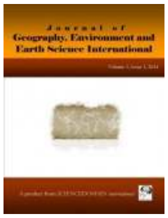

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Interdepedence and Variations of Earthquake Parameters on African Lithospheric Plate Using Gutenberg and Richter Relations

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Authors' contributions

This work was carried out in collaboration by all authors. Authors OSH and MOA designed the study and wrote the protocol. Authors OSH and OOS analyzed the data. Authors OSH and MOA interpreted the results. Authors OSH, MOA and GOB wrote the first and final draft of the manuscript. Authors GOB and OOS managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

The empirical variation of earthquake parameters such as frequency, focal depth and energy had been used in the past by seismologists to estimate the magnitude of large historic earthquakes from existing intensity maps. The Engineering geologists often need it to predict the intensity, focal depth and energy of earthquakes on the basis of maximum possible magnitude for a certain return period. The generalized earthquake scaling relations derived by Gutenberg and Richter [1] were used to determine the intensity and earthquake energy of individual events. The following were investigated: Frequency-magnitude variation; Focal depth's variation with intensity, magnitude and energy; Earthquake intensity's variation with energy of earthquakes; Magnitude's variation with intensity and energy of earthquakes.

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The earthquake energy, intensity and magnitude decrease with increase in focal depth and maxima at shallow focal depth on the African plate.
The seismic energy radiated from the earthquake focus could be used as the earthquake magnitude and intensity predictor.

Keywords: Focal depth; seismic activity; earthquake intensity; magnitude; seismic energy.

1. INTRODUCTION

Earthquake parameters serve as an important data base for the generalists and synthesizers in seismology and as an initial starting point for the applied theoreticians. The routine determination and reporting of source properties, for example, could make possible a new level of understanding in many seismological studies that would involve the use of routinely reported earthquake locations to define boundaries of tectonic plates world-wide. These advances are made possible now through the availability of digitally recorded seismic data and of computer programs for interactive analysis that permits more rapid efficient estimation of earthquake parameters. The empirical variation of earthquake parameters such as frequency, focal depth and energy had been used in the past by seismologists to estimate the magnitude of large historic earthquakes from existing intensity maps. The Engineering geologists often need it to predict the intensity, energy of earthquakes on the basis of maximum possible magnitude for a certain return period. Even focal depth of an earthquake can also be estimated using the empirical variation of earthquake parameters especially when it is poorly constrained by instrumental errors [2,3].

This research aimed at investigating the interdependence of earthquake parameters and their variations over African lithospheric plate.

1.1 Magnitude and Seismic Energy

Magnitude is a logarithmic measure of the size of an earthquake or explosion based on instrumental measurements. The magnitude concept was first proposed by Richter [4]. Magnitude of an earthquake is a measure of its size. For instance, one can measure the size of an earthquake by the amount of strain energy released by the fault rupture. This means that the magnitude of the earthquake is a single value for a given earthquake. Magnitudes are derived from ground motion amplitudes and periods or from signal duration measured from instrumental records. There is no a priori scale limitation to magnitudes as it exists for macroseismic intensity scales. Magnitudes are often misleadingly referred to in the press as "... according to the open-ended RICHTER scale...". In fact, the maximum size of tectonic earthquakes is limited by nature, i.e., by the maximum size of a brittle fracture in a finite and heterogeneous lithospheric plate. The largest moment magnitude, Mw, observed so far was that of the Chile earthquake in 1960 (Mw » 9.5) [5]. On the other hand, the magnitude scale is open at the lower end. Nowadays, highly sensitive instrumentation close to the sources may record events with magnitude smaller than zero. With empirical energy magnitude-relationships, the seismic energy, Es, radiated by the seismic source as seismic waves can be estimated. Common relationships are those given by Gutenberg and Richter [6,7] between Es and the surface-wave magnitude Ms and the body-wave magnitude Mb: log Es = 11.8 + 1.5 Ms and log Es = 5.8 + 2.4 Mb, respectively (where Es is given in erg; 1 erg = 10^{-7} Joule). According to the first relationship, a change of M by two units corresponds to a change in Es by a factor of 1000. Based on the analysis of digital recordings, there exist also direct procedures to estimate Es [8-12] and define an energy magnitude 'Me'. Since most of the seismic energy is concentrated in the higher frequency part around the corner frequency of the spectrum, Me is a more suitable measure of the earthquakes' potential for damage. In contrast, the seismic moment is related to the final static displacement after an earthquake and consequently, the moment magnitude, Mw, is more closely related to the tectonic effects of an earthquake.

1.2 Intensity

Intensity is a qualitative measure of the actual shaking at a location during an earthquake, and is assigned with Roman Capital Numerals. There are many intensity scales. Two commonly used ones are the Modified Mercalli Intensity (MMI) Scale and the MSK Scale. Both scales are quite similar and range from I (least perceptive) to XII (most severe). The intensity scales are based on three features of shaking-perception by people and animals, performance of buildings, and changes to natural surroundings. Intensity is the effect of an earthquake at a particular place. The effects generally considered in determining earthquake intensity are those on man, on construction, and on the earth's surface, but certain instrumentally measured parameters of ground motion have at times been included. A great number of intensity scales have been devised and revised to describe the varying degrees of sensation and damage caused by earthquakes. Forty-four of these scales were correlated by Gorshkov and Shenkarev and discussed briefly by Medvedev [13,14]. In the United States the Modified Mercalli scale (M.M. or M.M. 1931) of 12 units is in general use [15].

