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Probabilistic Earthquake Scenarios in Bangladesh Based on Magnitude and Depth Parameters

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Abstract: ***Geographical and tectonic settings of Bangladesh make it susceptible to seismic hazard. Besides, historical evidence says that numerous earthquakes with very large magnitude occur in this region. Currently, the Indian plate is gradually moving in the northeast and subduce beneath the Eurasian Plate. So, geologist suspects that a terrible earthquake with greater than eight (>8) magnitude is inevitable in this highly populated region. Therefore, assessing the integrated vulnerability of earthquake in this region is a prime concern for most of the geologists. In this paper, we performed a rigorous assessment of the earthquake's vulnerabilities by analysing the historical earthquakes from the last 118 years (1901-2018) that occurred in Bangladesh and the surrounding regions (20.65° N to 28.00° N latitude and 87.00° E to 93.75° E longitude). Moreover, we also perform probability-based distribution analysis to show the intrinsic relationship among various parameters, especially earthquake magnitude and depth. Here, the necessary data are collected from the USGS (United States Geological Survey).***

Keywords: ***Earthquake, frequency, magnitude, vulnerability.***

I. INTRODUCTION

Bangladesh has been treated as one of the worst countries in the world in terms of natural disasters, hitting a large number of people within the past decade. A person living in the Asia Pacific region is four times riskier than the ones in Africa and 25 times than in Europe or North America [1]. The settings of geography and the numerous anthropogenic features make this area vulnerable to devastating natural disasters. Due to the fact, Bangladesh is frequently suffering from catastrophic cyclones, storm surges, floods, riverbank erosion, tornados, cold wave, and drought. Among the earthquake is the most vulnerable one. The historical record of seismicity in Bangladesh and closely located areas indicate the high risk of earthquake. Since Bangladesh is geographically located close to the plate margins of Eurasian and Indian plates. The area of this country is bounded by the Shillong Plateau; the Himalayan Arc and the Dauki fault system in the north, Indian shield to the west, the Indo-Barma ranges to the east and Bay of Bengal to the south that makes the country a complex geographical position. So, there is history of occurrences of many strong and devastating earthquakes in Bangladesh. Presently, the plate of India is moving gradually in the north-east at a speed of almost 6 cm/year and the plan of Eurasia is moving to the north at 2 centimetres per year [2].

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There exist five major fault zones in and around Bangladesh. Threatened earthquake disaster inside Bangladesh may be expected from these active seismic zones. Depending on the previous geological survey record, at least 691 earthquakes have experienced by Bangladesh which are of minor-to-moderate magnitudes from 1901 to 2018. The earthquake of great India in 1897 with a magnitude of 8.7 Mw affected almost the whole Bangladesh area. Currently, the experts related to earthquake study are considering the recent earthquakes of ranges low to the medium magnitude as an advance alarm for Bangladesh for a potentially disastrous earthquake in the near future. Moreover, experts are also suspecting that if an earthquake with a magnitude of 7.0 on the Richter scale occurs in large cities of Bangladesh, there would be a major human tragedy and economic disaster. A good number of case study and researches have been performed on the earthquake in Bangladesh. In this analysis, we have assessed the risks of earthquakes in Bangladesh by adopting some statistical analysis to analyse the earthquakes that were generated in Bangladesh and closer area of last 118 years ranging from 20.65° N to 28.00° N latitude and 87.00° E to 93.75° E longitude.

II. TECTONICS AND GEOLOGY

Bangladesh is located at the intersection of three plates: the Eurasian Plate, the Indian Plate and the Burma Platelet [3]. The main part of the Bangladeshi region is occupied by one of the largest deltas which is formed by the Ganges Brahmaputra-Meghna river system. Bangladesh geology is closely related to its tectonic evolution which started during the late Cretaceous period when the Indian plate moving northward and collided with the Eurasian plate.

A. *Tectonic Evolution in Bangladesh*

India was a large island about 225 million years ago; located with the Australian coast and separated from Asia by the Tethys Ocean. After detaching from the supercontinent 110 Million years ago, Gondwana landmass (the Indian plate) started moving to the drift in northward towards the Asian region. During the late cretaceous period, the plate of India collided with the plate of Eurasia and formed the Tibetan Plate and the Himalaya Mountains, which are still rising [2]. After that at the end of the Eocene time, the second collision between the Indian plate and Eurasian plate occurred and the gulfs became shallow. The third collision, which occurred in Middle Miocene, created the thick pile sediments of Sylhet, Chittagong, and Assam.

