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Pattern of Seismicity Associated with the African Lithospheric Plate

O. S. Hammed[1*], M. O. Awoyemi[2], W. N. Igboama[1], G. O. Badmus[3] and U. C. Essien[4]

[1]Federal University, Oye Ekiti, Nigeria.
[2]Obafemi Awolowo University, Ile-Ife, Nigeria.
[3]Afe Babalola University, Ado-Ekiti, Nigeria.
[4]Bells University of Technology, Ota, Nigeria.

Authors' contributions

This work was carried out in collaboration by all authors. All authors read and approved the final manuscript.

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ABSTRACT

Knowledge of earthquake distribution pattern is very essential in exploration, understanding and forecasting of earthquake occurrence on the African plate. This paper focused on application of earthquake distribution pattern technique to investigate the regions of African plate that are prone to the seismic hazards. The earthquake epicenters for these regions were mapped out from the global seismicity map. The epicenters were located on Northern Africa (latitude 20°to 40°, longitude 0°to 50°), Southern Africa (latitude -10° to -30°, longitude 20° to 40°), Eastern Africa (latitude 10° to -25°, longitude 36° to 50°) and Western Africa (latitude 0° to 7°, longitude 0° to10°). The earthquake data corresponding with these epicenters were obtained from global earthquake catalogue. The data covered a 40-year period from January 1st 1974 to December 31st 2013 and in all, there were 58,649 earthquakes.

The results obtained revealed that all the regions on the African plate are prone to a significant level of seismic hazard except the West African region. This signifies that the seismicity of Africa is

**Corresponding author: E-mail: hammedolaide@yahoo.com;*

mainly concentrated in two main regions - Northern and South-eastern Africa. This implied that the seismotectonic process is marked by a relative motion alternating between left and right lateral along the African and Eurasian plate.

Keywords: African lithospheric plate; seismotectonic; epicenter; earthquake distribution.

1. INTRODUCTION

Knowledge of earthquake distribution pattern is very essential in exploration, understanding and forecasting of earthquake occurrence on the African plate. This paper focused on application of earthquake distribution pattern technique to investigate the regions of African plate that are prone to the seismic hazards. African continent is one of the few land masses where very few earthquakes have been reported. It was not until fairly recent that the data on the African earthquakes began to appear in scientific publications. At present, the African plate is the third largest tectonic plate (~60 million km^2) with approximately half of it covered by land. This plate comprises several old cratonic units and accreted younger crust, representing a period of more than 2.5 billion years of continental and oceanic crust growth [1]. The African plate (as shown in Figs. 1, 2 and 3) moved relatively slowly for the last 150 Ma [2] and [3]. However, its continental interior experienced many changes throughout this time including rifting and variations in sedimentary basin subsidence, most of them in regions situated thousands of kilometers away from plate boundaries. The African plate was also partly underlain by mantle with an above average temperature induced by a series of hot-spots that contributed to episodic volcanism (including several Large Igneous Provinces), basin-swell topography, and consequent sediment deposition, erosion, and structural deformation [4]. Long-term intra-continental crustal deformation may be related to local and regional tectonic events [5] and [6] and mantle-lithosphere interaction [7]. Far-field stresses related to changes in plate boundaries are able to propagate within the lithospheric plates over thousands of kilometers and therefore may trigger rifting, folding and changes in sedimentary basin subsidence rate in remote regions. The relationship between plate boundary forces and observed deformation within plate interiors has been studied for several large tectonic plates and numerous authors