1.3 Magnitude and Intensity

Magnitude of an earthquake is a measure of its size. For instance, one can measure the size of an earthquake by the amount of strain energy released by the fault rupture. This means that the magnitude of the earthquake is a single value for a given earthquake. On the other hand, intensity is an indicator of the severity of shaking generated at a given location. Clearly, the severity of shaking is much higher near the epicenter than farther away. Thus, during the same earthquake of a certain magnitude, different locations experience different levels of intensity. To elaborate this distinction, consider the analogy of an electric bulb. The illumination at a location near a 100-Watt bulb is higher than that farther away from it. While the bulb releases 100 Watts of energy, the intensity of light (or illumination, measured in lumens) at a location depends on the wattage of the bulb and its distance from the bulb. Here, the size of the bulb (100-Watt) is like the magnitude of an earthquake, and the illumination at a location is like the intensity of shaking at that location.

1.4 Intensity Variation as a Function of Focal Depth

Focal depth is a major variable affecting intensity distribution, but unfortunately accurate information on focal depths is not available for most earthquakes within the earth's crust, and studies relating focal depth to intensity have been adequately documented only for quakes beneath the crust. However, in some local areas, most of the earthquakes are considered to originate at about the same level; for example, 16 km in southern California [7], and the variation of intensity caused by different focal depths in such an area may be small. Information on the variation caused by different focal depths is important in attempting to compare the distribution of effects of earthquakes of different focal depths and to extrapolate earthquake effects to the shallow depths in which nuclear testing is conducted. The epicentral intensity increases with decreasing focal depth. The relationship was shown by Shebalin [16-19] as I_0 = l.5M-3.5 log h + 3.0 (normal earthquakes).

2. METHODS

The data used for this study was obtained from a website of the Northern California Earthquakes Data Centre. The region of study was located on latitude 40° and -30° and longitude 0° and 60° on African plate. The data covers a 40-year period from January 1st 1974 to December 31st 2013. In all, there were 58,649 events. The minimum and maximum magnitudes selected in the catalog search were 0.99 and 10.0. The minimum and maximum focal depths selected were 0.0 km and 300 km. Each datum comprised data of occurrence of earthquake, origin time, date, magnitude, event identification and focal depth of earthquake. The data were sorted out and filtered to remove errors due to duplication and mixing of data using Compicat software. Compicat is an earthquake catalog processing software.

The following earthquake parameters were derived from the data: Depth, frequency, magnitude (body wave magnitude and surface wave magnitude), intensity and energy of earthquakes. In seismological practice, there are various relations that connect the dependence of magnitude, energy and intensity of earthquakes. Therefore generalized earthquake scaling relations (shown in equations 2.1 – 2.3) derived by Gutenberg and Richter [6,7] were used to determine the intensity and earthquake energy of individual events:

$$Mb = 0.56Ms + 2.9 \quad (2.1)$$

$$\text{Log}_{10} E = 11.8 + 1.5Ms \quad (2.2)$$

$$Ms = 0.67I_0 + 1.7 \log_{10} h - 1.4 \quad (2.3)$$

Where Mb is Body wave magnitude, Ms= Surface wave magnitude, E= Energy of earthquake measured in ergs, h= Focal depth and I_0= Earthquake intensity.

2.1 Investigation of Frequency-Magnitude Variation

Earthquake frequency-magnitude relation helps to understand seismic activity in an area [20]. In this research, variation of earthquake frequency and cumulative frequency with the body wave magnitude were investigated to determine the size and frequency counts of magnitude range from 1.0 – 9.0 on richter scale for the seismic events in the region of study. To assess the trend of frequency – magnitude distribution associated with the earthquakes in the region, the graphs of frequency and cumulative frequency were plotted against magnitude distribution for the seismic period of 40 years (1974 - 2013) and the time intervals of 10 years: 1974 – 1983, 1984 – 1993, 1994 – 2003 and 2004 – 2013. Also the graph of body wave magnitude against surface wave magnitude distributions were plotted to investigate the trend of variation between the two parameters as regards their points of measurement.

2.2 Investigation of Focal Depth's Variation with Magnitude, Intensity and Energy of Earthquakes

To study the assessment of earthquake parameter's variation of a region, there is a need to detect all probable seismic sources and check their potential to generate strong ground motion [21]. This led us to investigate the trend of focal depth's variation with the earthquake parameters such as magnitude, intensity and energy in this work using the seismic equations 1.0, 2.0 and 3.0. Both body waves and surface wave magnitudes were considered. The graphs of these parameters were plotted against focal depth for the seismic period of 40 years (1974 - 2013).

2.3 Investigation of Earthquake Intensity's Variation with Energy of Earthquakes

The assessment of earthquake intensity on a descriptive scale depends on actual observations of earthquake effects. Observation on the performance of building structures, natural phenomena and human perceptions are essential for evaluating the earthquake intensity. In this work, Modified Mercalli Intensity (MMI) scale was used to evaluate the effects of earthquakes. MMI scale, designated in Roman numerals, composed of 12 increasing levels of intensity that range from imperceptible shaking to catastrophic destruction. Using the graph of earthquake intensity against energy, variation of the earthquake intensity with the seismic energy was investigated to examine the correlation between the two parameters over the African plate.

