Probabilistic Seismic Hazard Analysis of Nigeria: The Extent of Future Devastating Earthquake.

John Oluwafemi ¹, Olatokunbo Ofuyatan ¹, Solomon Oyebisi ¹, Tolulope Alayande ¹, John Abolarin ²

¹ Department of Civil Engineering, Covenant University, Ota, Ogun-State, Nigeria.
E-mail address: john.oluwafemi@covenantuniversity.edu.ng; spiritjohn20@gmail.com

Abstract. The several past seismic occurrences in Nigeria has recently led to warnings from research agencies and the forecast of large earthquake from researchers in Nigeria. Nevertheless, the major forecast from researchers has appeared to be open ended. To this end, this paper aimed at the probabilistic seismic hazard analysis of Nigeria and the limit to probable future earthquake magnitudes in Nigeria. The Gutenberg-Richter recurrence law was majorly employed for the purpose of this research. The Findings of this research established that Nigeria is at the risk of experiencing earthquake magnitudes as high 6.0 in the year 2020; 6.5 between the year 2021 and 2022; 7.0 between the year 2025 and 2026 and 7.1 in the year 2028 with a 36.79% probability. The probability that an earthquake of magnitude 7.1 will be experienced from 2019 to 2028 also ranges from 9% to 36.79%. The findings of this work inform on the sizes of probable future earthquake magnitude and it is recommended that the government of Nigeria pays rapt attention to earthquakes in Nigeria.

Keywords: earthquakes; magnitudes; recurrence interval; probability; intensity

1. Introduction

Earthquake is a global phenomenon experienced in most regions of the world. It is classified as one of the most devastating natural disasters that pose threat and has the capability to impact negatively on both human lives and the built environment. While other natural disasters such as drought, flood, famine, hurricane, tsunami and more can be devastating at the occurrence, an earthquake can cause much more damage in a swipe, depending on its magnitude. Hence, the continuous occurrence of earthquake events across the globe has continued to be a concern to humanity and some researchers have self-tasked themselves to work tirelessly to device means to mitigate the aftermaths of earthquake occurrence in the nations of the earth [1].

When an earthquake occurs, the trail of the adverse resulting impacts is not limited to the moment of its occurrence. The impact of an earthquake occurred in a nation can lead to a major setback in her development and her economic status and this can even linger for years after the event had occurred based on the magnitude of the earthquake [2][3]. According to [4], Earthquakes occur due to the sudden release of built-up energy within the rocks. Other activities carried out on land surface can also stimulate earthquake. Some of these activities include drilling of boreholes and erection of heavy buildings.

Earthquake is experienced by most nations of the earth depending on their level of seismicity, while some nations are known for high seismicity, some are known for none and some are known for low seismicity. Nigeria among other nations of the earth has reflected dispersed seismic events within the period of 1933 to recent times. Many of the events that occurred in time past were not captured due to non-availability of seismic recording instruments.

Nigeria in the past was believed to be certified free from earthquake hazards but the instrumental and historical records of Nigeria as presented in Table 1 has shown contrary to this belief. While the past earthquakes are believed to have occurred along the faults in Nigeria, future earthquake occurrences in Nigeria are also expected to occur along the seismic faults.
Table 1: Historical/Instrumental Earthquakes in Nigeria (Source:\textsuperscript{[5]})