The fourth and fifth collisions mainly caused vertical movements. The plateau of Shillong and Hills formed a horst and Dinajpur shield a graben at the time of the fourth collision. The red clay tablelands are uplifted by the fifth collision [5].

B. Tectonic plates current condition related to Bangladesh

The plate of India is most dynamic even after a long period. The Himalayas levels are gradually rising higher by more than 1 cm/year as India continually moving northwards into Asia, which indicates the occurrences of shallow-focus earthquakes in the region. Various scientific groups now undertake GPS studies to investigate the movement of the Indian plate. A survey based on GPS measurement of velocities and crustal deformations in the Indian subcontinent was published by Sridevi Jade which reveals that 2500 km stretch of the Himalayan arc from Kashmir to Arunachal Pradesh is about 1-2 cm/year, whereas, southern peninsular India moves as a rigid plate with a constant velocity. The research also shows that the plate of India moved at a rate of 14.9 cm/yr. during 40 million years ago and gradually it reduced and currently, the Indian plate is moving in the northeast at a speed of approximately to 5.5 cm/yr [6]. Comparatively the Eurasian plate is a slow-moving plate than Indian plate. It is important to note that the plate of the East-Asia is moving to the north gradually almost 2 centimetres/year. The continuous and gradual motion of the Indian plate towards the north-east direction and faces a heavy obstacle at the Eurasian boundary; led to the underthrusting of Northern Indian plate beneath Eurasia and convergence of the Himalayas. The convergence finally led to the accumulation of enormous strain that consequently made this area as seismically hazardous regions on the Earth.

III. EARTHQUAKE VULNERABILITY OF BANGLADESH

Nowadays, geologist thinks that megaquakes alongside the Himalayas Region aren't possible event but inevitable as the Indian Plate continues to push north below the Eurasian Plate. Earthquakes occur along the fault line and tectonically unstable area. The general tectonics of the Bangladesh and adjacent place is vulnerable for most the frequent and habitual earthquakes. The Shillong plateau located in the north of the country and its neighbouring region has high seismic status.Considering geology and tectonic Bangladesh and neighbourhood five tectonic blocks can be identified which has the potential for giving way to devastating earthquakes zone named as Bogra, Tripura, Shilong, Dauki and Assam. All of these can potentially produce earthquakes of a magnitude greater than seven (>7). Here fig and table represent the frequency of earthquake along this five-fault zone. Among them, the most active seismic zone is Assam fault zone, where minor to great total 379 number of earthquakes and maximum magnitude was 7.2m felt in the last 118 years. Tripura fault zone (one of the states of India) which is very close to Bangladesh is characterized by the high concentration of earthquake events where a total of 268 numbers of earthquakes felt. Among these fault zones, Dauki Fault has a history of creating high-magnitude seismic activities [7]. The Dauki fault zone along the Meghalaya-Bangladesh is a 300 km long north dipping reverse-fault. It has a major role in deforming the surrounding areas. A number of epicentres fall on or close to this fault and some of them were of damaging character. This fault has become inactive but it is still considered as one of the major threats for the earthquake in Bangladesh. In the last 118 years, a total of 37 earthquakes and maximum 7.1m occur here.

Fig. 1. Boundary of the plate between Indian and Eurasian, Akhter, S.H.(2010).

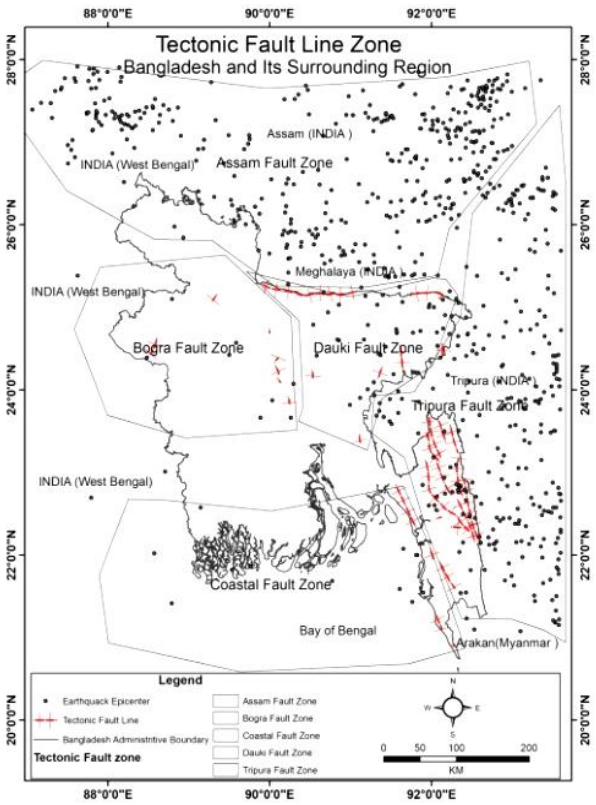


Fig. 2. Five active seismic zones in Bangladesh and its surrounding region with their frequency of earthquakes.