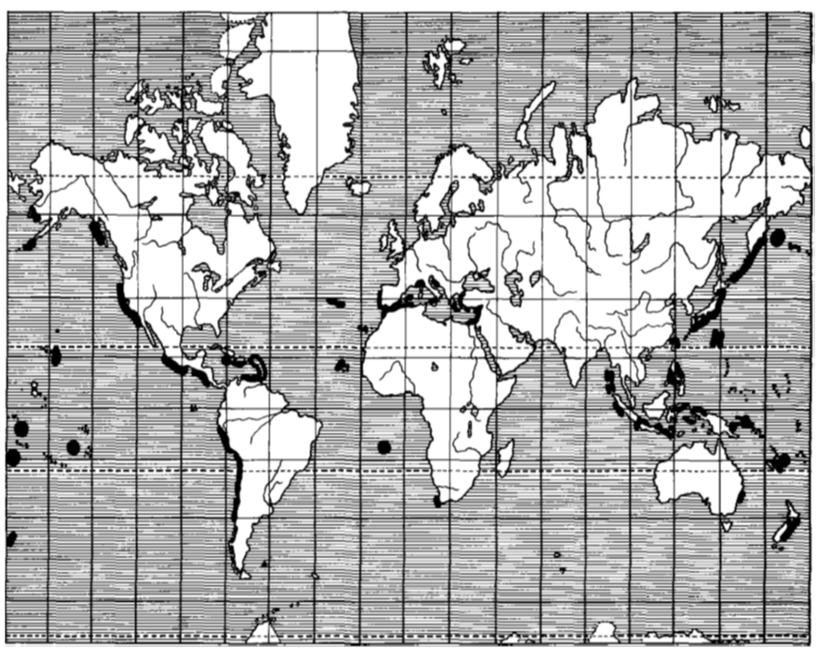

Fig. 1. Map of seismicity throughout the world compiled by Rudolf (adapted from UNESCO survey of the natural resources of African continent)

Fig. 2. Map of seismicity throughout the world compiled by Montessus de Ballore (adapted from UNESCO survey of the natural resources of African continent)

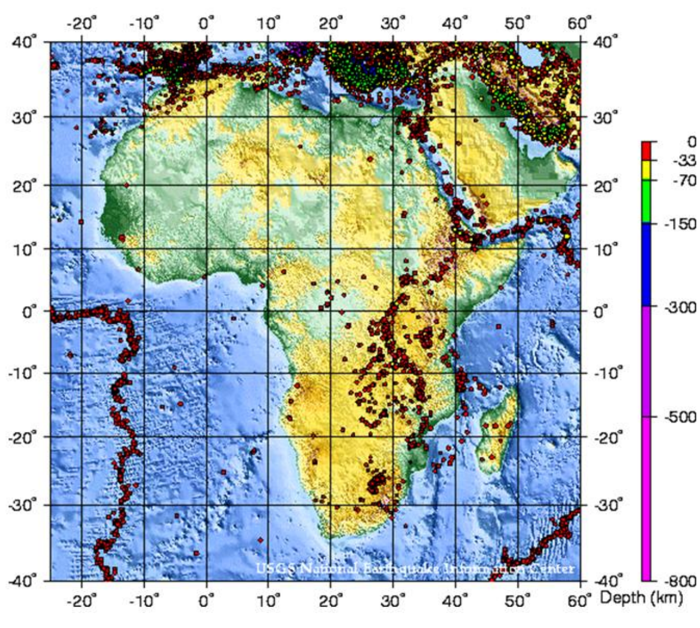

Fig. 3. A map showing seismicity of Africa (adapted from USGS national earthquake information center)

attempted modelling and quantification of ensuing present day and palaeo-stresses resulted from this connection: North America [8]; South America [9]; Africa [10]; Eurasia [11] and [12]; Australia [13] and [14] and Pacific [15] and [16].

2. MATERIALS AND METHODS

This research investigated four major regions of the African plate. To carry out this investigation, earthquake data for the regions were obtained from a website of the Northern California Earthquakes Data Centre (http://quake.geo.berkeley.edu/cnss/).The Centre is a joint project of the University of California Berkley Seismological laboratory and United States Geological Survey (USGS). The region of study is located between latitude 40° and -30° and longitude 0° and 60°. The data covers a 40-year period from 1974 to 2013 and in all, there were 58,649 earthquakes. The minimum magnitude selected in the catalog search is 0.5 and the maximum magnitude is 10.0. The minimum focal depth selected is 0.0 km while the maximum is 300 km. Each datum comprised data of occurrence of earthquake, origin time, date, magnitude, event identification and depth of earthquake. The regions investigated on the African lithospheric plate were Northern Africa (latitude 20° to 40°, longitude 0° to 50°), Southern Africa (latitude -10° to -30° , longitude 20° to 40°), Eastern Africa (latitude10° to -25°, longitude 36° to 50°) and Western Africa (latitude 0° to 7°, longitude 0° to10°). The data for these regions were mapped out from the global seismicity map. The data were sorted out, filtered and analysed to remove errors due to duplication and mixing of data using Compicat software. Compicat is an earthquake catalog processing software.

