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Investigation of Seismicity in Parts of African Plate

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Authors' contributions

This work was carried out in collaboration between all authors. Author AAA designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors AMG and MOK managed the analyses of the study. Authors EBU and POR managed the literature searches. All authors read and approved the final manuscript.

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ABSTRACT

This study investigated seismicity in parts of African plate to examine the pentad and annual variation of seismicity and to determine b-values for a period of 45 years. The data set for this work were obtained from the Advanced National Seismic System (ANSS), a website owned by Northern California Earthquake Data Centre, Berkeley UC, USA. The selected data consisted of earthquakes with $M_b \geq 0.2$ for the study area from 1st January 1971 to 31st December 2015 with focal depth from 0 – 700km. A total of 40,481 earthquake events were used in the study with North Africa having 39,068; South Africa 957; East Africa 448 and West Africa 8. A comparison of the patterns of seismicity in the regions of the study showed that seismicity is very high in North Africa, moderate in South Africa, low in East Africa and very low in West Africa. It was also found that the seismic activity in the different regions of Africa does not vary uniformly with time. Series in the four regions are fluctuating and no similarity among them. Analysis of the correlation among the four regions was stronger between North Africa and East African regions with correlation coefficient, r = 0.53. This shows that there might be a similarity between the two regions in the process of stress accumulation or release. The b - values in the study area were determined to be; North Africa: 0.49; South Africa: 0.47; East Africa: 0.69 and West Africa: 1.58. This indicates that West Africa

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region has reduced stress and hence more stable than other regions of Africa since it is related to the West African Craton. Therefore, North Africa, South Africa and East Africa are more vulnerable to earthquake hazards than West Africa.

Keywords: Seismicity; African plate; pentad; annual; b-value; West African craton.

1. INTRODUCTION

The African plate is the third largest tectonic plate (60 million km²) with approximately half of it covered by land [1]. Most devastating earthquakes are of tectonic origin and the epicentres of over 90% of global natural earthquakes take place at boundaries of major plates and some regions of the African continent especially North Africa is part [2].

African tectonic plate is made up of two types of plate boundaries around its border. The northern part of the plate is a convergent boundary where the African plate is subducting below the Eurasian plate. All other sides of the African plate are divergent boundaries. Along the eastern, southern and most of the western sides of the plates are Mid – Oceanic ridges are divergent plate boundaries marked by chains of volcanoes along the seafloor.

One of the significant features in this plate is the East African Rift System (EARS), a continental rift zone in East Africa which started forming from the beginning of the Miocene 22 – 25 million years ago [3]. In the past it was seen to be part of a larger Great Rift Valley that extended north to Asia Minor. The rift is a narrow zone that is a forming divergent tectonic boundary and this makes the African plate being in the process of splitting into two tectonic plates referred to as the Somalian plate and the Nubian plate at a rate of 6 - 7 mm yearly [4].

It is against this backdrop that this study is carried out to investigate seismicity in parts of African plate.

1.1 Seismicity of the Study Area

1.1.1 Seismicity of North Africa

North Africa is one of the most earthquake-prone areas of the Mediterranean. The May 2003 Zemmouri earthquake (Mw = 6.8) that happened east of the city of Algiers is the largest felt since that in February 1716 (I_0 = IX EMS). In February 2004, the city of Al Hoceima and the Rif Mountains of Morocco were hit, once again, by a large earthquake (Mw = 6.4), 10 years after the May 1994 (M = 6.0) event. The city of Cairo was struck in October 1992 by an Mw = 5.8 magnitude earthquake, which caused huge damage. In 1935, the Syrte region in Libya witnessed an M = 6.9 earthquake with serious damage [5] and [6]. Generally, North Africa has experienced moderate earthquakes. However, the region is still vulnerable as a result of the shallow character of its seismicity, the poor mechanical properties of its soil and local site conditions, and the consequent strength of the ground shaking. The damaging earthquakes of Agadir, Morocco, in 1960 (Mw = 5.9, 1,500 people were killed); EIA snam, Algeria, in 1980 (Mw =7.3, 3,000 people were killed); Cairo, Egypt, in 1992 (Mw =5.8, 541 people were killed); Zemmouri, Algeria, in 2003 (Mw = 6.8, 2,278 people were killed); and Al Hoceima, Morocco, in 2004 (Mw = 6.4, 600 people were killed) caused damages worth US $11.5 billion [7].

