NRIAG JOURNAL OF ASTRONOMY AND GEOPHYSICS
2020, VOL. 9, NO. 1, 220–225
https://doi.org/10.1080/20909977.2020.1723866

Preliminary investigation of earth tremors using total electron content: a case study in parts of Nigeria

J. E. Thomas, N. J. George, A. M. Ekanem and E. U. Nathaniel

Department of Physics, Geophysics Research Group (GRG), Akwa Ibom State University, Ikot Akpaden, Nigeria

ABSTRACT
Total electron content (TEC) was investigated using the Nigerian Global Navigation Satellite System Reference Network (NIGNET) global positioning system (GPS) station close to the two communities, known as oilfields, affected by the 11 July 2016 tremor in southeastern Nigeria. The oil-related activities are anthropogenic/seismogenic, which could trigger a tremor. Data from a station with code FPNO were obtained 10 days prior and 5 days after. The study revealed striking anomalies on the day of the tremor. However, to distinguish solar and geomagnetic activities from seismogenic activities, the planetarische Kennziffer (Kp) and disturbance storm time (Dst) indices were also checked within this time frame. The aim of this study was to check for the possible cause of a micro earthquake/tremor generally attributed to the passage of energy, in the form of a seismic wave, through the earth's outer shell, or to anthropogenic activities, such as mining, construction of dams, exploration of oil and gas, groundwater extraction, geothermal energy production, etc., in an area. From the results it was found that the geomagnetic indices (Kp and Dst) showed no activity on the tremor day, and as a result, the strong variation observed in the TEC – evidence of perturbation – is a strong pointer to the micro-earthquake experienced on that day in the study area.

ARTICLE HISTORY
Received 8 February 2019
Revised 15 September 2019
Accepted 21 January 2020

KEYWORDS
Tremor; anthropogenic activities; total electron content; geomagnetic indices; seismic activities

1. Introduction

Nigeria, which is located on the eastern side of theAtlantic Ocean and has been noted for being aseismic, is now known to be experiencing micro-earthquakes in some locations of the country. More specifically, from Jurassic times, the Atlantic Ocean margins have constantly been opening with no history of destructive earthquakes, unlike the margins of the Pacific Ocean, which are characterised by subduction caused by plate movements and inundated with persistent, damaging vibrations of the earth. The Atlantic margins are believed to be quiet. Thus, there is little or no expectation of wanton natural destruction of earthquake magnitude, or need for its mitigation, in West Africa (and in Nigeria in particular). Nonetheless, some seismic events (tremors) occasioned by anthropogenic activities have occurred within the last 70 years in different parts of the country (Table 1). One such occurrence was the 11 July 2016 tremor in parts of Rivers and Bayelsa states, which, however, did not cause wanton destruction of property and loss of lives but rather was reported as vibrations, which cracked some engineering structures as shown in the daily post of 25 September 2016 (Figure 1). This is symptomatic of the fact that tremors might be occurring without being quantified due to lacking or insufficient seismic data resulting from unavailability of seismic data stations, which quantify the magnitudes and state the locations of the events (Akpan and Yakubu 2010). Interestingly, devastating earthquakes have been chronicled in some countries like Ghana, Ivory Coast and Liberia (Burker, 1969; Sierra Leone and Guinea according to Kogbe and Delbos (1984) and Kogbe (1989), near the Atlantic Ocean on the western coast of Africa. Earthquakes are harmful natural occurrences, which are caused by the passage of energy, in the form of seismic wave, through the earth's outer shell. According to Afegbua et al. (2011), earthquake occurrences are dominant along faults, tectonic plate boundaries, etc., principally due to the sudden release of seismic energy from failure of strained/built-up energy. Earthquakes can occur naturally or can be induced by anthropogenic activities. Anthropogenic activities are human activities, which add or remove a large amount of pressure to the geography of an area which can cause that area to shift – sometimes resulting in surface tremors, or induced earthquakes. An earth tremor is an earthquake of lower magnitude or a micro earthquake, where there is an involuntary quivering or vibrations that cause movement of the ground (Ibanga et al., 2018). Usually, earthquake magnitude is conventionally presented using the Richter scale or according to the related moment scale. Magnitudes of 2.5 or less on the Richter scale cannot be measured or felt by

CONTACT N. J. George nyaknojimmyg@gmail.com; nyaknogeorge@aksu.edu.ng Department of Physics, Geophysics Research Group (GRG), Akwa Ibom State University, Ikot Akpaden, Nigeria

Table 1. Upgraded statistics of historical/instrumental tremors felt in Nigeria and its environs (after Tsalha et al. 2015).