2.4 Investigation of Magnitude's Variation with Intensity and Energy of Earthquakes

The most widely accepted indicators of the size of an earthquake are magnitude, intensity and energy of earthquakes. The magnitude is the measure of an earthquake in terms of the intensity and the released energy. To quantify the size of earthquakes and assess the potential risks in the region of study, variation of magnitudes with the intensity and energy of earthquakes were investigated using the Richter scale. The graphs of earthquake intensity against magnitude and graphs of earthquake energy against magnitude were plotted for the seismic period of 40 years (1974 - 2013).

3. RESULTS AND DISCUSSION

The analysis of earthquake frequency – magnitude relation for both cumulative and non cumulative frequency for four decades (Fig. 1a) and each decade Figs. (1b, 2a, 2b, 2c and 2d) revealed that the lower bound earthquake magnitudes were predominant on the African plate. These magnitudes varied between 2.0 and 5.0 on Richter scale. The predominant low bound earthquakes may be partly attributed to the microseismic events due to the rock fracturing within the plate. This implies that there are notable intra-plate earthquakes in the region. The increase in earthquakes on a decade basis (as shown in Fig. 1b) in the region also revealed that there was a relative motion between the fault planes along the fault zones within the plate which is a characteristic of a seismogenic zone. With time, this could lead to a large accumulation of stress in the fault zones which could trigger more earthquakes in the region.

Focal depth distribution of the seismic events on the plate revealed that most of the energy, intensity and magnitude values of earthquakes (as shown in Fig. 3) were clustered or concentrated at shallow focal depth ≤ 70 km and dispersed at intermediate focal depth ≥ 70 km. The earthquake energy, intensity and magnitude were maxima at the shallow focal depth on the African plate. The values of these parameters also decrease with increase in focal depth. This result validates the Papadopoulos and Pavlides findings [22] that there is a thick (70 km) seismogenic layer on some of the lithospheric plates, the upper part (0 – 40 km) of which is more active than the lower (40 – 70 km). Also, Bath [23] showed that the average seismic activity and energy increase exponentially with the decrease in focal depth.

The graph of energy versus intensity of earthquakes (shown in Fig. 4), revealed that the earthquake energy is proportional to the earthquake intensity. Thus the earthquake energy could be employed as a useful tool in predicting the earthquake intensity and vice versa on the African plate regions.

The analysis of body wave magnitude and surface magnitude as shown in Fig. 5, revealed that they were correlated. This implies that the data is measuring the same phenomenon such that the variability of body wave magnitudes are interdependent with surface wave magnitudes for the African lithospheric plate particularly when either of them is poorly constrained by instrumental errors. Earthquake intensity scale and energy of the earthquakes increase with magnitude as shown in Figs. 6 and 7. As the magnitude increases, the energy and intensity of earthquakes increase. This implied that the values of earthquake energy and scale values of intensity of earthquakes are magnitude dependants.

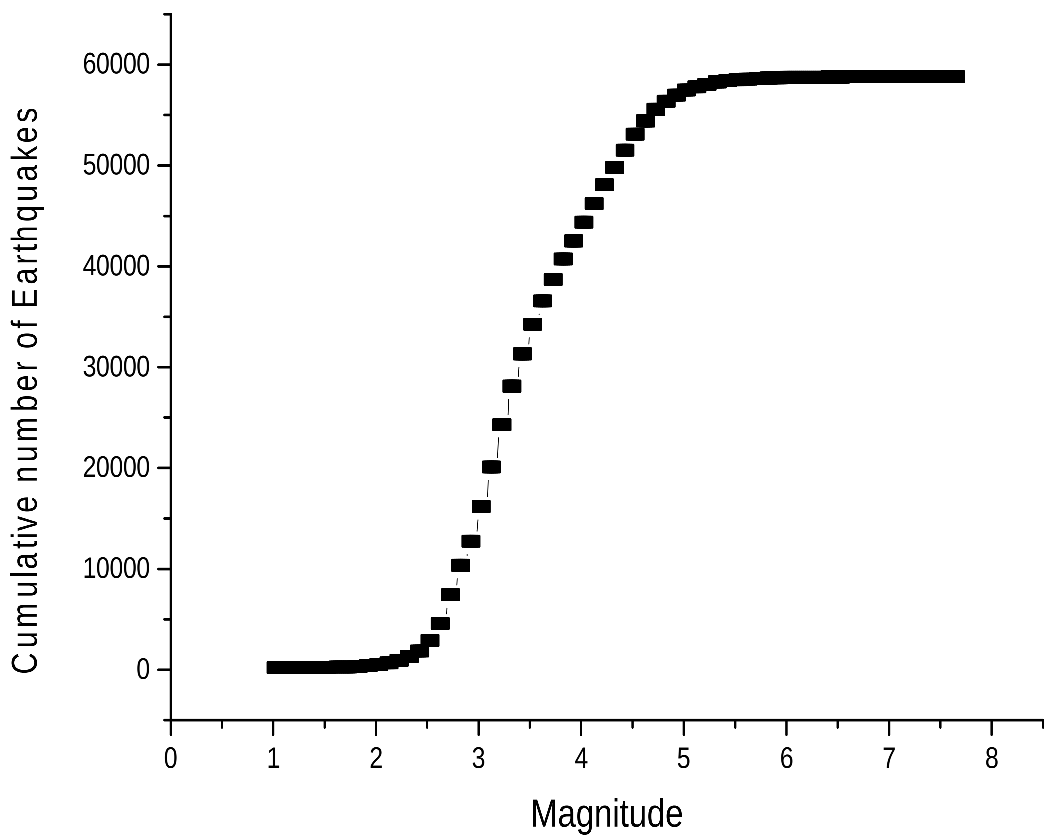

Fig. 1a. Cumulative number of earthquakes against magnitude (1974 – 2013)