To study the seismic pattern or hazard of a region, there is a need to investigate seismic parameters to mitigate the future occurrence of earthquakes [17]. Focal depth, frequency, seismic energy and epicenters relations play a paramount role in understanding seismic activity of the earth regions [18]. The relationship between the size distributions of earthquakes over a large range of magnitudes in a seismogenic volume can be described by a power law equation [19].

The relationship between size distribution of earthquakes and magnitude was discovered by [20] in California. One of the forms of power law is given as;

$$\text{Log}N = a + bM \quad (1)$$

Where N is the number of earthquakes with magnitude greater than or equal to M and a and b are constants.

The parameter ‘a’ describes the productivity of a volume and ‘b’, the slope of the frequency Magnitude distribution, describes the relative size distribution of events. Parameter ‘a’ is a function of quantity of earthquakes throughout the years covered in the study area while ‘b’, in general is approximately equal to 1. Large value for b (>1) indicates predominantly small earthquakes while small values of b (<1) implies predominantly large earthquakes. The values of ‘a’ and ‘b’ were obtained from intercept and slope of the graph of Log N against M. The b-value in Gutenberg-Richter law Equation 1 is very important because it reveals a lot in the studies of seismotectonic, seismic risk analysis, prediction and hazard. Therefore, its correct computation represents an important challenge and gives vital information as per seismology of a given area.

In order to investigate the earthquake distribution patterns in the study area, the earthquake focal depths were plotted against the Longitude and Latitude parameters of earthquake epicenters.

The frequencies of earthquakes were obtained and plotted against earthquake epicenters in order to investigate the frequency distribution of the earthquake along the epicenters in the regions of study.

The weighted sums of seismic energy were obtained for each region of study and correlated with the latitudinal and longitudinal earthquake epicenters to investigate the seismotectonic activities of the African plate.

3. RESULTS AND DISCUSSION

The Gutenberg – Richter relation for the whole region of African plate gives values of 6.68 and 0.904 as “a” and ‘b’ values respectively as shown in Fig. 4. The parameter ‘a’ value characterized the general level of seismicity in the whole African lithospheric plate. This value (greater than 1) indicates that the earthquake productivity in the region, in terms of quantity is significant. The b value (less than 1) signifies that there are many intermediate earthquakes than smaller ones in the region. The distribution of smaller and intermediate earthquakes is almost equal and the ratio is slightly below unity. The a and b values obtained from the Gutenberg – Richter relation for Northern Africa, Eastern Africa, Southern Africa and Western Africa portions of African plate were: a = 6.796, b = 0.923, a = 2.014, b = 0.213, a = 2.0, b = 0.309 and a = 0.7, b = 1.0652 as shown in Figs. 5, 6, 7 and 8 respectively. Interpretation of these values is that the Northern, Southern and Eastern regions of Africa are prone to a significant level of seismic hazard. Thus, they are regarded as seismic zones of the African plate. This is connected to the 'a' value (greater than 1) obtained for the three regions. The higher the 'a' value obtained for a region, the more the earthquake occurrence in that region. Thus the level of seismicity is highest in the Northern region owing to its highest value of 'a'. The rate of earthquake occurrence in the West Africa region is low due to its lowest value of 'a' (less than 1) obtained for the region. This implies that the West African region is an aseismic zone of the Africa plate. However in the West African sub regions, there had been some recorded cases of spectacular and disastrous earthquakes. For instance, the December 1983 Guinea earthquake which claimed 300 lives and injured 10,000 more. In 1983, a 6.5 magnitude earthquakes hit Ghana and many people were killed with severe damage to properties. Other tremors in this region include 21st December 1963 Ijebu-Ode tremor with intensity 5.0 Richter scale, 1st July 1975 tremor near Gary in Dambata, Kano and Yola tremor of 8th December 1984, Ibadan tremor of 2001 all in Nigeria. Therefore this does not means that the region is free from earthquake occurrence.