S/N	Date (year-month-day)	Origin time	Felt areas	Intensity/magnitude	Probable epicentre	Coordinates Longitude (degrees)	Coordinates Latitude (degrees)
1	1933 -	-	Warri	-	-	5.7564	5.5283
2	1939-06-22	19:19:26	Lagos, Ibadan, Ile-Ife	6.5 (Ml)	Akwapin fault in Ghana	3.3833	6.5031
3	1948-07-28	-	Ibadan	-	Close to Ibadan	-	-
4	1961-07-02	15:42	Ohafia	-	Close Ohafia area	7.7891	5.6208
5	1963-12-21	18:30	Ijebu-Ode	5	Close to Ijebu–Ode	-	-
6	1981-04-23	12:00	Kundunu	3	At Kundunu village	-	-
7	1982-10-16	-	Jalingo, Gembu	3	Close to Cameroun volcanic line	-	-
8	1984-07-28	12:10	Ijebu-Ode, Ibadan, Shagamu, Abeokuta	6	Close to Ijebu–Ode	-	-
9	1984-07-12	-	Ijebu Remo	4	Close to Ijebu–Ode	3.3667	7.1958
10	1984-08-02	10:20	Ijebu-Ode, Ibadan, Shagamu, Abeokuta	5	Close to Ijebu–Ode	-	-
11	1984-12-08	-	Yola	3	Close to Cameroun volcanic line	-	-
12	1985-06-18	21:00	Kombani Yaya	4	Kombani Yaya	-	-
13	1986- 07-15	10:45	Obi	3	Close to Obi town	8.7667	8.3667
14	1987-01-27	-	Gembu	5	Close to Cameroun volcanic line	11.2500	6.7000
15	1987- 03-19	-	Akko	4	Close to Akko	10.9500	10.2833
16	1987-05-24	-	Kurba	3	Close to Kurba village	10.200	11.4833
17	1988-05-14	12:17	Lagos	5	Close to Lagos	-	-
18	1990-06-27	-	Ibadan	3.7	Close to Ijebu–Ode	3.9667	7.3667
19	1990-04-05	-	Jerre	5	Close to Jerre Village	-	-
20	1994-11-07	05:07:51	Ojebu-Ode	4.2	Dan Gulbi	-	-
21	1997 -	-	Okitipupa	4	Close to Okitipupa Ridge	-	-
22	2000-08-15	-	Jushi-Kwari	3	Close to Jushi Kwari village	7.7000	14.050
23	2000-03-13	-	Benin	4	Benin City (55 km from Benin)	-	-
24	2000-03-07	15:53:54	Ibadan, Akure, Abeokuta, Ijebu-Ode, Oyo	4.7	Close to Okitipupa	-	-
25	2000-05-07	11:00	Akure	4	Close to Okitipupa Ridge	-	-
26	2001-05-19	-	Lagos	4	Close to Lagos city	-	-
27	2002-08-08	-	Lagos	4	Lagos city	-	-
28	2005-03	-	Yola	3	Close to Cameroun volcanic line	-	-
29	2006-03-25	11:20	Lupma	3	Close to Ifewara- Zungeru Fault	-	-
30	2009-09-11	-	Abomey-Calavi	2	Close to Benin	-	-
31	2011-11-05	-	Abeokuta	4.4	Close to Abeokuta	-	-
32	2016-07-10	-	Saki	4	Oyo	-	-
33	2016-08-10	-	Bayelsa and Rivers states	3	Igbogene	-	-
34	2016-09-11	-	Kwoi	3.1	Kaduna	-	-
35	2016-09-12	-	Sambang Dagi	3	Kaduna	-	-
36	2018-09-05	2:30	Abuja, Gitata	3.5	Mpape	-	-