| S/N | Year-Month-Day | Origin Time | Felt Areas | Intensity/Magnitude | Probable Epicenter | Coordinates |
|-----|----------------|-------------|------------|---------------------|--------------------|-------------|
| 1   | 1933           | -           | Warri      | -                   | -                  | 05º 45¹ 23¹¹E 05º 31¹ 42¹¹N |
| 2   | 1939-06-22     | 19:19:26    | Lagos, Ibadan, Ille-Ife | 6.5 (Ml) | Akwapin fault in Ghana | 03º 23¹ 00¹¹E 06º 30¹ 11¹¹N |
| 3   | 1948-07-28     | -           | Ibadan     | -                   | Close to Ibadan    | -            |
| 4   | 1961-07-02     | 15:42       | Ohafia     | -                   | Close to ijebu-Ode | -            |
| 5   | 1963-12-21     | 18:30       | Ijebu-Ode  | V                   | Close to Ijebu-Ode | -            |
| 6   | 1981-04-23     | 12:00       | Kundunu    | III                 | At Kundunu Village | -            |
| 7   | 1982-10-16     | -           | Jalingo, Gembu | III       | Close to Cameroun Volcanic Line | -            |
| 8   | 1984-07-28     | 12:10       | Ijebu-Ode, Ibadan, Shagamu, Abeokuta | VI       | Close to Ijebu Ode | -            |
| 9   | 1984-07-12     | -           | Ijebu Remo | IV                  | Close to Ijebu Ode | 03º 23¹ 00¹¹E 07º 11¹ 45¹¹N |
| 10  | 1984-08-02     | 10:20       | Ijebu-Ode, Ibadan, Shagamu, Abeokuta | V       | Close to Ijebu Ode | -            |
| 11  | 1984-12-08     | -           | Yola       | III                 | Close to Cameroun Volcanic Line | -            |
| 12  | 1985-06-18     | 21:00       | Kombani Yaya | IV                 | Kombani Yaya    | -            |
| 13  | 1986-07-15     | 10:45       | Obi        | III                 | Close to Obi town | 08º 46¹E 08º 22¹N |
| 14  | 1987-01-27     | -           | Gembu      | V                   | Close to Cameroun Volcanic Line | 11º 15¹E 06º 42¹N |
| 15  | 1987-03-19     | -           | Akko       | IV                  | Close to Akko    | 10º 57¹E 10º 17¹N |
| 16  | 1987-05-24     | -           | Kurba      | III                 | Close to Kurba village | 10º 12¹E 11º 29¹N |
| 17  | 1988-05-14     | 12:17       | Lagos      | V                   | Close to Lagos   | -            |
| 18  | 1990-06-27     | -           | Ibadan     | 3.7(ML)             | Close to Ijebu-Ode | 03º 58¹E 17º 22¹N |
| 19  | 1990-04-05     | -           | Jerre      | V                   | Close to Jerre Village | -            |
| 20  | 1994-11-07     | 05:07:51    | Ojebu-Ode  | 4.2(ML)             | Dan Gulbi        | -            |
|   | Year   | Date       | Location     | Magnitude | Details                                      |
|---|--------|------------|--------------|-----------|----------------------------------------------|
| 21| 1997   | -          | Okitipupa    | IV        | Close to Okitipupa Ridge 07° 42'E 14° 03'N |
| 22| 2000   | 08-15     | Jushi-Kwari  | III       | Close to JushiKwari village                  |
| 23| 2000   | 03-13     | Benin        | IV        | Benin City (55km from Benin)                |
| 24| 2000   | 03-07     | Ibadan, Akure, Abeokuta, Ijebu-Ode, Oyo | 4.7 (ML)  | Close to Okitipupa                          |
| 25| 2000   | 05-07     | Akure        | IV        | Close to Okitipupa Ridge                    |
| 26| 2001   | 05-19     | Lagos        | IV        | Close to Lagos city                         |
| 27| 2002   | 08-08     | Lagos        | IV        | Lagos city                                 |
| 28| 2005   | 03        | Yola         | III       | Close to Cameroun Volcanic Line             |
| 29| 2006   | 03-25     | Lupma        | III       | Close to Ifewara                            |
| 30| 2009   | 09-11     | Abomey-Calavi| II        | Close to Benin                              |
| 31| 2011   | 11-05     | Abeokuta     | 4.4       | Close to Abeokuta                           |
| 32| 2016   | 07-10     | Saki         | IV        | Oyo State                                  |
| 33| 2016   | 08-10     | Igbogene     | III       | Bayelsa                                    |
| 34| 2016   | 09-11     | Kwoi         | III       | Kaduna State                               |
| 35| 2016   | 09-12     | SambangDa gi | III       | Kaduna                                     |

There are also indications from the development of recent times that devastating earthquakes are likely to occur in Nigeria and in West Africa in the nearest future and it is, therefore, important that these indications be taken into cognizance.\[6\]\[7\]\[8\] explained that the reason why Nigeria hardly experiences earthquake hazard like other high earthquake-prone nations is likely to be as a result of the location of her geological framework which is believed to be situated in her continent’s mobile belt between the Congo and West Africa Craton where notable damage was reported to have occurred in the past leading to bit of impact on the adjacent craton.

The prevention of earthquake occurrence in any country is impossible, different approaches that help to assess their likelihood of occurrence go a long way in helping authorities to make decisions and to implement certain rules that will help minimize or mitigate the aftermath of the hazards.\[9\] Despite the fact that researchers have warned that Nigeria is at the risk of experiencing devastating earthquakes in the nearest future, there is still no knowledge of the extent of the probable future earthquake magnitude. Hence, probabilistic seismic hazard analysis has been carried out for Nigeria in this research with the employment of the Gutenberg-Richter recurrence law.