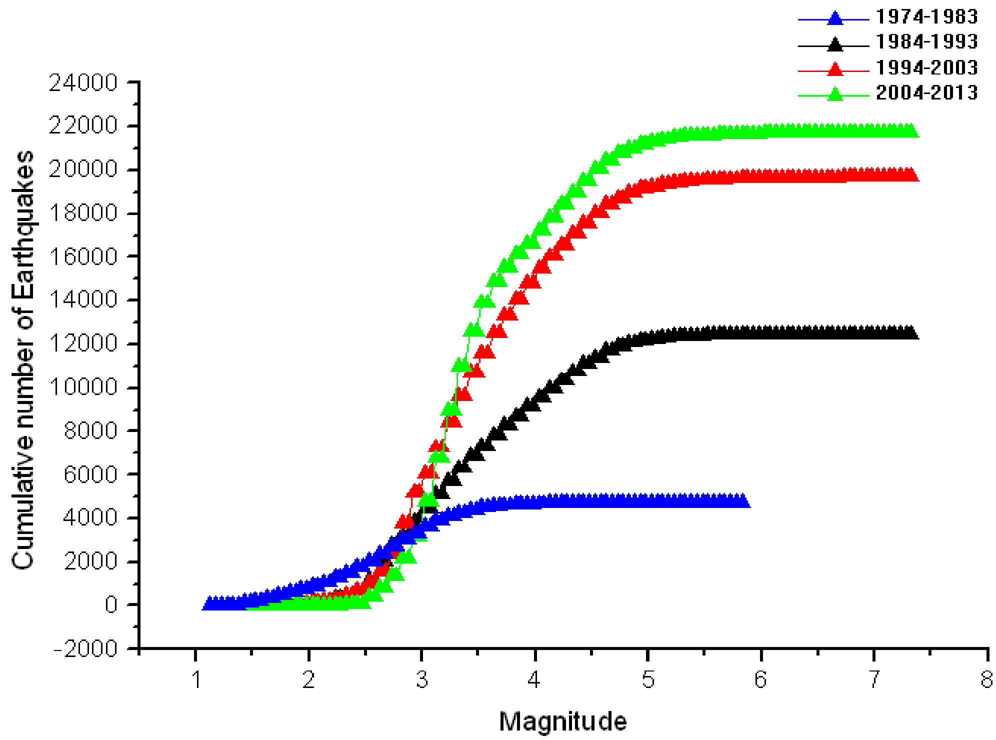

Fig. 1b. Cumulative number of earthquakes against magnitude at each decade

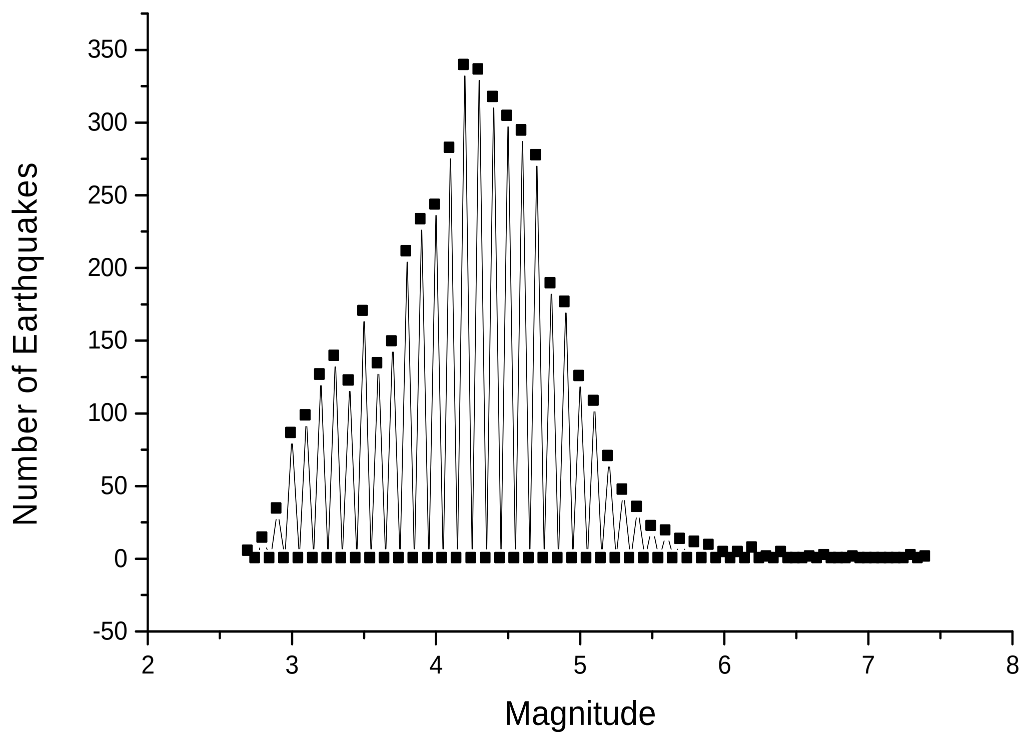

Fig. 2a. Number of earthquakes against magnitude (1974 – 1983)