1.1.2 Seismicity of South Africa

South Africa region is located within an intraplate area with complex seismic characteristics. Though considered to lie in a stable continental region, earthquakes are recorded and located on daily basis. Large events have been recorded that caused serious damage to infrastructure in nearby towns, farms, underground mines and even death. The source of these earthquakes is from mining activities and it account for about 95% of earthquakes in South Africa.

In South Africa, the areas of seismic activities include Mozambique, Zimbabwe and Northern Botswana. These activities are believed to be an extension of the East Africa Rift System [2]. The strongest and most devastating earthquake that happened in the 20th century was the Tulbagh earthquake of 29 September 1969, with M_L= 6.3. This earthquake was widely experienced over the Western Cape, especially in Ceres, Tulbagh, and Wolseley. An *Mw* = 7.0 earthquake happened on 23 February 2006 in the western province of Manica in Mozambique. The earthquake was felt throughout Mozambique, as well as in parts of the neighboring countries of Swaziland, Zambia, Zimbabwe and South Africa [8].

1.1.3 Seismicity of East Africa

East Africa is a very active region and there are three major zones of seismic weaknesses in the crustal segments: The East African Rift System, the Gulf of Aden and along the Red sea [9]. These three zones constitute the Afar Triangle [10]. Movement in these three zones makes this region an active tectonic and volcanic zone [9]. In Ethiopia for instance, 90% of the seismicity and volcanicity is related to the East African Rift System. The East African Rift System is a 50 km to 60 km wide zone of volcanoes and faults that extend north to south in East Africa for more than 3000 km, from Ethiopia in the north to the Zambezi in the south. It cuts across Ethiopia in an NE - SW direction [10].

1.1.4 Seismicity of West Africa

West Africa is generally regarded as a stable region with low seismic activity. The theory of plate tectonics shows that manifestations of orogenic activities (such as volcanism and earthquakes) are concentrated mainly on lithospheric plate boundaries, though there are recorded cases of intraplate earthquakes. The West African region is situated far from any of such boundaries. The worldwide distribution of earthquakes [11] and [12] have shown that the isolated epicentre is situated in Accra area of Ghana and several large and destructive earthquakes are experienced here and to the north of Cape Verde Islands majorly coastal areas (with maximum intensity 6 to 7). The occurrences of these large and destructive earthquakes pose a problem to design structures. The main issue is not the occurrence of these large and destructive earthquakes, but the absence of geological and tectonic correlation in the region. This has made it very difficult to understand the occurrence of these earthquakes in this region.

2. MATERIALS AND METHODS

2.1 Source of Data

The data set for this work were extracted from the Advanced National Seismic System (ANSS), a catalogue owned by Northern California Earthquake Data Centre, Berkeley UC, USA. The selected data consisted of earthquakes with $M_b \geq 0.2$ for the study area from 1st January 1971 to 31st December 2015 (45years) with focal depth from 0 – 700 km. The data set comprised date of occurrence of earthquake, origin time, coordinates of epicentre, magnitude, event identification, focal depth of earthquake and event type E. The regions of study are situated within the coordinates: North Africa: latitudes 20^0N – 40^0N and longitudes 0^0E – 50^0E; South Africa: latitudes 10^0S – 30^0S and 20^0E – 40^0E; East Africa: latitudes 10^0N – 25^0S and longitudes 36^0E– 58^0E and West Africa: latitudes 0^0 – 7^0N and longitudes 0^0 – 10^0E (Fig. 1). A total of 40,481 events were employed in the study with North Africa having 39,068, South Africa 956, East Africa 448 and West Africa 8 events respectively.

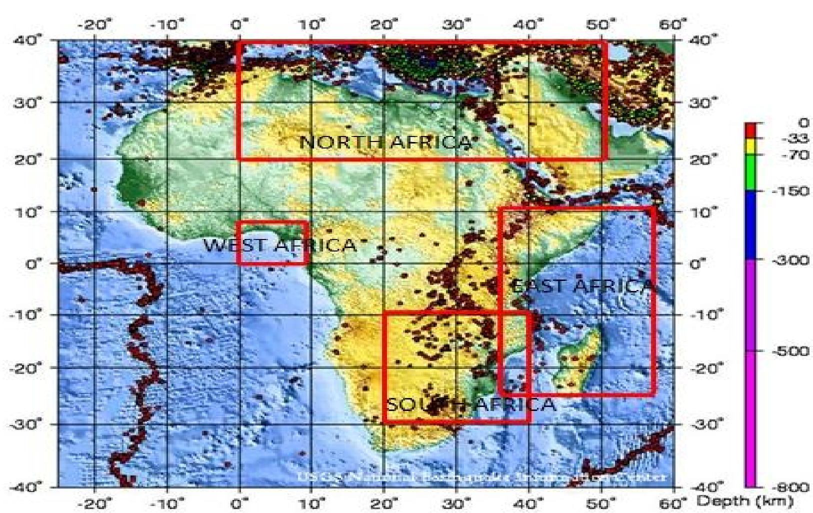

Fig. 1. Seismicity map of Africa with red rectangle showing the study locations (Modified from [1])