1.1 Earthquake Forecast
In the study of earthquakes, it is possible to pinpoint locations where future earthquakes have the likelihood of occurrence by examining tectonic plates’ movement in a location. Nevertheless, this approach can still turn out to be inaccurate. Hence, scientists are yet to successfully discover an approach to predict future earthquakes, considering time and location with accuracy and precision [10]. According [11] Earthquake forecast is a statement of probability that an earthquake of a particular magnitude will occur at a particular time and at a particular location. Earthquake forecast is distinctively different from earthquake prediction as many confuse the two to be the same. Unlike in forecasting, prediction comes as a statement of certainty.

Several researchers have related different approaches to assess future earthquakes in times past. As follow, some of these approaches include the study of radon gas emission, seismic waves study, and future earthquake assessment using animal unusual behavior prior to major earthquake event:

i. [12] pointed out that radon emission as earthquake precursor is a good facilitator of knowledge towards earthquake prediction. Studies have shown that there is always very high radon concentration at the site of earthquake occurrence. Hence, its concentration level in groundwater and soil is a good indicator.

ii. The earliest unusual behavior of the animal in response to earthquake occurrence was that of 373BC in Greece in which animals migrated from their different homes to safe locations few days to a major earthquake [13]. [14] described the responses of animals to the earthquake as an inbuilt escape instinct or survivor instinct due to the ability of the animals to sense seismic signals.

iii. Seismic waves carry earthquake energy which can be analyzed for some seismic parameters that will make earthquake assessment feasible. The seismogram is used for capturing these waves and the output is presented as seismograph which is analyzed for the extraction of necessary parameters such as earthquake magnitude, frequency and wavelength [12].

1.2 Gutenberg-Richter Recurrence Law

The Gutenberg-Richter recurrence law was first proposed by [15]. This relationship relates the cumulative number of the earthquake to the magnitude of the earthquake in a region. The Gutenberg-Richter recurrence law is presented in the equation 1.

\[ \log_{10} N = a - bM \]  

According to [16], global earthquake occurrences including the ones with great depth follow the trend of the G-R recurrence law. The “N” in the equation 1 represents the total number of earthquakes, a and b are referred to as seismicity parameters while “M” is the magnitude of earthquakes. The establishment of the G-R recurrence law’s linearity has remained unchanged for more than fifty years [17].

2. Material and Methods

The data used for the purpose of this assessment was the instrumental and the historical data presented in Table 1. The equation 2 as related by [18] was employed for the conversion of every event reported using intensity scale to the Richter magnitude scale.

\[ M_L = 1 + 0.667I_o \]  


The Gutenberg-Richter recurrence law presented in the equation 1 was used to generate the Gutenberg-Richter plot of Fig. 1 for Nigeria by plotting the cumulative number of earthquakes in Nigeria against the corresponding magnitudes. The seismicity parameter “a” was derived from the intercept of the plot in Fig. 1 and the b-value was derived by finding the gradient of the plot.

The logarithmic values of the vertical axis of the G-R plot gave the yearly occurrence for each earthquake magnitude while the recurrence interval for each magnitude was obtained by using the equation 3.

\[
\text{Recurrence Interval} = \frac{1}{\text{Number of earthquake occurrence per year}} \quad (3)
\]

The equation 4-5 related by (19) for the bounded Gutenberg-Richter relationship was used to establish the probability distribution function and the cumulative distribution function for the yearly occurrence of earthquake magnitudes of interest.

\[
\beta = 2.303b \quad (4)
\]

\[
\text{PDF} = f_i(m) = P[M = m] = \frac{\beta e^{-\beta(m-m_{\text{min}})}}{[1 - e^{-\beta(m_{\text{max}} - m_{\text{min}})}]} \quad (5)
\]

\[
\text{CDF} = f_i(m) = P[M < m] = \frac{1 - e^{-\beta(m-m_{\text{min}})}}{[1 - e^{-\beta(m_{\text{max}} - m_{\text{min}})}]} \quad (6)
\]

The \( M_{\text{max}} \) was set as 7.1 as obtained from the G-R plot of the Fig. 1 while the \( M_{\text{min}} \) was set at the magnitude of 3.0. Other distribution models such as Burr, t Location-Scale, Rayleigh, and Gamma distribution models were used to test for the distribution of earthquake events in Nigeria and the PDF and CDF for the best fitting distribution models was compared to that of the bounded Gutenberg-Richter distribution model.

