangladesh is a south Asian developing country which is used to struggle with various natural disasters and the earthquake is one of them. Here we have tried to discuss about the peril of earthquakes in Bangladesh and the possible earthquakes in near future. The number of earthquake is increasing each of every year and its magnitudes level also increases time to time. These earthquake recurrences of certain magnitude are very dangerous for us and its impact will be demonstrated in near future. Proper preparedness according to a probabilistic prediction can save lives and losses indeed.

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