Pak. j. sci. ind. res. Ser. A: phys. sci. 2025 **68A**(2) 207-212

Seismicity Rate and Radiated Energy of Earthquakes in Parts of the African Plate

Abong Augustine Agwul[a]* and Atsu, J.U.[b]
[a]Department of Mathamatics, Cross River University of Technology, Calabar, Nigeria
[b]Department of Physics, Cross River University of Technology, Calabar, Nigeria.

(received May 17, 2023; revised July 24, 2024; accepted July 25, 2024)

Abstract. The occurrence of earthquakes and radiated energy in parts of the African plate were evaluated. The data for this study were extracted from the International Seismological Centre (ISC) earthquake catalogue. The data were analysed using seismicity rate, radiated energy model and Gutenberg - Richter's relationship. The findings of the study revealed that seismicity rate in all the regions of Africa under study varies arbitrarily with time. The total seismicity rate was higher in north Africa, followed by south Africa, east Africa and the least in west Africa. The b-values were determined to to be 0.49 in north Africa, 0.47 in south Africa, 0.69 in east Africa and 1.58 in west Africa. This indicates that a large b-value in a region shows that small earthquakes occur frequently and a small b-value shows that small earthquakes are not so frequent and that large earthquakes are more likely to happen. The radiated energy was also determined to 3.39607×10^{13} J/Km^2/year in north Africa, 20.3563×10^{13} J/Km^2/year in south Africa, 223.292×10^{13} J/Km^2/year in east Africa and 1873.82×10^{13} J/Km^2/year in west Africa. The energy per unit area per year follows this increasing trend in the order: north Africa - south Africa - east Africa - west Africa. This indicates that the radiated energy is highest in west Africa and lowest in north Africa. The implication of this study is that the regions of study are under stress especially north Africa and the lithospheric plate is gradually becoming unstable.

Keywords: seismicity, earthquakes, african plate, gutenberg-richter's relationship, east african rift system, radiated energy

Introduction

The rate of seismicity varies from one region to the other. Earthquake epicentres are not evenly distributed over the surface of the earth, but tend to occur mostly along the narrow zones within the rigid outer layer of the earth. The circum-pacific zone, is one of the most active zones of the world accounting for 75% to 80% of the yearly release of seismic energy (Lowrie, 2007) which consists of the subduction zones along the west coast of Asia, Australia, New Zealand and the Americas. In addition, the Mediterranean-Trans-asiatic zone, accounts for 15% to 20% of the yearly seismic energy release. This zone starts at the Azores triple junction in the Atlantic ocean and extends along Azores-Gibratar ridge. After crossing through the Italian Peninsula, the Alps and the Dinarides, it then cuts through Turkey, Iran, the Himalayan mountain chain and Island arcs of the southeast Asia which ends at Circum-pacific zone (Olayinka, 2010). The oceanic ridges and rises are also active seismic zones and are responsible for 3% to 7% of the yearly released seismic energy (Lowrie, 2007). These zones apart from their seismicity, are also associated with active volcanism. The remaining portion of the earth can be regarded as aseismic i.e. (not seismically active). However, no part of earth is free from earthquake since intraplate earthquake events account for 1% of global seismicity.

*Author for correspondence;
E-mail: austine9u2008@yahoo.com

The African plate according to (Hammed *et al.*, 2016) has a land mass of 60 million square kilometres (Km^2) and with major earthquakes predominantly from tectonic activities. North Africa is close to the active subducting zones that are subducting beneath the Eurasian plate (Aderemi *et al.*, 2013). In addition, the African tectonic plate comprises the active East African Rift System (EARS). It was formed during Miocene 22-25 million years ago (Ebinger, 2005). At early stages scientists considered it to be Great Rift Valley from north to Asia minor with more information, it is now clear the divergent plate boundary is responsible for the formation of two plates the Somalian plate and the Nubian plate separating at a rate of 6-7 mm yearly (Fernandes *et al.*, 2004).

Since, there is evidence of drifting of the Somalian plate and Nubian plate though at a slow rate, this has aroused the interest of the researcher to evaluate seismicity rate, a- and b-values and radiated energy of earthquakes in the African plate. This information provides an insight above the African plate and create room for more research.

Materials and Method

Source of data. The data for this study were extracted from an earthquake catalogue from the International Seismological Centre (ISC). The data had $M_w \geq 0.2$ from 1st January 1971 to 31st December 2015 (45 years) with focal depth varying from 0-700 Km. The region of study is situated within the coordinates as shown in Fig. 1. The catalogue was declustered so that only known magnitudes were used and all unknown magnitudes were deleted.