2.2 Pentad Variation

The time interval was varied from 1971 – 1975, 1976 – 1980, 1981 – 1985, 1986 – 1990, 1991 – 1995, 1996 – 2000, 2001 – 2005, 2006 – 2010 and 2011 – 2015 for North Africa, South Africa, East Africa and West Africa and the corresponding number of earthquake events were recorded.

2.3 Yearly (Annual) Variation

The earthquake events were arranged yearly from 1971 to 2015 for North Africa, South Africa, East Africa and West Africa and the number of events in each region was recorded.

2.4 Frequency – Magnitude Relationship

[13] developed a relationship with the frequency–magnitude distribution (FMD), in the form:

$$\text{LogN} = a - bM \tag{1}$$

For a given region and time interval, equation (1) gives the cumulative number of earthquakes (N) with magnitude (M), where a and b are positive, real constants. The parameter a is the measure of the number of events above magnitude '0'. It is determined by the event rate and for a given region depends on the volume and time window used. The b parameter is a tectonic parameter that describes the properties of the seismic medium.

2.5 Pearson's Product Moment Correlation Coefficient

The raw – score formula for Pearson's **r** is given by [14]:

Pearson's **r** =

$$\frac{N\sum XY - \sum X \sum Y}{\sqrt{[N\sum X^2 - (\sum X)^2][N\sum Y^2 - (\sum Y)^2]}} \tag{2}$$

Where

N Number of earthquake events
$\sum X$ Sum of X
$\sum Y$ Sum of Y
$\sum X^2$ Square of sum X
$\sum Y^2$ Square of sum Y
$\sum XY$ Sum of the cross – product of X and Y

The correlation coefficient values and their associated relationships are as given by [14]:

+ 1.00	Perfect positive relationship
+ 0.40 – + 0.99	High(strong) positive relationship
+ 0.10 – + 0.39	Low (weak) positive relationship
-0.09 – + 0.09	Very weak or no relationship
-0.10 – - 0.39	Low (weak) negative relationship
-0.40 – - 0.99	High (strong) negative relationship
-1.00	Perfect negative relationship

3. RESULTS AND DISCUSSION

3.1 Pentad Variation of Earthquakes

The number of earthquakes $M_b \geq 0.2$ that occurred in each region during the period of 5 - year duration beginning from 1971 to 2015 are calculated and shown in Table 1. The variation patterns of the pentad values are shown in Fig. 2. It has been observed that the number of earthquakes in North Africa gradually increases from the time range 1971 - 1975 till 1981 - 1985. From 1986 - 1990 to 2011 - 2015, the number of earthquakes started fluctuating (i.e increase and decrease). In the South Africa region, the number of earthquakes increases from the time range 1986 - 1990 till 1996 - 2000. From 1971 - 1975 to 1976 - 1980, 2001 - 2005 to 2011 - 2015, the number of earthquakes begin to fluctuate. In the East Africa region the number of earthquakes increases from time interval 1971 – 1975 to the time range 1981 – 1985, then started fluctuating till the time range 2011 – 2015. In West Africa, the number of earthquakes occurred at the time range 1986 - 1990, 2001 - 2005 and 2006 - 2010 and no events in other years.

A comparison of the patterns of seismicity in the regions of the study showed that seismicity was very high in North Africa, moderate in South Africa, low in East Africa and very low in West Africa (Table 1 and Fig. 2).

It was also found that the seismic activity in the different regions of Africa does not vary uniformly with time [15]. This means that there are differences in the generation of the stress field in different regions of Africa. Throughout the study period, seismicity was significantly high in North Africa as compared to other regions.