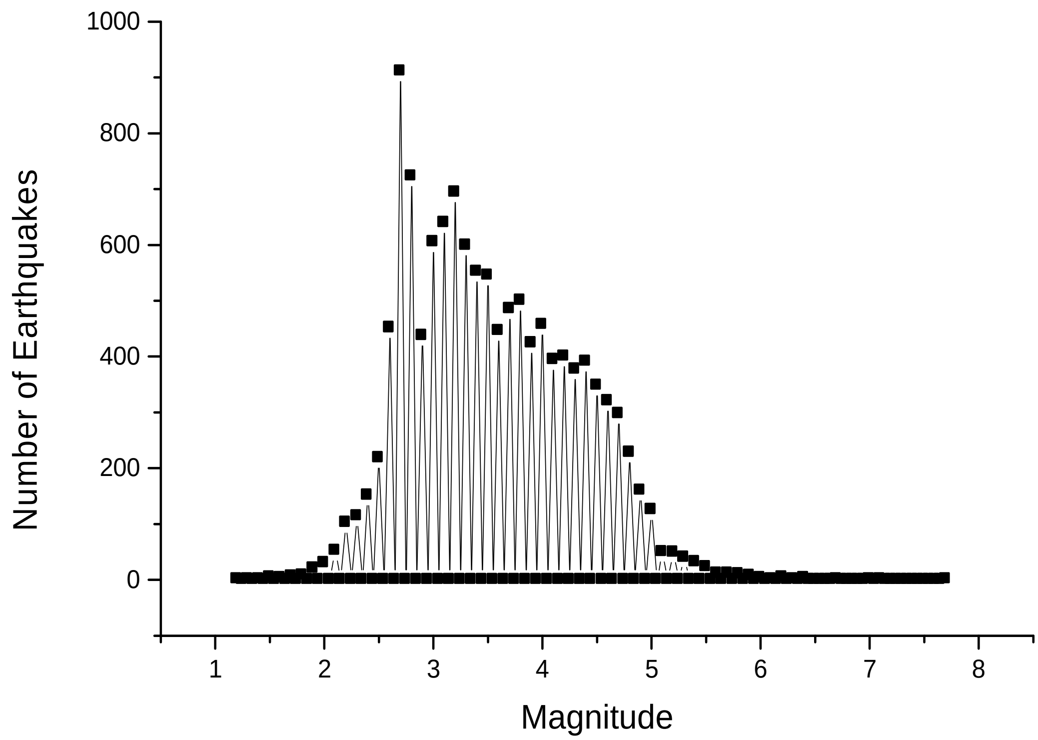

Fig. 2b. Number of earthquakes against magnitude (1984 – 1993)

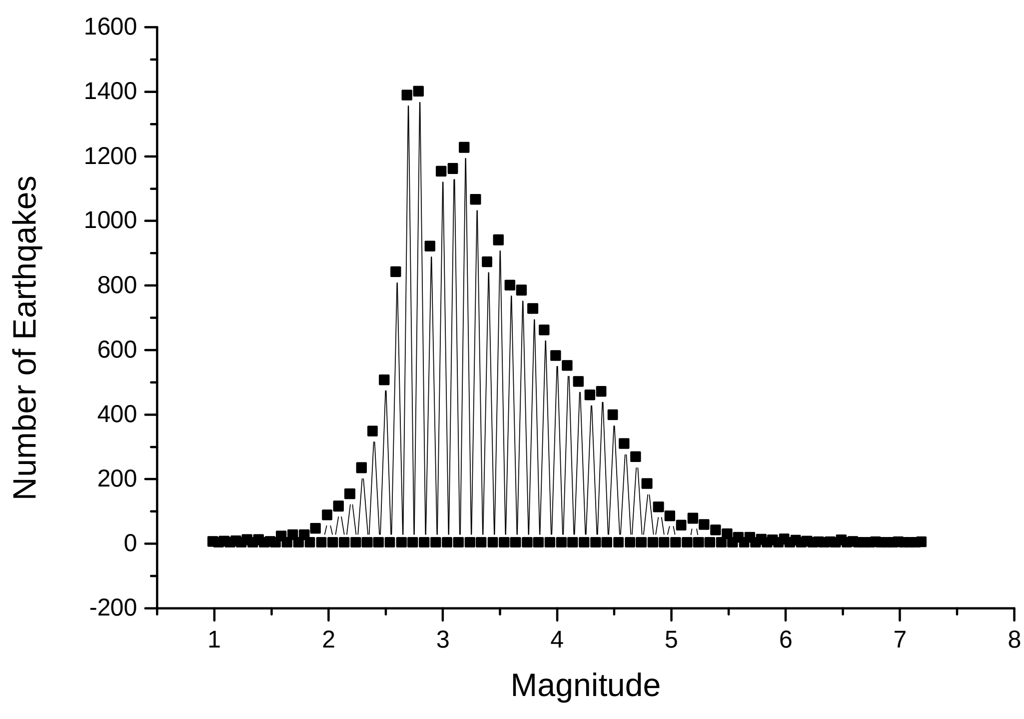

Fig. 2c. Number of earthquakes against magnitude (1994 – 2003)