Seismicity rate. The rate of occurrence of earthquakes of different magnitudes in the region is given as:

$\lambda = N/T$ ....(1)

where:
λ is the seismicity rate, N is the number of earthquakes in time interval T of 45 years

Radiated energy. The seismicity of any given geographical region can be explained in terms of radiated energy of earthquakes by taking into account an arbitrary region of area A and N earthquakes happened over a given period of time T.

$\text{Log}_{10} E = 1.5M_w + 11.8$ ....(2)

where:
M_w is the moment magnitude (Kanamori, 1977).

From equation (2), the total energy radiated by an earthquake of magnitude M is given by:

$E = 10^{(1.5M_L + 11.8)}$ ....(3)

The amount of energy radiated per unit area is given by:

$E_R = \frac{1}{T} \sum_{k=1}^{N_k} \frac{10^{(1.5M_L+11.8)}}{A}$ ....(4)

where:
$M = M_w$, geographical area of each region was calculated using the standard formula: as given by (Adedeji, 2012):

$A = (\pi/180)\, R^2 \{\sin(lat_1) - \sin(lat_2)\} \{lon_1 - lon_2\}$ ....(5)

where:
A is the geographical area, R is the radius of the earth, lat_1 and lat_2 are minimum and maximum latitude, lon_1 and lon_2 are minimum and maximum longitude.

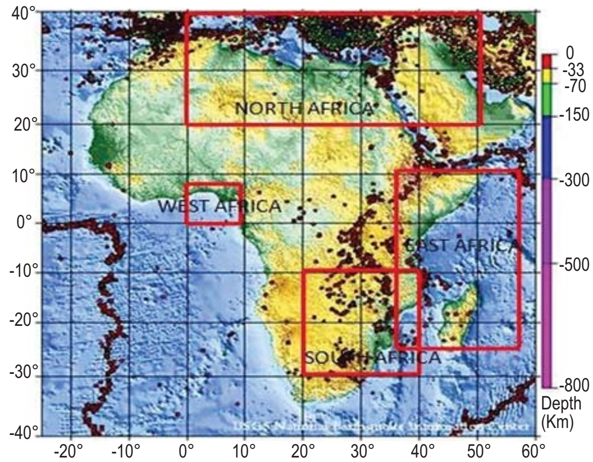

Fig. 1. Earthquake map of Africa indicating the after (Hammed *et al.*, 2016).

The Gutenberg-Richter's relationship. The Gutenberg-Richter's relationship is given by:

$\text{LogN} = a - bM$ ....(6)

where:
a and b are regression constants, M and N are magnitude and cumulative number of earthquakes within a given time interval. A large b-value in a region shows that small earthquakes occur frequently and a small b-value shows that small earthquakes are not so frequent and that large earthquakes are more likely to happen (Fowler, 2005).

equation (6) can be expressed given by Adedeji (2012) as:

$N = 10^{(a-bM)}$ ....(7)

$10^M = 10^{(a/b)} N^{(-1/b)}$ ....(8)

Substituting equation (8) in equation (4) yields

$E_R = \frac{1}{TA} \sum_{k=1}^{n} \frac{10^{(a_k/b_k)}}{N^{(1/b_k)}} \times 10^{11.8}$ ....(9)

Conversion Ms and Mw (surface wave magnitude into moment magnitude) is given by Scordilis (2006) as:

$M_w = 0.67(\pm 0.05)Ms + 2.07(\pm 0.03)$ for $3.0 \leq Ms \leq 6.1$ ....(10)

$M_w = 0.99(\pm 0.02)Ms + 0.08(\pm 0.13)$ for $6.2 \leq Ms \leq 8.2$ ....(11)

Conversion M_b and M_w (body wave magnitudes into moment magnitude):

$M_w=0.85(\pm0.04)M_b+1.03(\pm0.23)$ for $3.5\leq M_b\leq6.2$ ....(12)

Conversion M_L and M_w (local magnitude into moment magnitude)

$M_w=0.722M_L+0.743$ (from ML>2 for intraplate domains) ....(13)

This conversion was done due to the fact that radiated energy is related to moment magnitude (equation 2).