3.2 Annual (yearly) Variation of Earthquakes

The number of earthquakes $M_b \geq 0.2$ occurred in each year in all the regions during the period 1971-2015 is as shown (Fig. 3). Series in the four regions are fluctuating and no similarity among them. The maximum number of earthquakes occurred in North Africa in 2008 and minimum number in 1972; South Africa maximum number of events in 1996 and minimum in 1978; East Africa, maximum number of events in 2007 and minimum in 1984, 1971, 1977, 1994 and no events in 1972; West Africa, maximum number of events in 1999 and minimum in 1993, 2001, 2009 and no events in other 41years (Table 2 and Fig. 3). This indicates that West Africa region is more stable than other regions of Africa since it rests on West African craton (a stable old crust). Analysis of the correlation among the four regions was stronger between North Africa and East African regions (correlation coefficient, r = 0.53). This shows that they might be similarity between the two regions in the process of stress accumulation or release. The pattern of stress in the lithosphere in North Africa is controlled by local forces (i.e stress concentration) as a result of the structure of layers of the Mediterranean subduction/plate convergence on the North Africa passive continental margin. In South Africa, gold mines are excavated at greater depths. Mining causes stress concentration to rock mass. The rupture results in mine earthquakes.

Table 1. Pentad variation of seismicity in the African plate

Time interval	North Africa	South Africa	East Africa	West Africa
1971 – 1975	810	109	11	0
1976 – 1980	998	35	27	0
1981 – 1985	1482	89	61	0
1986 – 1990	1270	78	35	1
1991 – 1995	1909	108	29	0
1996 – 2000	5692	182	36	6
2001 – 2005	13399	67	35	0
2006 – 2010	11668	202	160	1
2011 – 2015	1840	87	54	0
Total	**39068**	**957**	**448**	**8**

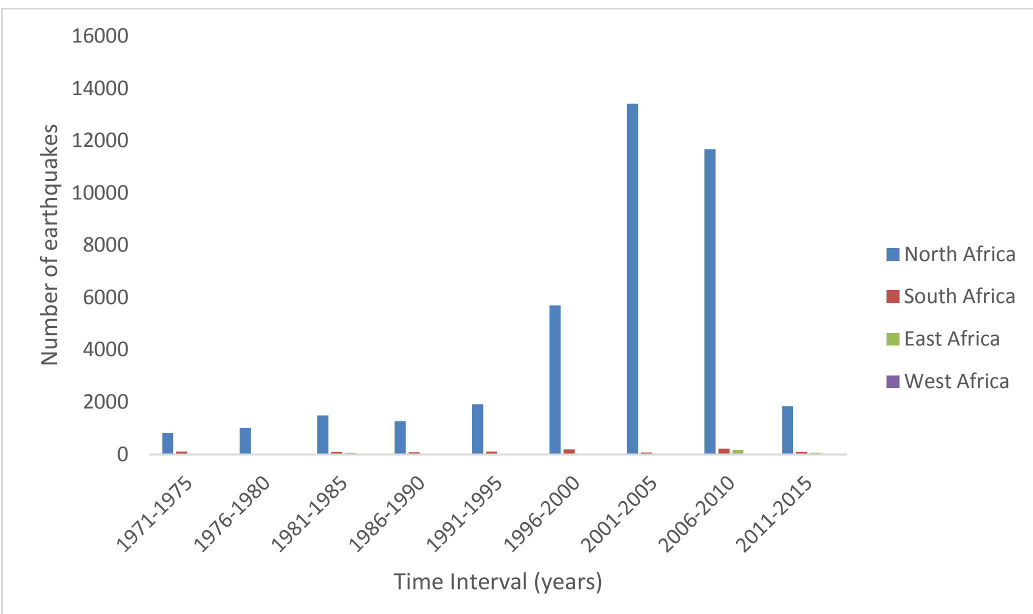

Fig. 2. Bar chart showing pentad variation of seismicity in the Africa plate

Table 2. Annual (yearly) variation of seismicity in the African plate

Year	North Africa	South Africa	East Africa	West Africa
1971	170	35	1	0
1972	117	27	0	0
1973	146	33	3	0
1974	153	9	4	0
1975	224	5	3	0
1976	244	5	3	0
1977	159	3	1	0
1978	143	2	3	0
1979	176	9	9	0
1980	276	16	11	0
1981	422	23	5	0
1982	260	21	5	0
1983	340	13	8	0
1984	229	20	1	0
1985	231	12	42	0
1986	201	21	9	0
1987	218	14	8	0
1988	251	13	3	0
1989	259	12	13	0
1990	341	18	2	0
1991	194	10	6	0
1992	226	9	2	0
1993	235	13	5	1
1994	167	3	1	0
1995	1087	73	15	0
1996	1098	114	10	0
1997	599	14	4	0
1998	1242	12	3	0
1999	1642	20	13	5
2000	1111	22	5	1
2001	1803	16	3	0
2002	2284	19	8	0
2003	2838	8	9	0
2004	2962	13	7	0
2005	3512	11	8	0
2006	3381	113	35	0
2007	3927	18	87	0
2008	3986	16	22	0
2009	182	34	5	1
2010	192	21	11	0
2011	390	19	9	0
2012	366	15	16	0
2013	278	12	6	0
2014	496	25	9	0
2015	310	16	14	0
Total	**39068**	**957**	**448**	**8**