Table-I: Five active seismic zone in Bangladesh

SI. No.	Fault zone	Number of earthquakes	Maximum (Magnitude)
1	Bogra fault zone	8	5.2
2	Tripura fault zone	268	6.2
3	Dauki fault zone	37	7.1
4	Assam fault zone	379	7.2
5	coastal fault zone	14	5.8

The coastal fault zone is very much vulnerable for creating a destructive tsunami for Bangladesh. Recently, a northeast-southwest trending fault named as Bogra fault has been discovered, to the northwest part of Bangladesh. This fault is located to the west of the Jamuna River and south of Rangpur, Rajshahi, Comilla are vulnerable to earthquake disaster. Based on the analysis, the Bangladesh region can be divided into three earthquake potential zones

Zone-1: Sylhet Mymensing is with the possible magnitude of 7 on the Richter scale

Zone-2: Comilla, Chittagong, Dhaka, and Tangail are with the potential magnitude of 6 on the Richter scale

Zone -3: rest of the country with the other possible earthquakes.

Bogra town. Bogra fault is a gravity fault deposited by alluvium is susceptible to earthquakes. For the existence of the geological boundary of the plate and the fault lines threatened serious earthquake disaster inside. So much of the country, including Sylhet, Chittagong, Dhaka, Mymensing,

Earthquakes occur along faults, so to study earthquake risk in Bangladesh Michael Steckler, a geophysicist and his team of structural geologists studied the active faults in and around Bangladesh [8]. Geologist states that Megathrust faults can occur at subduction zones, and gradually, one plate is moving under another plate due to earth's tectonic plates are colliding with each other. These faults can potentially produce the largest earthquakes, reaching and even exceeding 9.0 magnitudes [9]. The study carried by, a geophysicist Michael Steckler and his team revealed that a massive hidden fault buried under millions of tons of sediment beneath Bangladesh, parts of Myanmar and east India could realize an earthquake of magnitude 8.2 to 9.0. Bangladesh lies in the world largest delta drained by Ganges and Brahmaputra rivers.

The rivers are most important for hundreds of millions of people living in this region. The flow of two massive rivers carried massive amount of sediment from upland and finally deposits these in this floodplain region. The geology below the Ganges Delta obscured due to the constant overlaying of sediments. These millions of tons of sediment that pile up in the delta region of these rivers that creates another danger of earthquake, in addition to the potentially devastating megathrust fault. In an earthquake, the shaking will cause the sandy ground to behave like a liquid in a process known as liquefaction. This makes the shaking even more devastating to buildings built on this sandy ground.

For experimental purpose, earthquake experts installed some highly precise and sensitive GPS devices throughout India, Bangladesh and Myanmar in 2003-2014. Combining data with the existing GPS data obtained from Myanmar, India and the measurements indicate that the east part of Bangladesh and a bit of the eastern part of India are moving diagonally into the west part of Myanmar at a rapid clip—46 millimetres per year, or about 1.8 inches. As a result, distance from Myanmar to Bangladesh is being shortened by 17 millimetres/year. One plate is driving under the other deep beneath the surface in an area encompassing Bangladesh, eastern India and parts of Myanmar. [10]. (Bangladesh, North-East India, Nepal, and Myanmar) make the region vulnerable to frequent earthquakes. The history of earthquakes in Bangladesh and surrounding areas indicates that many severe earthquakes with considerably large magnitude greater than 7.0 (Richter) have occurred in this landmass in the past. More than 100 earthquakes vibrated Bangladesh during the 20th century.