Results and Discussion

The results obtained in this study are as shown (Table 1, Fig. 2-8)

Figure 2 shows the variation of seismicity rate with the time interval in north Africa. It indicates that seismicity rate increases with time from 1971-1975 till 1981-1985, 1996-2000 to 2001-2005 and decreases from 1981-1985 to 1991-1995, 2001-2005 and 2011-2015. The highest seismicity rate was recorded between 2001 and 2005, while the lowest seismicity rate was between 1971 and 1975. Seismicity rate varies arbitrarily with time. The north Africa region, from Egypt to Morocco has experienced various devastating earthquakes in the past. The largest recorded seismic event reached Mw 7.3 in 1980 at El Asnam in the Tell Atlas of Algeria (Meghraoui *et al*., 2014). The occurrences of these events in the northern region were associated with its location along the Africa-Eurasia plate boundary. The Gulf of Suez in northeastern part of Egypt has also been reported to experience seismicity of low to intermediate magnitudes (Toni *et al*., 2016). Higher activities of earthquake were majorly reported around the southern part of the Gulf of Suez linked to triple junction and relative plate movements of the Arabian plate, African plate and Sinai-sub plate (Morsy *et al*., 2011; Hussein *et al*., 2006).

In Fig. 3 depicts the seismicity rate in south Africa region. Seismicity rate varies arbitrarily with highest rate in 2006-2010 and the least at 1976-1980. South of Africa has only recorded moderate seismicity over the years; majority of which are mining-related seismicity, triggered by deep rooted mining activities which cause instability within the earth (Alabi *et al.*, 2013). Most of earthquakes reported in the region have therefore been earthquakes of small local magnitude between 2 and 5 (Mangongolo *et al*., 2017).

Figure 4 shows variation of seismicity rate in east Africa. Seismicity rate varies arbitrarily with highest rate in 2006-2010 and the least at 1971-1975. East Africa is one of the first regions to be regarded as seismic in Africa and this was because of the occurrence of earthquakes with high magnitude and intensities. It has been established from geological studies that the seismicity of this region (eastern Africa) is linked to its situation along the east African rift system (Alaneme *et al*., 2018).

In Fig. 5 shows the seismicity rate in west Africa. Seismicity rate was constant between 1971-1975, 1976-1980, 1981-1985, 1991-1995, 2001-2005 and 2011-2015 and highest in 1996-2000.

It therefore means that region of west Africa is unchanging as compared to other parts of Africa. This is due to the fact that it seats on a stable old crust known as west African craton (Abong *et al*., 2018). Plate tectonic theory stipulates that those distinct processes

Table 1. Number of earthquake events and seismicity rate in different regions of Africa

	North Africa		South Africa		East Africa		West Africa	
Time interval	Events	Seismicity rate	Events	Seismicity rate	Events	Seismicity rate	Events	Seismicity rate
1971-1975	810	162.00	109	21.80	11	2.2	0	0
1976-1980	998	199.60	35	7.00	27	5.4	0	0
1981-1985	1482	296.40	89	17.80	61	12.2	0	0
1986-1990	1270	254.00	78	15.60	35	7	1	0.2
1991-1995	1909	381.80	108	21.60	29	5.8	0	0
1996-2000	5692	1138.40	182	36.40	36	7.2	6	1.2
2001-2005	13399	2679.80	67	13.40	35	7	0	0
2006-2010	11668	2333.60	202	40.40	160	32	1	0.2
2011-2015	1840	368.00	87	17.40	54	10.8	0	0
Cumulative N	39068.00	868.18	957.00	21.27	448.00	9.96	8.00	0.18

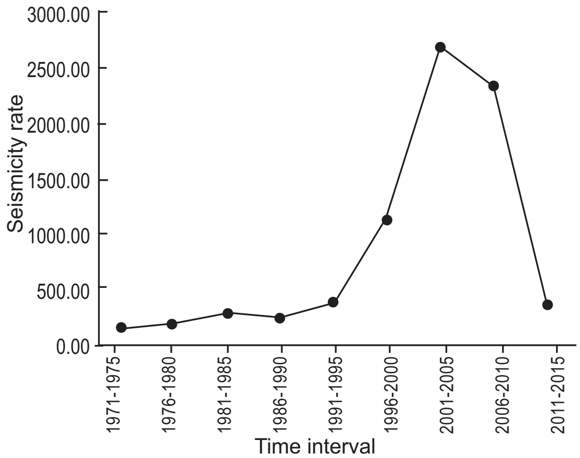

Fig. 2. Bar chart showing the seismicity rate in north Africa.