3.3 b-values

The b-values were obtained using least squares regression method as in equation (1) (Figs. 4-7).

The b-value was highest in West Africa, followed by East Africa, then North Africa and the least value in South Africa (Table 3 and Fig. 8). The high b - value indicates reduced stress after a major earthquake and low b-value indicates high stress. The low *b* - value is a characteristic feature of the intraplate environment [16]. The regions with a lower value of **b** are probably the regions under higher applied shear stress after the main shock, whereas the regions with a higher value of **b** are the areas that experienced the strike-slip [17]. One possible explanation for this observation is that within the plate the rocks are not intensively fractured [16]. Also [18] found that *b* - value depends on the mechanical heterogeneity of the rock mass and increases with the increase in heterogeneity (intensive fractured rocks). Thus there tend to be fewer smaller events relative to larger events (low *b* - value) [19].

Table 3. b - values and coefficient of determination in the study regions of African plate

Region	b	R^2
North Africa	0.49	0.89
South Africa	0.47	0.84
East Africa	0.69	0.88
West Africa	1.58	0.88

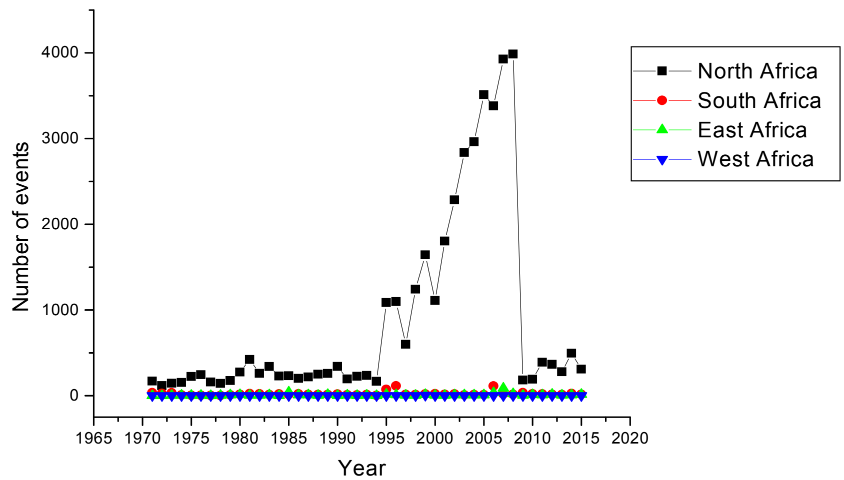

Fig. 3. Annual variation of seismicity in the African plate from 1971 - 2015

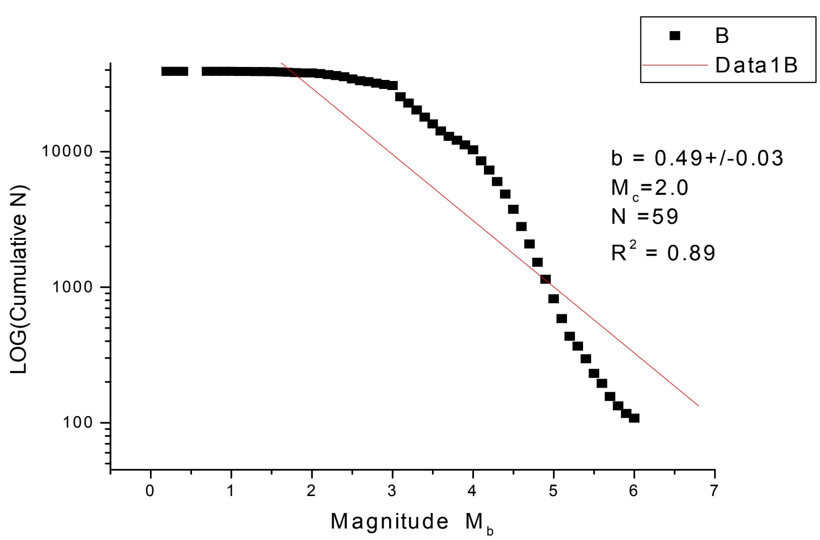

Fig. 4. Frequency –Magnitude relationship in North African region

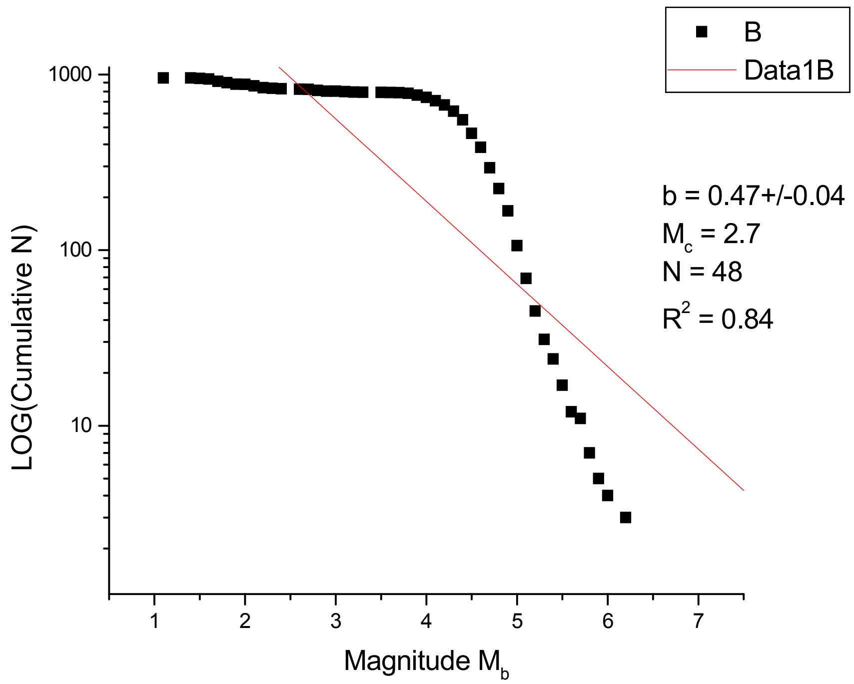

Fig. 5. Frequency – Magnitude relationship in South African region

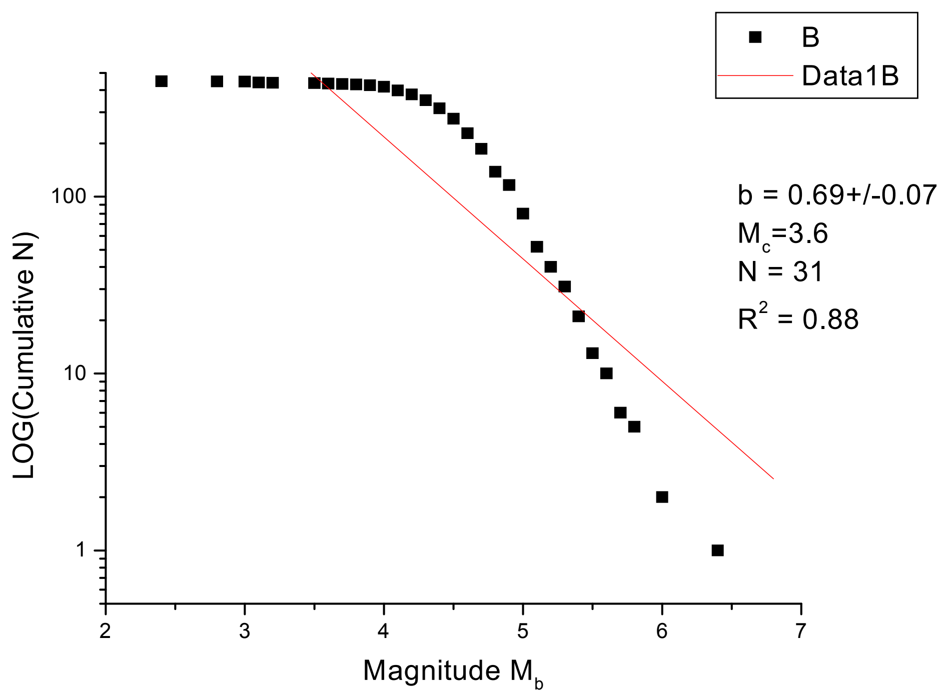

Fig. 6. Frequency –Magnitude relationship in East African region

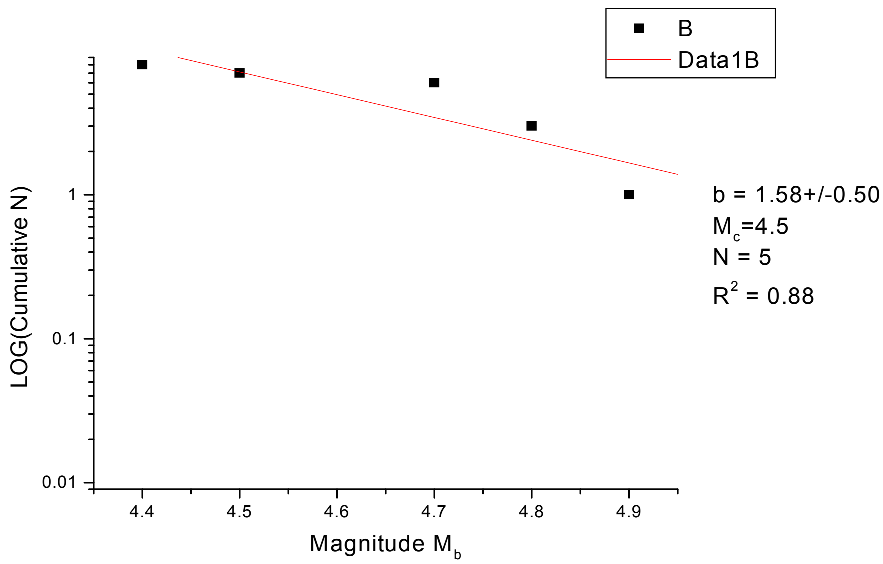