The poison probability distribution model of equation 7 was employed to establish the probability that certain selected earthquake magnitude will occur in the recurrence year and also that earthquake magnitude of 7.1 will occur in Nigeria from 2019-2028.

\[
P[N = n] = \frac{(\lambda t)^n e^{-\lambda t}}{n!} \quad (7)
\]

This was done for each consecutive year starting from the time this research was carried out to the recurrence interval year for an earthquake of magnitude 7.1. Matlab 2017a version software was very instrumental in generating all the plots presented in the paper.

3. Results and Discussion

The results obtained from this assessment is well outlined out as follows:

3.1  The Gutenberg-Richter Relationship Plot for Nigeria

The Gutenberg-Richter plot generated for Nigeria using her instrumental and historical data is presented in the Figure 1. From the critical analyses of the G-R plot, it shows that earthquake magnitude that is as high 7.1 is likely going to be experienced in Nigeria in the future. The G-R approach also gave 7.1 magnitudes as the limit to the possible earthquake magnitude in Nigeria. As a basis for comparison, (20) forecasted that earthquake magnitude greater than 5.0 will be experienced in the nearest future. While the findings of (20) is open-ended, the results of this research gave a guide to the extent of earthquake magnitude to be expected in Nigeria. The b-value for Nigeria from the plot is 0.99.
According to [21], when the b-value ranges between $0.72 \pm 0.07$ to $1.20 \pm 0.015$, the seismotectonic setting of such region is that of an intraplate. Hence, Nigeria’s seismotectonic setting is of intraplate. This suggests that the seismic events that ever occurred in Nigeria lie without the margin plate’s region. The value of “a” is found to be 16.8. The value of “a” is high and due to infrequent earthquake occurrences in Nigeria.

$$\log_{10} \lambda m = 16.8 - 0.99M$$

The equation 8 is therefore proposed for the determination of the mean annual rate of exceedance for earthquake magnitude of interest. The equation 8 is only valid for Nigeria provided that it obeys equation 9.

$$0 \leq M \leq 7.1$$

The “a” and b-value solely depends on the number of events being considered. Therefore, these values are subject to slight changes if more seismic events are considered in the future.

### 3.2 Yearly Earthquake Occurrence and Earthquake Recurrence Interval for Nigeria

The yearly occurrence of earthquake magnitude and the recurrence intervals for earthquake magnitudes are shown in the Figure 2 and Figure 3 respectively. Earthquakes with smaller magnitudes have a higher number of occurrences yearly than earthquakes with high magnitudes. This is similar to nature of earthquakes globally. From Figure 2, earthquake magnitudes of 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0, and 7.1 are likely to occur 38 times, 19 times, 9 times, 4.2 times, 2.3 times, 1 time, 0.5 times, 0.27 times, 0.13 times, and 0.1 times respectively in a year.
Likely also, the recurrence interval of earthquakes as shown in the Figure 3 reveals that earthquake magnitudes of 3.0, 3.5, 4.0, 4.5, 5.0, 5.5, 6.0, 6.5, 7.0 and 7.1 have the recurrence intervals of 0.026 year, 0.053 year, 0.111 year, 0.2938 year, 0.435 year, 1 year, 2 years, 3.704 years, 7.692 years and 10 years respectively in Nigeria. Therefore, assessing the results from the year 2018 shows that there is the likelihood of occurrence for earthquake magnitudes as high as 6.0 in the year 2020; 6.5 between the year 2021 and 2022; 7.0 between the year 2025 and 2026 and 7.1 in the year 2028. The probability that these earthquakes will occur in the recurrence year is 36.79%. [20] also stated 6.0% to 91.1% probability for earthquake greater 5.0 magnitude to occur between the year 2017 and 2028.

3.3 Annual Probability of Occurrence Using Bounded G-R Law
The probability distribution function and the cumulative distribution function using the engagement of the bounded G-R recurrence law is shown for the discontinuous earthquake events in Table 2 and Table 3 respectively. Earthquake magnitudes with small values exhibited a higher probability of occurrence and vice versa.

Table 2 Probability Distribution Function of Earthquake in Nigeria

| Earthquake Magnitude | 3.5 | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 | 7.1 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| PDF = X=x            | 0.7293 | 0.2332 | 0.0746 | 0.0239 | 0.0076 | 0.00244 | 0.0008 | 0.0003 | 0.0002 |
| CDF = X<x            | 0.6802 | 0.8978 | 0.9674 | 0.9896 | 0.9967 | 0.9990 | 0.9997 | 0.9999 | 1.0000 |

The least earthquake magnitude under consideration being 3.5 in Table 2 has an annual 72.94% probability of occurrence while magnitude 7.1 has an annual 0.02% probability of occurrence. Thus, the chances of yearly occurrence for an earthquake of magnitude 7.1 is low.