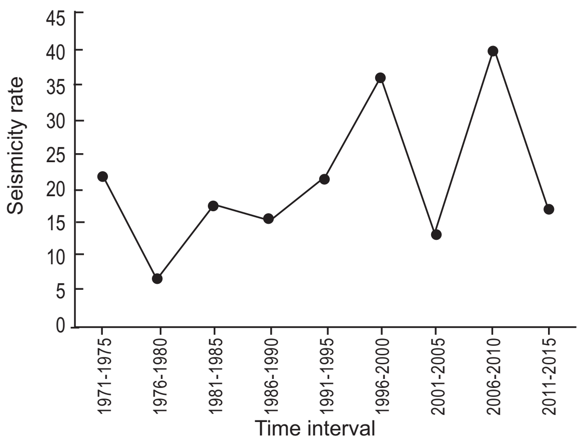

Fig. 3. Bar chart showing the seismicity rate in south Africa.

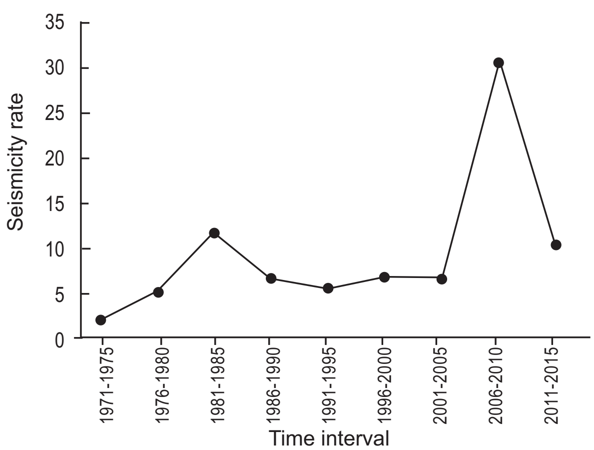

Fig. 4. Bar chart showing the seismicity rate in east Africa.

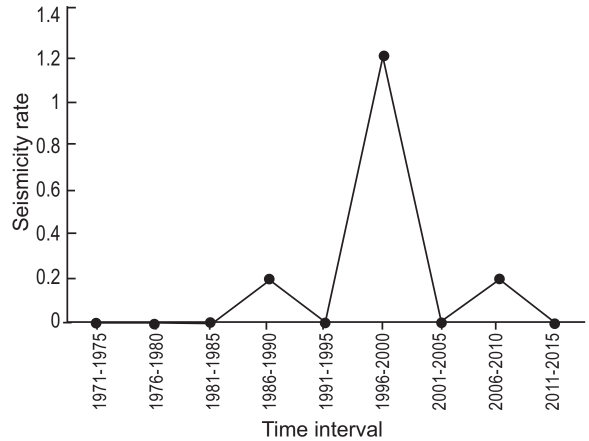

Fig. 5. Bar chart showing the seismicity rate in west Africa.

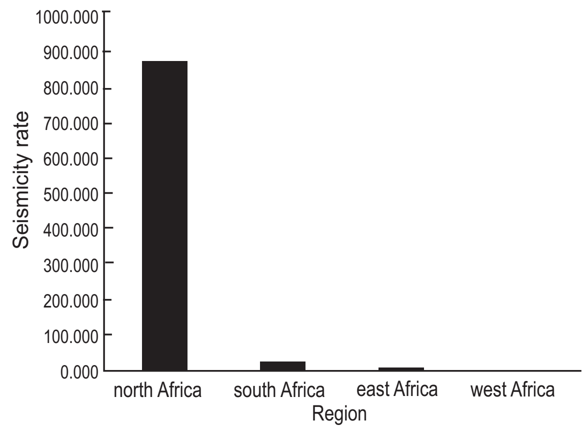

Fig. 6. Bar chart showing the seismicity rate in west Africa.

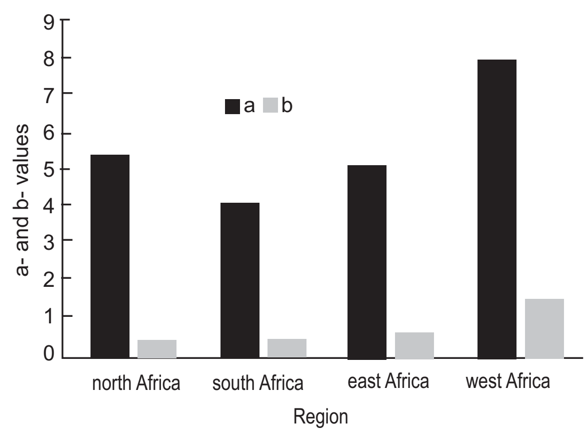

Fig. 7. Bar chart showing the a- and b- values of earthquakes in the study area.