Fig. 7. Frequency –Magnitude relationship in West African region

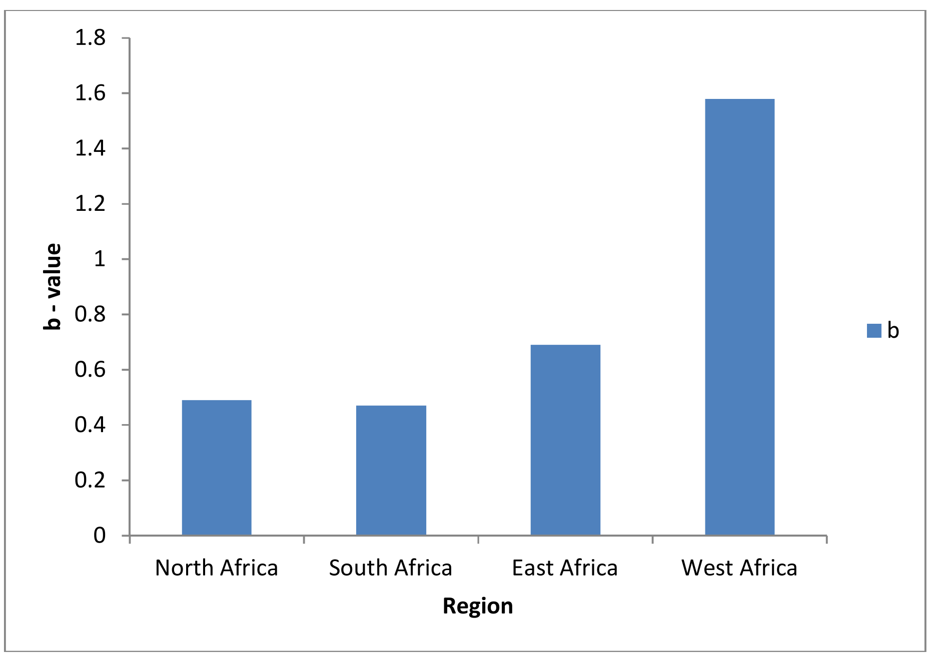

Fig. 8. Bar chart showing b-values in the different regions of African plate

4. CONCLUSION

The results of this study showed that seismicity is very high in North Africa, moderate in South Africa, low in East Africa and very low in West Africa during the period 1st January 1971 to 31st December 2015 (45years). It was found that the seismicity in the different regions of Africa does not vary uniformly with time. It was also revealed that series in the four regions are fluctuating and no similarity pattern among them. Analysis of the correlation coefficient among the four regions of Africa showed a strong correlation coefficient of r = 0.53 between North Africa and East Africa regions. This indicates that there might be a similarity between the two regions in the process of stress accumulation or release. The b-values in the study area were determined to be; North Africa: 0.49; South Africa: 0.47; East Africa: 0.69 and West Africa: 1.58. This implies that West Africa region has reduced stress and hence more stable than other regions of Africa, though no portion of the earth can completely be said to be aseismic. The stability is related to the West African craton (a stable old crust) that has remained tectonically stable since 1.7Ga [20] and 2.2 – 1.8Ga [21]. The implication of this study is that North Africa, South Africa and East Africa are more vulnerable to earthquake hazards than West Africa. Therefore, seismicity in Africa plate is concentrated majorly in Northern and South-eastern regions of Africa.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hammed OS, Awoyemi MO, Igboama WN, Badmus GO, Essien UC. Seismicity Associated with the African Lithospheric plate. Physical Science International Journal. 2016;10(3):1-11.