The Africa region is characterized by shallow and intermediate focal depth earthquakes as shown in Fig. 9. The shallow focal depth earthquakes are predominant in the African plate with the exception of the Northern part of the region where very few intermediate focal depth earthquakes occurred. This means that the earthquake epicenters in the region range from 0 - 300 km.

The seismicity of Africa is mainly concentrated in two main regions - Northern and South-Eastern Africa (Figs. 9, 10 and 11). This implied that the seismotectonic process is marked by a relative motion alternating between left and right lateral along the African and Eurasian plate. The South-Eastern African region covers a region which is prone to a significant level of seismic hazard due to the presence of the East African rift system. The whole region is crossed by a tectonically active rift system within a stable African shield known as the East African Rift System (EARS). The East African Rift trends largely north south. The West African region experienced less seismicity.

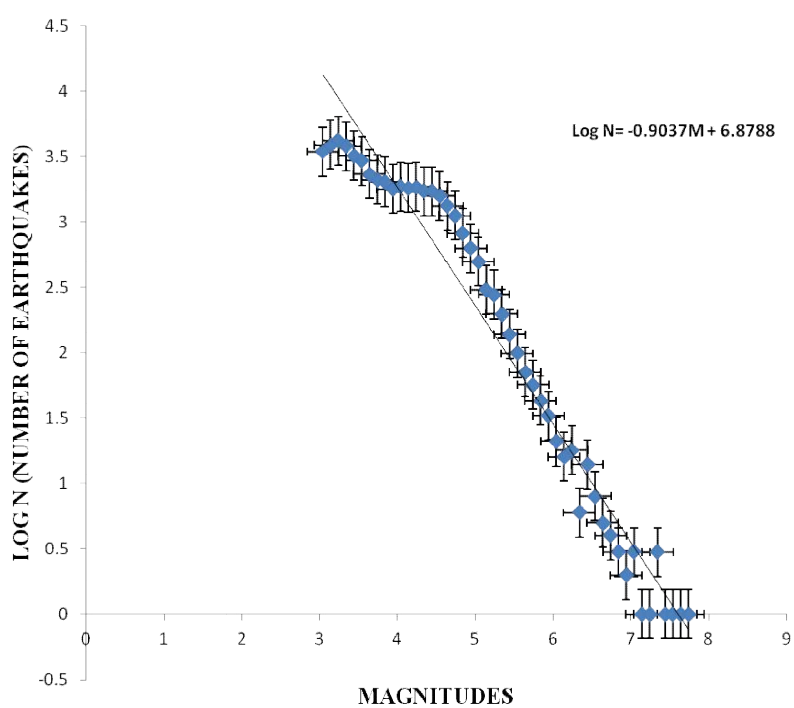

Fig. 4. The Gutenberg – Richter relation for the African plate seismicity

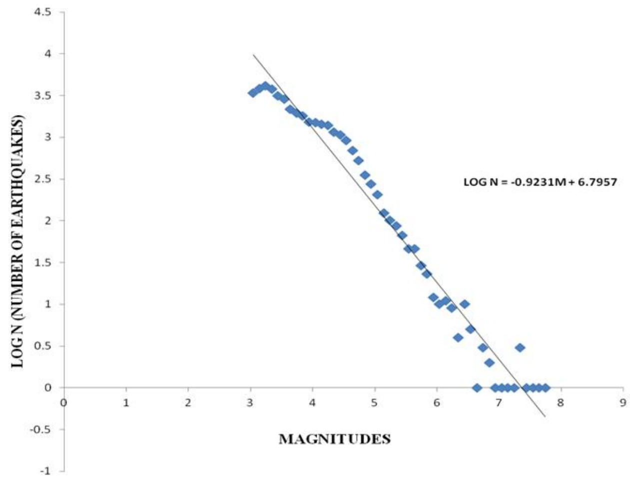

Fig. 5. The Gutenberg – Richter relation for the Northern Africa seismicity

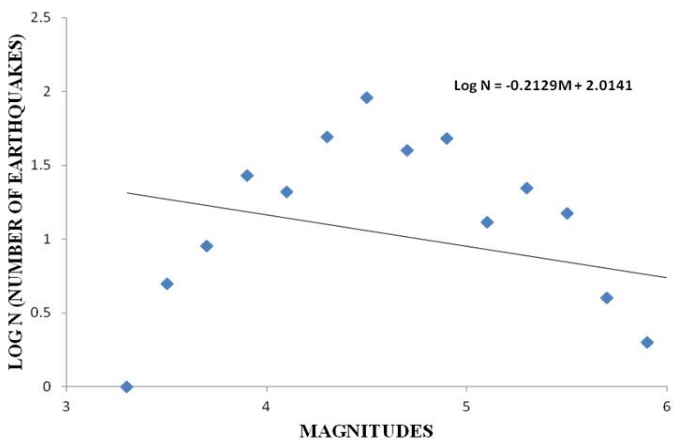

Fig. 6. The Gutenberg – Richter relation for the Eastern Africa seismicity

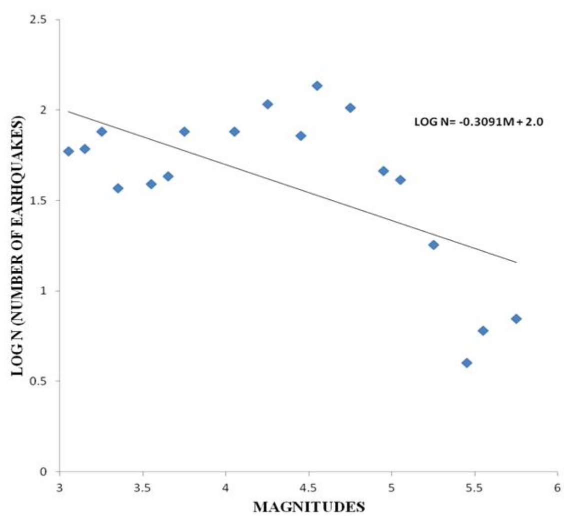

Fig. 7. The Gutenberg – Richter relation for the Southern Africa seismicity

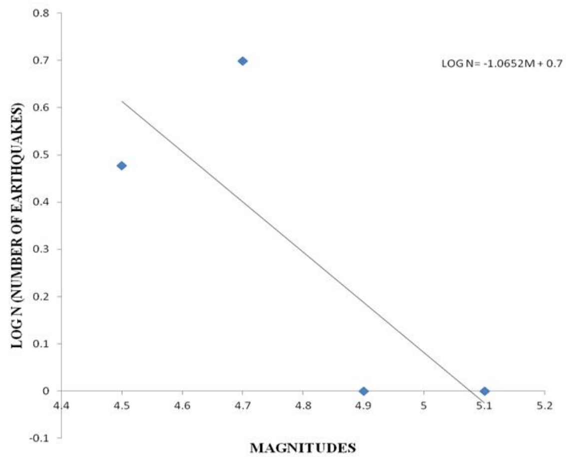

Fig. 8. The Gutenberg – Richter relation for the Western Africa seismicity

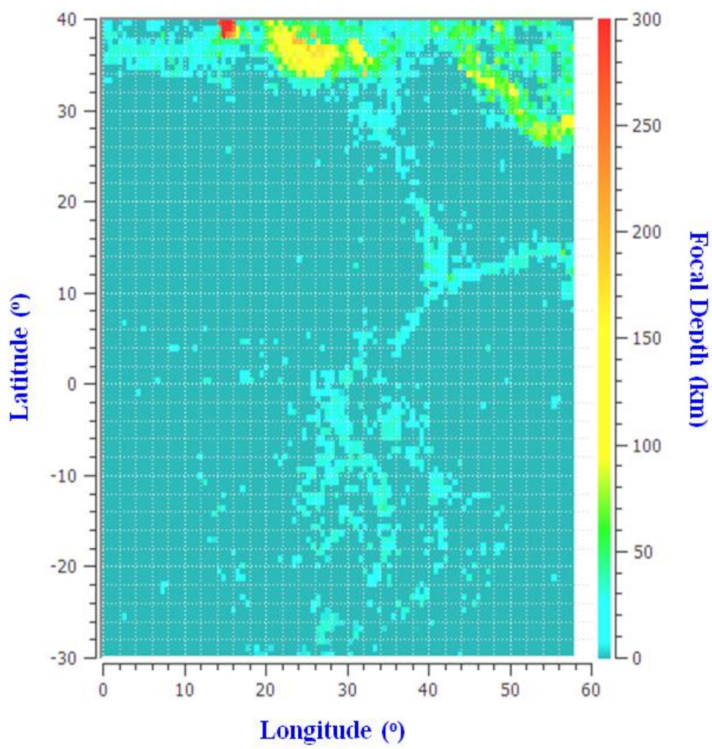

Fig. 9. Focal depth against Latitude and Longitude of earthquakes in Africa 1974 – 2013