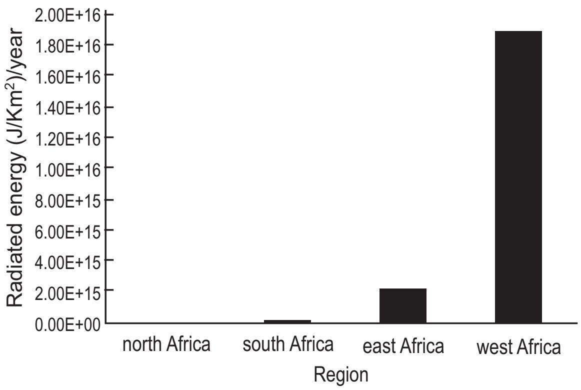

Fig. 8. Bar chart showing average radiated energy per area per year.

Table 2. a and b values in the different region of Africa

Region	a	b	Energy per area per year $\times 10^{13}$ (J/Km^2/year)
North Africa	5.44	0.49	3.39607
South Africa	4.16	0.47	20.3563
East Africa	5.1	0.69	223.292
West Africa	7.97	1.58	1873.82

like earthquakes and volcanoes tend to tilt predominantly to plate boundaries even though intraplate earthquake events exist. West Africa is very far from plate boundaries and therefore is characterized by low rate of seismicity.

Generally, the total seismicity rate is higher in north Africa, followed by south Africa, east Africa and the least in west Africa. The distribution is as shown in Fig. 6.

Table 2 shows the a- and b- values and radiated energy of the study areas namely, north Africa, south Africa, east Africa and west Africa. The distribution is as shown in Fig. 7 and Fig. 8.

It is observed that west Africa region has a high b-value and south Africa the least b-value in this study. A large b-value in a region shows that small earthquakes occur frequently and a small b-value shows that small earthquakes are not so frequent and that large earthquakes are more likely to happen (Fowler, 2005). The decreasing b-values reported by Urbancic *et al*. (1992) which correlate with increasing stress release estimates and that larger events tend to occur where the b-value has its steepest gradient. They further observed that b-values provide the best estimates for stress conditions within the seismogenic volume as they include information from both spectral-(seismic moment) and time domains (peak amplitudes). Also, (Geffers *et al*., 2022) revealed that lower b-values correspond to a higher level of induced seismic activity while high b-values correspond to a low and moderate seismic activity.

Which shows the large b-value reported by Enescu and Ito (2002) in a given region or area in a relative abundance in small earthquakes. Areas with low b-values on the other hand are probably under higher applied stress after the main shock. They also suggested that the rupture process in an earthquake and previous earthquake activity are the major factors controlling the spatial distribution of b-value.

Figure 8 shows the distribution of radiated energy in the different regions of African plate. The energy per unit area per year follows this increasing trend in the order: north Africa-south Africa-east Africa-west Africa. This indicates that the radiated energy is highest in west Africa and lowest in north Africa. According to the USGS (2023), the total energy from an earthquake consists of energy required to create new cracks in rock, energy expelled as heat through friction and energy elastically radiated through the earth. Out of these, the only amount that can be measured is that which is radiated through the earth. It is the radiated energy that shakes buildings and is recorded by seismographs. This energy can be measured directly from velocity seismograms and converted to magnitude.

Conclusion

Earthquakes are natural disasters and have caused a lot of damages throughout the human history. Properties worth billions of dollars are destroyed especially countries within the pacific ring of fire. Based on the findings of this study, it was revealed that seismicity rate in all the regions of Africa under study varies arbitrarily with time. The total seismicity rate was higher in north Africa, followed by south Africa, east Africa and the least in west Africa. The b-value was determined to be 0.49 in north Africa, 0.47 in south Africa, 0.69 in east Africa and 1.58 in west Africa. The radiated energy was also determined to 3.39607×10^{13} J/Km^2/year in north Africa, 20.3563×10^{13} J/Km^2/year in south Africa, 223.292×10^{13} J/Km^2/year in east Africa and 1873.82×10^{13} J/Km^2/year in west Africa. The energy per unit area per year follows this increasing trend in the order: north Africa-south Africa-east Africa-west Africa. The implication of this study is that the regions of study are under stress especially north Africa and the lithospheric plate is gradually becoming unstable.

Acknowledgement

The authors wish to thank International Seismological Centre (ISC) United Kingdom for granting access to the website to obtain data for this study.