2. Aderemi AA, Akinyemi OD, Adewale A. seismicity pattern in Southern Africa from 1986 to 2009. Earth Science. 2013;2(2): 1-10.
3. Ebinger CJ. Continental break up: the East African perspective. Astronomical Geophysics. 2005;46:21-216.
4. Fernandes RMS, Ambrosus BAC, Noomen R, Bastos L, Combrink L, Miranda JM, Spakman W. Angular velocities of Nubia and Somalia from continuous GPS data: implications on present – day relative kinematics. Earth Planetary Science Letters. 2004;222:197–208.
5. Suleiman A, Doser D. Seismicity, seismotectonics and earthquake hazards of Libya, with detailed analysis of the April 19, 1935, M=7.1 earthquake sequence. Geophys J Int. 1995;120:312–322.
6. Suleiman A, Albini P, Migliavacca P. A short introduction to historical earthquakes in Libya. Ann Geophys, 2004;47(2-3):545–554.
7. Benouar D. Earthquake risk in Africa: a community leader's guide. UN/ISDR/, Africa; 2005.
8. Fenton CH, Bommer JJ. The Mw 7 Machaze, Mozambique, earthquake of 23 February 2006. Seismological Research Letters. 2006;77:426-439.
9. Haile M. Seismic microzonation for the city of Addis Ababa by using microtremors. Paper No. 2092 submitted to 13th World Conference on Earthquake Engineering, Vancouver, August 1 – 6; 2004.
10. Ayele A, Kulhánek O. Spatial and temporal variations of seismicity in the Horn of Africa from 1960 to 1993. Geophysical Journal International. 2007; 130(3):805–810.
11. Nelson LB, Ganse RA. Significant earthquakes 1900--1970. NGSDC/NOAA, Boulder, Colorado; 1980.