The cumulative distribution function on the other hand in Table 2 appears to have high probabilities for values below magnitudes of interest. This is because the probability is open to arrange of several events below the certain magnitude of interest. Hence, CDF for bounded range as presented in Table 3 is further generated.

Table 3 Cumulative Distribution function of earthquake within bounded range

| Earthquake Magnitude | 4.0<M<4.5 | 4.5<M<5.0 | 5.0>M<5.5 | 5.5>M<6.0 | 6.0>M<6.5 | 6.5>M<7.1 |
|----------------------|------------|------------|------------|------------|------------|------------|
| CDF                  | 0.0696     | 0.0222     | 0.0071     | 0.0023     | 0.0007     | 0.0003     |

The CDF for magnitude 4.0 < M < 4.5 is 6.96% annually and CDF for 6.5 < M < 7.1 is as low as 0.03% annually.

3.4 Probability Distributions for Earthquakes in Nigeria

The Plots for the PDF and CDF using the Burr, t Location-Scale, Rayleigh, and Gamma distribution models are presented in the Figure 4 and Figure 5. While Rayleigh distribution appears to have no correlation with the seismic data in Nigeria, the Burr and t Location distributions tend to fit better by observation. This is the same both for the PDF and the CDF.
Fig. 4 Probability Distribution Models for Earthquake

![Image of probability distribution models for earthquake magnitudes]

Fig. 5 Cumulative Distribution Models for Earthquake

Hence the corresponding PDF and CDF for the Burr and t Location-Scale distribution models are presented in Table 4 and Table 5 respectively.

Table 4 PDF for Burr & t Location Distribution model for earthquakes in Nigeria

| Earthquake Magnitude | 4.0 | 4.5 | 5.0 | 5.5 | 6.0 | 6.5 | 7.0 |
|----------------------|-----|-----|-----|-----|-----|-----|-----|
| Burr                 | 0.349938 | 0.166391 | 0.082108 | 0.042954 | 0.023723 | 0.013731 | 0.008275 |
| t Location-Scale     | 0.472999 | 0.207019 | 0.071628 | 0.024539 | 0.009070 | 0.003686 | 0.001640 |

Table 5 CDF for Burr & t Location Distribution model for earthquakes in Nigeria

| Earthquake Magnitude | 4.0<M<4.5 | 4.5<M<5.0 | 5.0<M<5.5 | 5.5<M<6.0 | 6.0<M<6.5 | 6.5<M<7.0 |
|----------------------|-----------|-----------|-----------|-----------|-----------|-----------|
| Burr                 | 0.123435  | 0.059386  | 0.030072  | 0.016129  | 0.009104  | 0.00537   |
| t Location-Scale     | 0.16647   | 0.064278  | 0.021889  | 0.007713  | 0.002967  | 0.001254  |

The results of the PDF and the CDF using Burr and t Location-scale distribution model are relatively close and slightly higher to the PDF and CDF given by the bounded GR recurrence law.

3.5 Probability of 7.1 Magnitude from 2019 to 2028 in Nigeria

The Figure 7 presents the plot showing the probability that earthquake magnitude of 7.1 will occur in Nigeria from 2019 to 2028.
Fig. 7 The probability of 7.1 earthquake magnitude occurrence from 2019 to 2028

The Plot of Fig. 7 shows a yearly and gradual leap in the probability of magnitude 7.1 from 9% in 2019 to 36.79% in 2028.

4. Conclusion

The findings of this assessment established that Nigeria is at the risk of experiencing devastating earthquakes in the future. These Probable earthquake magnitudes are as high as 6.0 in the year 2020; 6.5 between the year 2021 and 2022; 7.0 between the year 2025 and 2026 and 7.1 in the year 2028. The probability that these events will take place in the forecasted year is 36.79%. The probability that an earthquake of magnitude 7.1 will also occur from 2019 to 2028 is between 9% and 36.79%. The b-value for Nigeria is 0.99 and this suggests that the seismotectonic setting of Nigeria is that of an Intraplate. The equation 8-9 is also proposed for the assessment of the annual mean rate of exceedance for earthquakes in Nigeria. It is therefore recommended that the Nigerian authority begins to enforce the law as regards earthquake considerations in structural designs in places such as the South-West region that has displayed most seismic events in times past. It is also recommended that activities such as heavy rock blasting should be relocated to non-residential places to reduce earthquake stimulations in residential areas.