Conflict of Interest. The authors declare that they have no conflict of interest.

References

Abong, A.A., George, A.M., Kanu, M.O., Ulem, E.B., Robert, P.O. 2018. Investigation of seismicity in parts of African plate. *Journal of Scientific Research and Reports*, **18:** 1-11.

Adedeji, O.A. 2012. Development of Models for Rating Seismic Activities Using Radiated Energy of Earthquakes. *M.Sc. Thesis*, University of Ibadan, Ibadan, Nigeria. DOI: http://80.240.30.238/handle/123456789/217

Aderemi, A.A., Akinyemi, O.D., Adewale, A. 2013. Seismicity pattern in southern Africa from 1986 to 2009. *Earth Science*, **2:** 1-10.

Alabi, A.A., Akinyemi, O.D., Adewale, A. 2013. Seismicity pattern in southern Africa from 1986 to 2009. *Earth Science Research*, **2:** 1-10.

Alaneme, K.K., Okotete, E.O. 2018. Critical evaluation of seismic activities in Africa and curtailment policies-a review. *Geoenvironmental Disasters*, **5:** 24. DOI: http://doi.org/10.1186/s40677-018-0116-2

Ebinger, C.J. 2005. Continental break up: the east African perspective. *Astronomical and Geophysics*, **46:** 16-21.

Enescue, B., Ito, K. 2002. Spatial analysis of the frequency-magnitude distribution and decay rate of aftershock activity of the 2000 western Tottori earthquack. *Earth, Planets and Space*, **54:** 847-859.

Fernandes, R.M.S., Ambrosus, B.A.C., Noomen, R., Bastos, L., Combrink, L., Miranda, J.M., Spakman, W. 2004. Angular velocities of Nubia and Somalia from continuous GPS data: implications on present - day relative kinematics. *Earth Planetary Science Letters*, **222:** 197-208.

Fowler, C.M.R. 2005. *The Solid Earth: An Introduction to Global Geophysics*, 2nd edition, pp. 123, Cambridge University Press, Cambridge, UK.

Geffers, G.M., Main, I.G., Naylor, M. 2022. *Geophysical Jornal International*, **229:** 1840-1855. DOI: 10.1093/gji/ggaco223.

Hammed, O.S., Awoyemi, M.O., Igboama, W.N., Badmus, G.O., Essien, U.C. 2016. Seismicity associated with the African lithospheric plate. *Physical Science International Journal*, **10:** 1-11.

Hussein, H.M., Marzouk, I., Moustafa, A.R., Hurukawa, N. 2006. Preliminary seismicity and focal mechanisms in the southern Gulf of Suez: August 1994 through December 1997. *Journal of African Earth Sciences*, **45:** 48-60.

Kanamori, H. 1977. The energy released in great earthquakes. *Journal of Geophysics Research*, **82:** 2981-2876.

Lowrie, W. 2007. *Fundamentals of Geophysics*, 2nd edition, Cambridge University Press, Cambridge, UK. DOI: http://10.1017/CB09780511807107

Mangongolo, A., Strasser, F.O., Saunders, I., Rathod, G.W. 2017. Depths of earthquakes in south Africa. *Seismological Research Letters*, **88:** 1-11.

Meghraoui, M., Harbi, A., Hussein, H.M. 2014. Preface to the special issue Seismotectonics and seismic hazards in north Africa. *Journal of Seismology*, **18:** 203-204.

Morsy, M., Hussein, H.M., Abou Elenean, K.M., El-Hady, Sh. 2011. Stress field in the central and northern parts of the Gulf of Suez area, Egypt from earthquake fault plane solutions. *Journal of African Earth Sciences*, **60:** 293-302.

Olayinka, I.A. 2010. *Imaging the Earth's Subsurface*: *An Inaugural Lecture*, University of Ibadan, Nigeria.

Scordilis, E.M. 2006. Empirical global relations converting MS and mb to moment magnitude: *Journal of Seismology*, **10:** 225-236.

Toni, M., Barth, A., Ali, S.M., Wenzel, F. 2016. Analysis of the similar epicenter earthquakes on 22 January 2013 and 01 June 2013, central Gulf of Suez, Egypt. *Journal of African Earth Sciences*, **121:** 274-285.

Urbancic, T., Trigu, C-I., Long, J.M., Young, R.P. 1992. Space time correlation of b-values with stress release. *Pure and Applied Geophysics*, **139:** 449-462.

USGS, 2023. Magnitude, United States Geological Survey. http://www.usgs.gov/earthquakes