12. Osagie EO. Source parameters in the Intraplate Event in Guinea, West Africa. Pacific Journal of Science and Technology. 2010;11(2):636-638.
13. Gutenberg B, Richter C. Seismicity of the Earth and associated phenomena. Princeton Univ. Press, Princeton, NY; 1954.
14. Joshua MT. Fundamentals of test and measurement in Education. The University of Calabar Press; 2005.
15. Abong AA, George AM, Awhuwhe EA. Investigation of time scale dependence of Gutenberg – Richter's relationship in South Africa. International Journal of Applied Science and Engineering Research. 2016;5(2):129–136.
16. Talwani P. Characteristic Features of Intraplate Earthquakes and the Models Proposed to explain them. the NATO Advanced Research Workshop on Causes and Effects of Earthquakes at Passive Margins and in Areas of Postglacial Rebound on both Sides of the North Atlantic Vordingborg, Denmark, (9 - 13) May, 1988. 1989; 563-579.

17. Enescu B, Ito K. Spatial analysis of the frequency–magnitude distribution and decay rate of aftershock activity of the 2000 western Tottori earthquake. Earth Planet Space. 2002;54:847-859.
18. Shaik M, Srivastava S. Statistical parameters of Bhuj Earthquake sequence of January 26th, 2001. Earth Planets Science. 2003;112:397 – 400.
19. Al-Heety EAM. Historical seismicity of the stable continental Regions (SCRs) in the Arabian plate (preliminary study). Mesf Cyber Journal of Earth Science. 2005;3: 22-41.
20. Amponsah PE. Seismic activity in Ghana: past, present and future. Annals of Geophysics. 2004;47:539-543.
21. Meghraoui M, Amponsah P, Ayadi A, Ayele A, Ateba B, Bensuleman A, El Gabry M, Fernandes RM, Midzi V, Roos M. The seismotectonic map of Africa. Episodes. 2016;39(1):9-18.

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