References

[1] DAR M A, DAR A, QURESHI A, RAJU A. A Study on Earthquake Resistant Construction Techniques [J]. American Journal of Engineering Research, 2013, 20(12): 258-264.
[2] AKPAN A E, ILORI A O, ESSIEN N U. Geophysical investigation of Obot Ekpo Landslide site, Cross River State, Nigeria [J]. Journal of African Earth Sciences, 2015, 109: 154-167.
[3] OFUYATAN O, ADEOLA A, SULYMON N, EDE A, OYEBISI S, ALAYANDE T, OGUNDIPE J. Pseudo-Dynamic Earthquake Response Model of Wood-Frame with Plastered Typha (Minima) Bale Masonry-Infill [J]. International Journal of Civil Engineering and Technology, 2018, 9(2): 27-35.
[4] SHANNON D, AMY D, CATHERINE P, KIRSCH T D. The Human Impact of Earthquakes: a Historical Review of Events 1980-2009 and Systematic Literature Review [J]. PLOS Currents Disasters, 2013.
[5] ABOLARIN J, ADEDEJI A. Investigating Earthquake Magnitude by Seismic Signals and Wavelet Transform in Optimal Design [J]. Websjournal of Science and Engineering Application, 2016, 5: 305-322.

[6] UMAR A K, TAHIR A Y, OFONIME U A, DUNCAN D, SATURDAY U E. Towards an integrated seismic hazard monitoring in Nigeria using geophysical and geodetic techniques [J]. International Journal of the Physical Sciences, 2011: 6385-6393.

[7] AWOYERA P, OGUNDEJI P, ADERONMU P. Simulated Combined Earthquake and Dead Load Lateral Resistance Building Systems using Nigeria Seismic Data [J]. J. Mater. Environ. Sci., 2016, 7(3): 781-789.

[8] TSALHA M S, LAR U, YAKUBU T A, KADIRI U A, DUNCAN D. The Review of the Historical and Recent Seismic Activity in Nigeria [J]. Journal of Applied Geology and Geophysics, 2015: 48-56.

[9] GAUDIO C D, RICCI P, VERDERAME G M, MANFREDI G. Urban-scale seismic fragility assessment of RC buildings subjected to L'Aquila earthquake [J]. Soil Dynamics and Earthquake Engineering, 2017: 49-63.

[10] National Earthquake Prediction Evaluation Council. Evaluation of Earthquake Predictions, 2016: 1-6.

[11] CONSOLE R, PANTOSTI D, ADDEZIO G. Probabilistic approach to earthquake prediction [J]. Annals of Geophysics, 2002, 45(6): 723-731.

[12] SAJJAD M, FAISAL A. Computational seismic algorithmic comparison for earthquake prediction [J]. International Journal of Geology Issue, 2011, 3(5): 53-59.

[13] QUAMMEN D. Animals and earthquakes: This World [J]. San Francisco Chronicle, 1985: 15-16.

[14] KIRSCHVINK J. Earthquake Prediction by Animals: Evolution and Sensory Perception [J]. Bulletin of the Seismological Society of America, 2000, 90(12): 312-323.

[15] GUTENBERG B, RICHTER C. Magnitude and Energy of Earthquake [J]. Annali di Geofisica, 1956: 1-15.

[16] ZHAN Z. Gutenberg–Richter law for deep earthquakes revisited: A dual-mechanism hypothesis [J]. Earth and Planetary Science Letters, 2017: 1-7.

[17] CRAMPIN S, GAO Y. The Physics Underlying Gutenberg-Richter [J]. Journal of Earth Science, 2015, 26(1): 134-139.

[18] MURTY C. What are Magnitude and Intensity? [J]. Indian Institute of Technology Kanpur, 2004: 5-6.

[19] ROSHAN A, BASU P. Application of PSHA in low seismic region: A case study on NPP site in peninsular India [J]. Nuclear Engineering and Design, 2010: 3443-3454.

[20] ADEPELUMI A A, ONIBIYO O, ISOGUN M A. Short-term probabilistic prediction of earthquake occurrence in Southwestern Nigeria [J]. Environntropica, 2010:1-11.

[21] EMAD A. Variation of b – value in the earthquake frequency – magnitude distribution with depth in the intraplate regions [J]. International Journal of Basic & Applied Sciences, 2011, 11(06): 29-37.