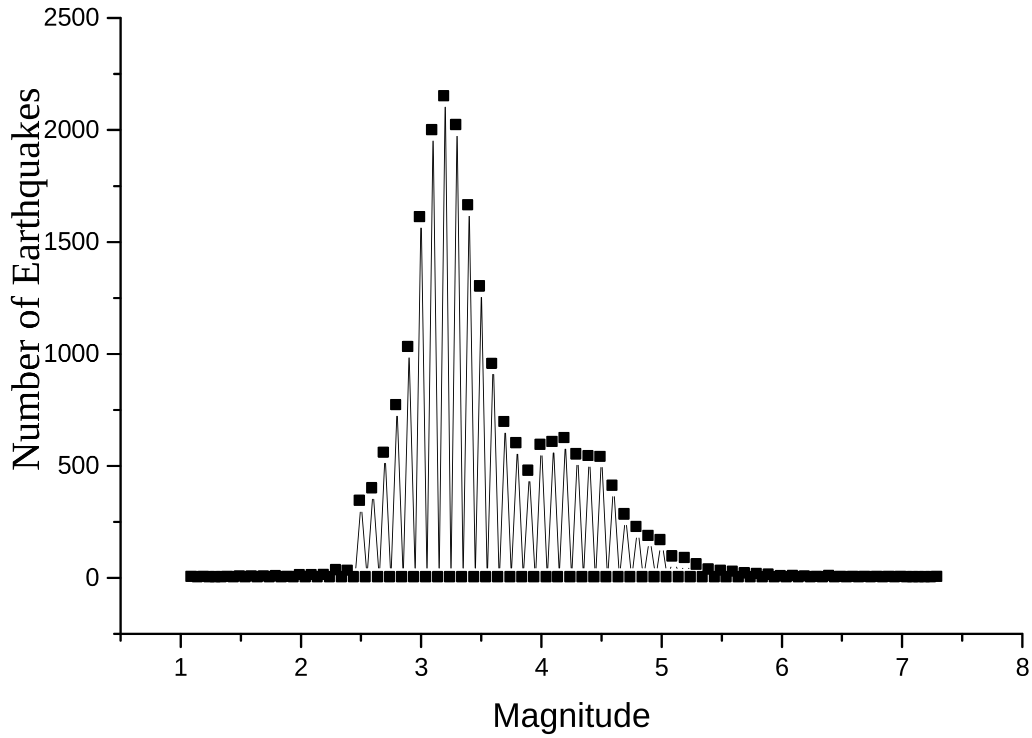

Fig. 2d. Number of earthquakes against magnitude (2004 -2013)