The histogram featuring the latitudinal variation of earthquakes (Fig. 10) revealed that the earthquakes were highly concentrated in the Northern region and less concentrated in the Southern region of the plate. This is in consonance with the 'a' value results obtained.

The longitudinal variation of earthquakes analysis (Fig. 11) showed that the earthquakes were highly concentrated in the Eastern region and extremely less concentrated in the Western region of the plate. The concentration of the earthquakes in the Eastern African may be as a result of the East African Rift System.

The weighted sum of seismic energy along the epicenters was notably significant in the Northern region (Fig. 12) and extremely minimal in

Western African region (Fig. 13) with the predominant shallow focal depth. This implies that there are more shallow earthquakes than intermediate earthquakes in the regions.

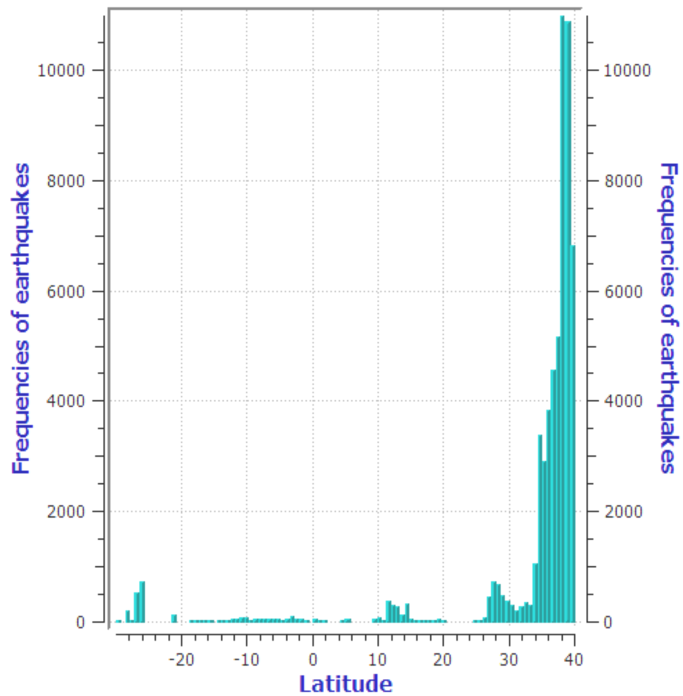

Fig. 10. Frequency against latitude of earthquakes in Africa 1974 – 2013

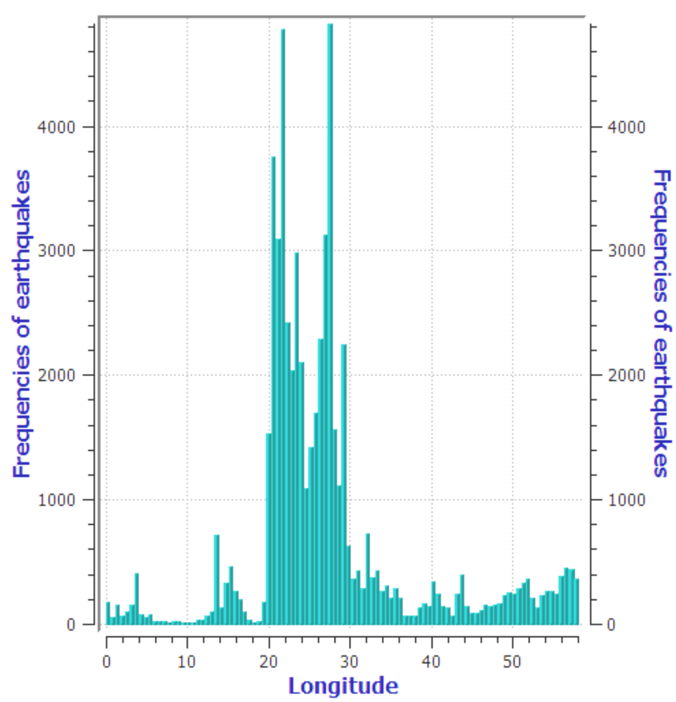

Fig. 11. Frequency against longitude of earthquakes in Africa 1974 – 2013