Table-II: List of the biggest earthquakes >6 magnitude that have occurred in this region from 1901 to 2018. (United States Geological Survey, 1901-2018)

Date	Place	latitude	longitude	Depth	Magnitude
18th sep 2011	Sikkim, India	27.73	88.16	50.00	6.90
21th sep 2009	Bhutan	27.33	91.44	14.00	6.10
21th Nov 1997	India-Bangladesh border region	22.21	92.70	54.40	6.10
08th May 1997	India-Bangladesh border region	24.89	92.25	34.90	6.00
30th Dec 1984	India-Bangladesh border region	24.64	92.89	22.60	6.00
06th May 1984	Manipur, India region	24.26	93.55	33.00	6.00
19th Nov 1980	Sikkim, India	27.39	88.75	17.00	6.10
22th Jan 1964	Myanmar-India border region	22.31	93.59	70.00	6.20
14th Dec 1955	Myanmar-Bangladesh border region	21.82	92.66	35.00	6.20
23th Feb 1954	Bhutan	27.67	91.61	15.00	6.20
16th Aug 1950	Arunachal Pradesh, India	27.49	92.80	15.00	6.00
15th Aug 1950	Meghalaya-Assam region, India	25.34	92.94	25.00	6.00
21th Jan 1941	Bhutan	27.17	91.86	15.00	6.60
02nd July 1930	Meghalaya, India region	25.93	90.18	15.00	7.10
09th Sep 1923	Bangladesh	24.94	90.72	15.00	6.80
08th July 1918	Bangladesh	24.60	90.85	15.00	7.20
03rd Dec 1915	Bhutan	27.70	91.64	15.00	6.50

Table-III: Frequency of occurrence of earthquakes

Descriptor	Magnitude	Number of occurrences
Major	>8	0
Strong	7-7.9	02
Moderate	6-6.9	14
Light	5-5.9	112
Minor	4-4.9	516
Very Minor	3-3.9	47
	2-2.9	0

Recently, seismic activity was found to be increased in Bangladesh. Also, we don't find information related to the earthquakes around 500 years ago except a few historical evidences which are not adequate to specify the actual intensity or magnitude of the earthquakes occurred. There are many evidences of severe earthquakes felt in Chittagong, Sylhet, and Dhaka in the year ranges from 1548 to 1869. Among them, The Cachar Earthquake of January 10, 1869, with epicentre in the northern border Jaintia Hill of Assam caused great damage in Assam. In Bangladesh vibration was felt all over the country and the major damage occurred only in the eastern parts of the Sylhet district. The earthquake that occur at July 14, 1885, caused unignorable damages in Sirajganj, Jamalpur, Bogra, Sherpur, Mymensingh region with estimated magnitude of 7.0 in the Richter scale. The earthquake that occur in India at 1897 with a magnitude of 8.1 and an whose distance was only 230 km north of Dhaka caused severe damages in the region located near to Dhaka. Moreover, the earthquakes in Dhaka region causes possibility of earthquake in the region located near this region.

The 1918 Srimongal earthquake (M=7.6) had its epicentres within Bangladesh, it caused considerable damage locally. significant parts of Bangladesh. It was perhaps the cause of the most significant and most widespread earthquake damages. The 1762 Chittagong earthquake, also a local earthquake with estimated magnitude M=7.5. In recent years, small to moderate earthquakes are regularly occurring with epicentres in neighboring India and Burma (some within the country) which are being felt in many parts of the country, particularly in the northeast Sylhet and southeast Chittagong region. In our current research, we take an attempt to assess the seismicity of Bangladesh 20.65° N to 28.00° N latitude and 87.00° E to 93.75° E longitude. The region under study has a similar geological process, similar historical development and socio-economic and demographic conditions, etc., are vital parameters in the whole process of seismic hazard studies in the region. In our study, considering the earthquakes with the magnitude level 6 and above since these earthquakes are strong enough to damage various manmade infrastructures and to cause the loss of lives for human and animals. Table ii: shows the date, place name, epicentre (latitude and longitude), depth, the magnitude of selected earthquake >6 magnitude which affects significantly in this study area. In the last 118 years, seventeenth major earthquakes (> 6) have occurred in this region. Out of the17th earthquakes, two (viz. 1930 and 1918) had their magnitude >7. Two earthquakes (VIZ.1918, 1923) had their epicenters within Bangladesh,