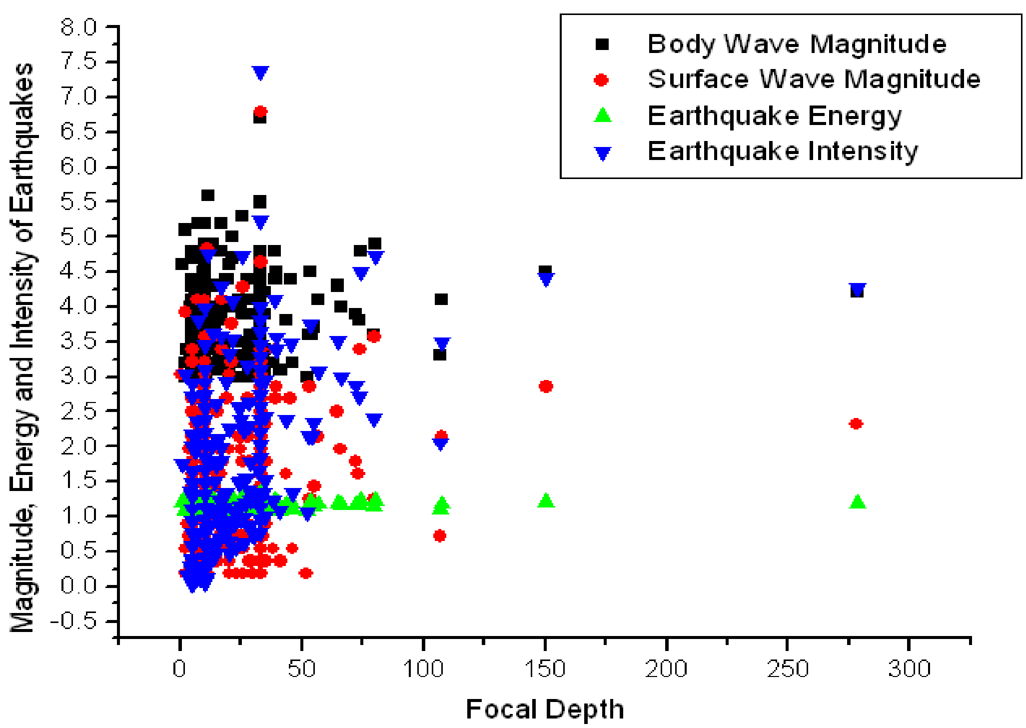

Fig. 3. Focal depth distribution of magnitude, earthquake energy and intensity

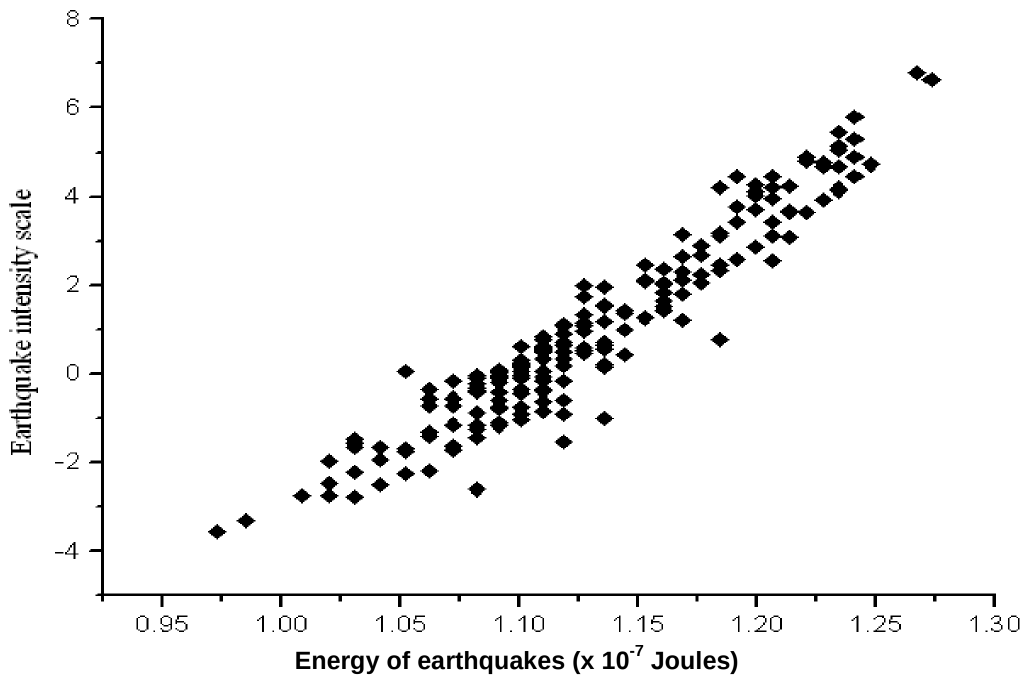

Fig. 4. Energy of earthquakes against earthquake intensity scale (1974 – 2013)

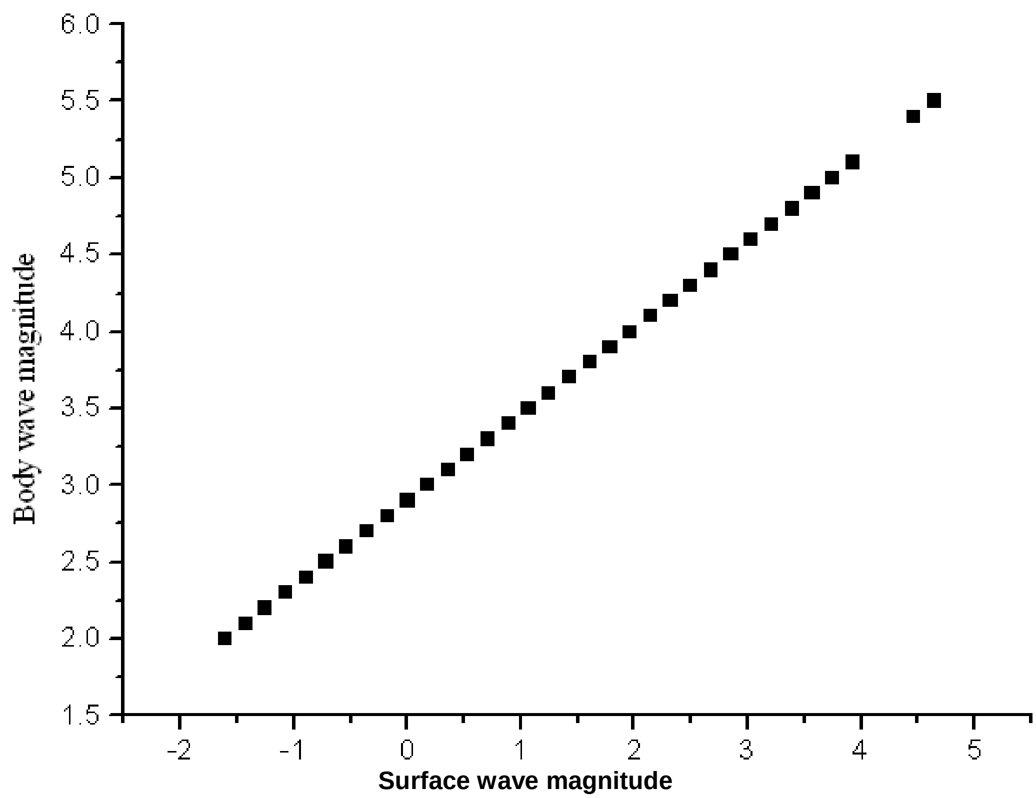

Fig. 5. Body wave magnitude against surface wave magnitude (1974 – 2013)