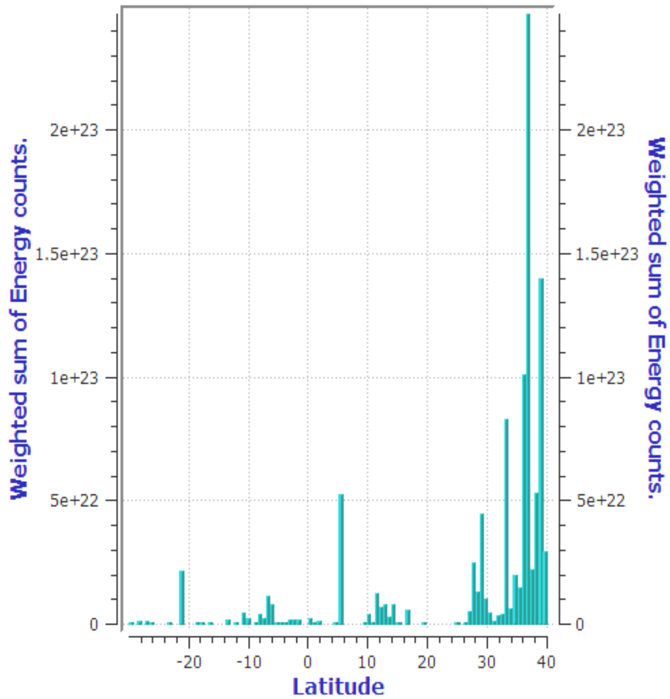

Fig. 12. Weighted sum of seismic energy against latitude of earthquakes in Africa 1974 – 2013

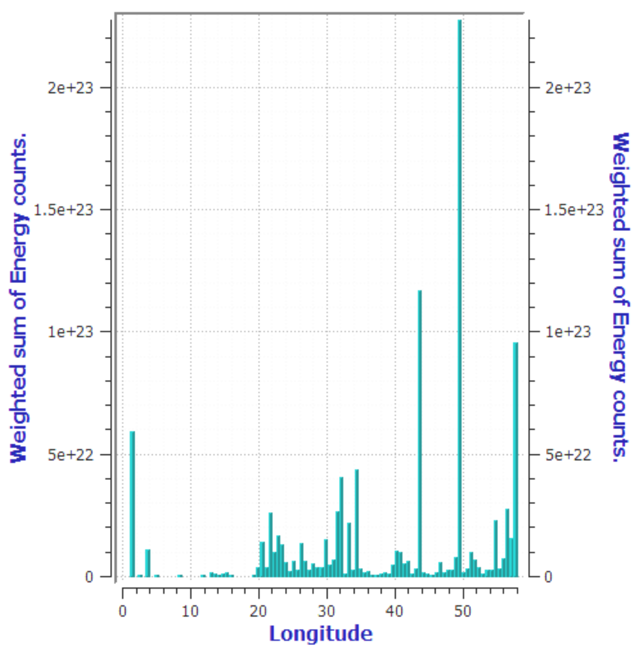

Fig. 13. Weighted sum of seismic energy against longitude of earthquakes in Africa 1974 – 2013

4. CONCLUSION

The Northern and Eastern regions of the African plate are more prone to earthquake hazards.

The earthquake clusters at the Northern Africa area and is dispersed at other regions of the African plate. Both shallow and intermediate focal depths occur in the African plate, but the immediate focal depths are notable in the northern and Eastern part of Africa.

Earthquakes occurring in the African lithospheric plate concentrate mainly in the Northern and South-Eastern region. The level of seismic activity is low in the Southern Africa and extremely low in Western Africa region but notably significant in the Northern region. Increase in seismic energy is predominant in both Northern and Eastern Africa.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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