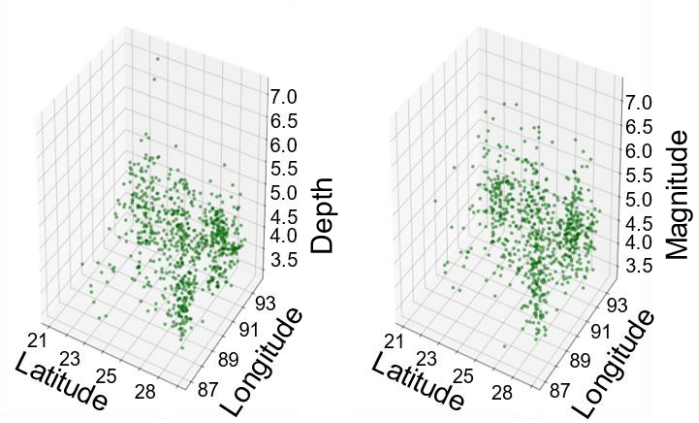


Fig. 6. 3d model (a) distribution of earthquakes vs depth (b) distribution of earthquakes vs magnitude.

three (1984,1997, 1997) had their epicenters in the India-Bangladesh border region and the rest of them were very close to Bangladesh. According to Hagiwara, the classification the earthquakes that occurred can be done based on the magnitude, as follows: magnitude Classification 7 M < 8 are major earthquakes, 5 M < 7 are moderate earthquakes, 3 < M < 5 are small earthquakes, 1 M < 3 are micro earthquakes and M < 1 are categorized as ultra-microearthquakes [5]. The major earthquakes that affected Bangladesh and caused severely damaged; most of these epicentres were located in the boundary between Bangladesh and India. Table iii shows the number of occurring earthquakes in Bangladesh and their surrounding areas are really large. Earthquakes which have lower magnitudes (ms 4.0 to ms 5.0) are larger in numbers and bear less threat for human civilization. There are few numbers of earthquakes with higher magnitudes (ms ≥ 6.0) but they are very destructive for any country. Bangladesh faced a large number of earthquakes in past and still continued. Figure 3 shows the number of occurrences of earthquake versus year. The frequency of earthquakes in past from 1991 to 1970 was less but in recent time after 1980 the number of occurrences is increasing in a very alarming rate. So now a day's earthquake became a matter of big concern.

IV. ANALYSIS OF EARTHQUAKE DATA

Now we will analyze the earthquakes those generated in between 20.65° N to 28.00° N latitude and 87.00° E to 93.75° E longitude for the last 118 years (1901-2018). In this analysis, the areas we have considered covered the region of Bangladesh and its very nearly located regions. The data necessary for this analysis are extracted from the USGS (United States Geological Survey). Our data contains the depth, magnitude of the earthquakes, time of occurrences and some other related information's. For our statistical analysis, we have considered earthquakes that occurred from 1901 to 2018. We observed from figure 5, most of the earthquake occurred in this region were ranged

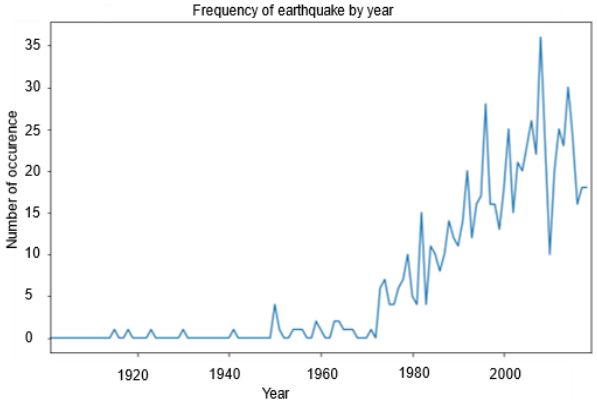


Fig. 3. Number of occurrences of Earthquake versus year (USGS).