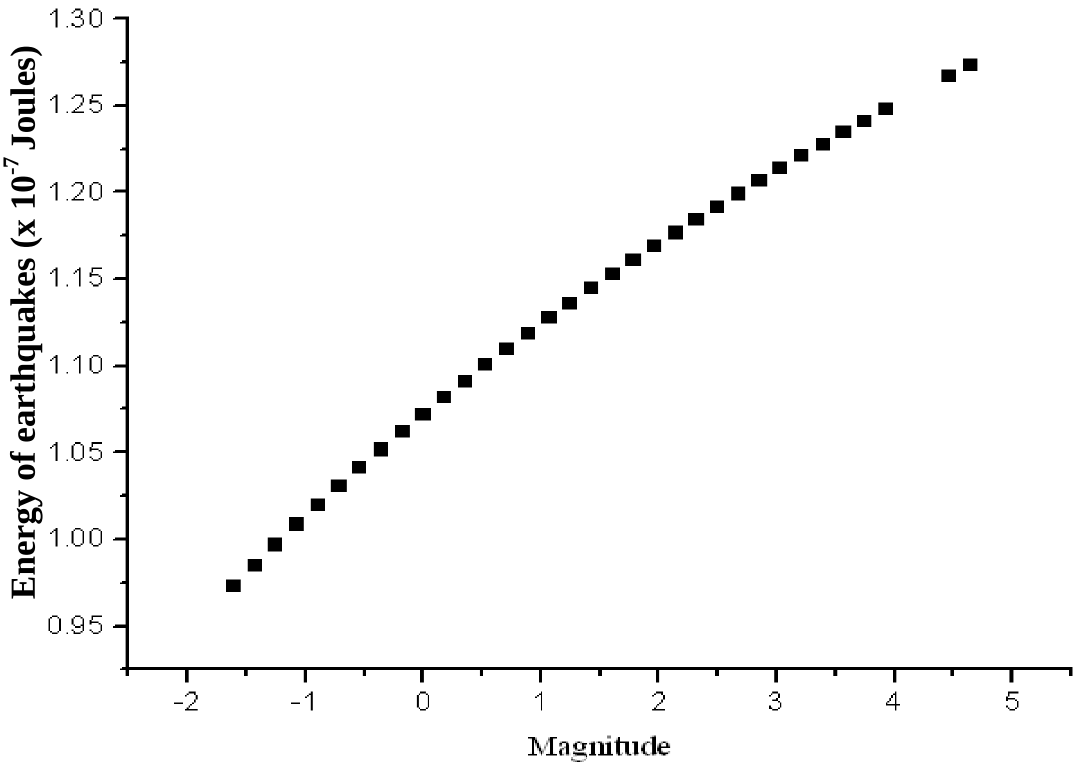

Fig. 6. Energy of earthquakes against magnitude (1974 – 2013)

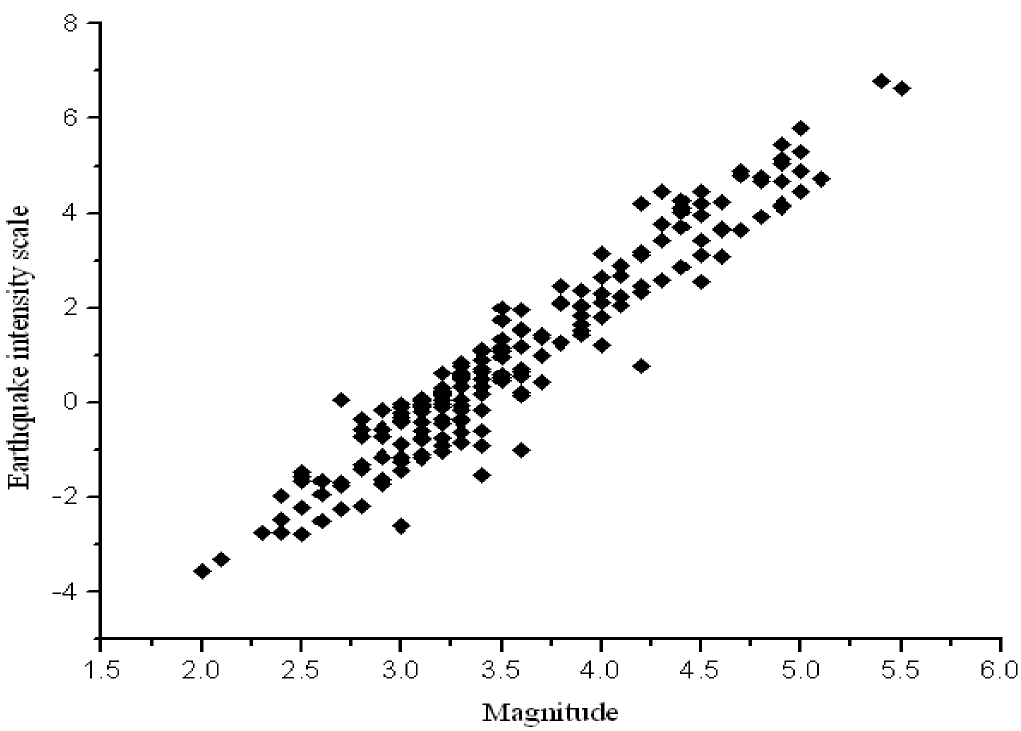

Fig. 7. Earthquake intensity scale against magnitude (1974 – 2013)

4. CONCLUSION

The earthquake energy, intensity and magnitude decrease with increase in focal depth and maxima at shallow focal depth on the African plate.

The surface wave magnitude could be used to investigate the level of variation of body wave magnitude and vice versa for the African lithospheric plate particularly when either of them is poorly constrained by instrumental errors.

The seismic energy radiated from the earthquake focus could be used as the earthquake magnitude and intensity predictor.

The intra-plate earthquakes are predominant on the African lithospheric plate. These earthquakes increased with time on the plate, indicating that the region is a potential seismogenic zone.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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