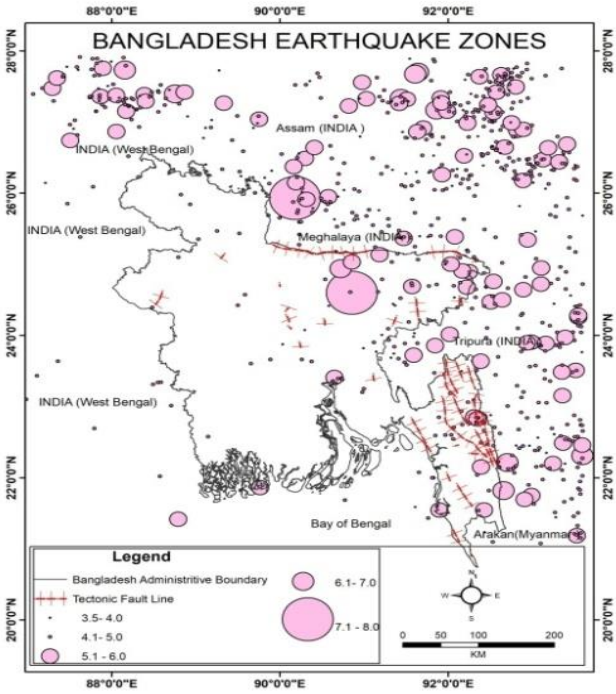
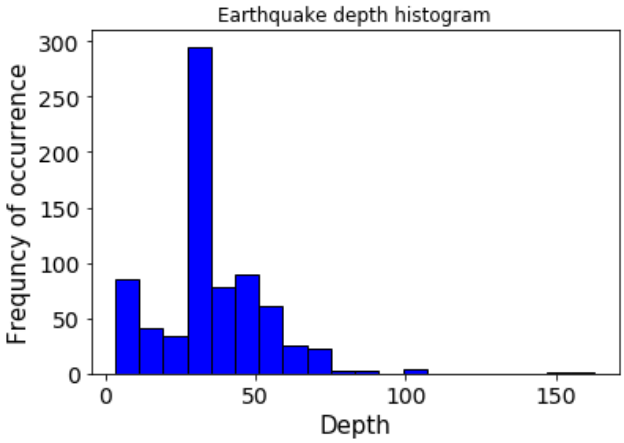
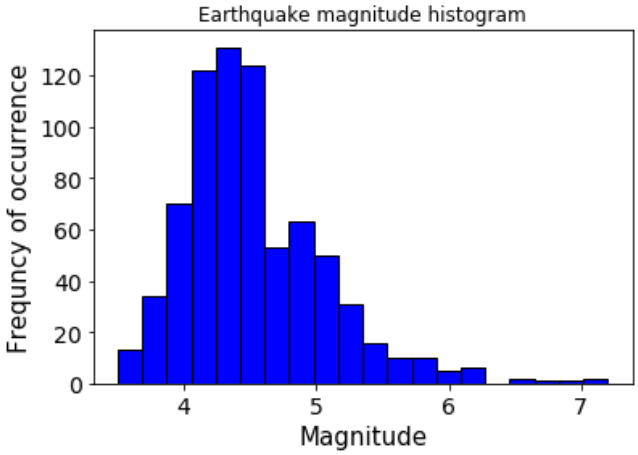


Fig. 4. Map showing the Geographical distribution of seismicity of Bangladesh and adjacent region.



(a) Earthquake Vs Depth



(b) Earthquake Vs Magnitude

Fig. 5. Frequency of occurrence of earthquakes with (a) Depth & (b) Magnitude (United States Geological Survey, 1901-2018).

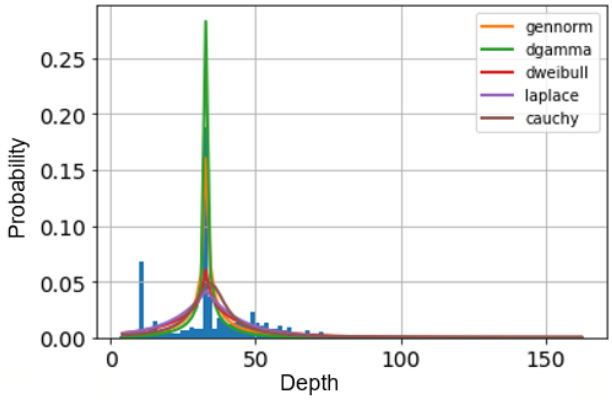


Fig. 7. Earthquake depth distribution with best fit model

These very few high magnitude earthquakes may occur severe damage. The average depth of epicentre varied between 20 to 40 km and in this depth, the chance of liquefaction be increased, which makes the area more vulnerable. We can also find some epicentre which generated 70kilometers beneath the earth surface and the magnitude of the earthquake is very closely related to the depth. These two are almost linearly related to each other. If the magnitude and depth are high, the damage can be severe. Figure 6(a). Shows the distribution of earthquake based on three-parameter longitude, latitude and depth. Again, Fig. 6(b) shows the magnitude of the earthquake using two-parameter latitude and longitude. Finally, in Fig. 7 shows the best fit distribution followed by earthquake depth parameter. From the figure, we found gennrom distribution is best fitted with sum of squared error 0.011305 while other distributions have the higher fitting error.

V. CONCLUSION

By analysing the historical data, the result indicates that the past earthquake event was frequent but less devastating. On the other hand, earthquake occurrences are increasing significantly. As the two most important plate are seducing each other, so the possibility of great earthquakes is increased. Hence, the government of Bangladesh should put much interest to manage this disaster.

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