Figure 1. Destruction of engineering site at the Bayelsa–Rivers state boundary (source: *Daily Post*, dailypost.ng/2016/09/25/earth-tremor-rivers-bayelsa-communities-cry-out/).

seismographs due to the dynamic range of the seismometer. Values of 3–3.9, 4–4.9, 5–5.9, 6–6.9, 7–7.9 and 8 and above on the Richter scale represent, respectively, minor (tremor), light, moderate, strong, major and great earthquakes (World CBS News, 2011). Anthropogenic activities that can cause tremors include mining, construction of dams, exploration for oil and gas, groundwater extraction, geothermal energy production, etc. According to Wilson et al. (2015, 2017), mining activities over the last few centuries have been identified as an industrial inducer of vibrations of the earth which are huge enough to cause significant destruction of properties and lives. The first case of a micro earthquake/tremor in Nigeria was recorded in Warri, characterised by many oilfields, in the year 1933, and since that time various other cases of earth vibrations have also been recorded (Tsalha et al., 2015). These tremors have been associated with the Ifewara–Zungeru fault, which spans east of Ijebu–Ode in the southwest through Kalangai in northwestern Nigeria (Akpan and Yakubu 2010). This Ifewara–Zungeru fault is responsible for almost all the tremors experienced in Nigeria over the past few years. However, the 10 July 2016 tremor in parts of Rivers and Bayelsa, the southeastern oil rich zones, was not associated with the Ifewara–Zungeru fault as this fault does not span these areas (Figure 2). The Rivers and Bayelsa states of Nigeria are characterised by a rich history of oil and gas exploration. According to Wilson et al. (2017), exploration for oil and gas has been identified as one of the anthropogenic activities which could induce tremors in an area. This is possible owing to the pressure differential created by the drilled borehole as well as seismic sources used within these areas during oil exploration. It is pertinent to note that nothing has been reported on the earth tremors of 10 July 2016 in Nigeria. Therefore, this present work seeks to investigate the vertical total electron content (VTEC) before,

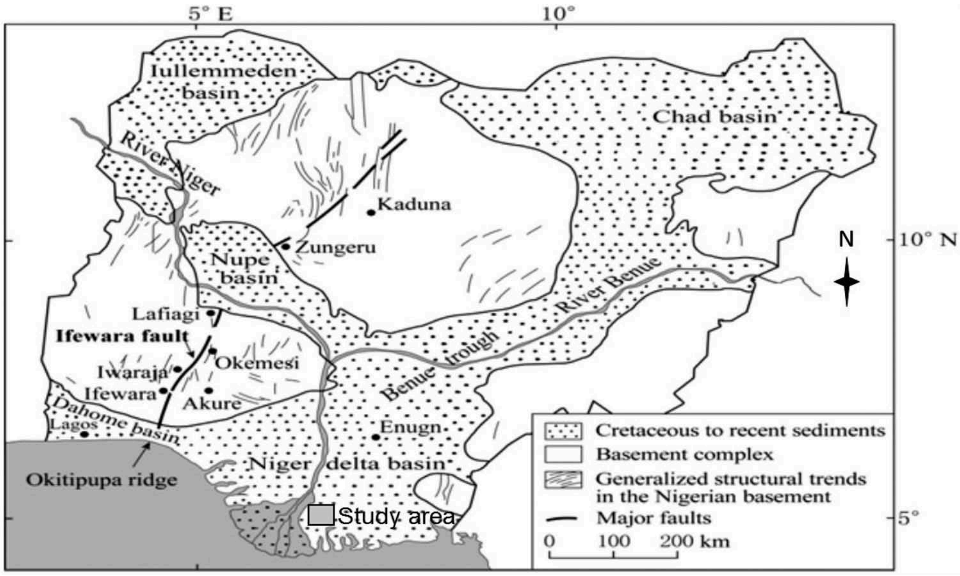

Figure 2. Map of Nigeria showing the study area, the Zungeru–Ifewara fault and some major towns along the fault line.

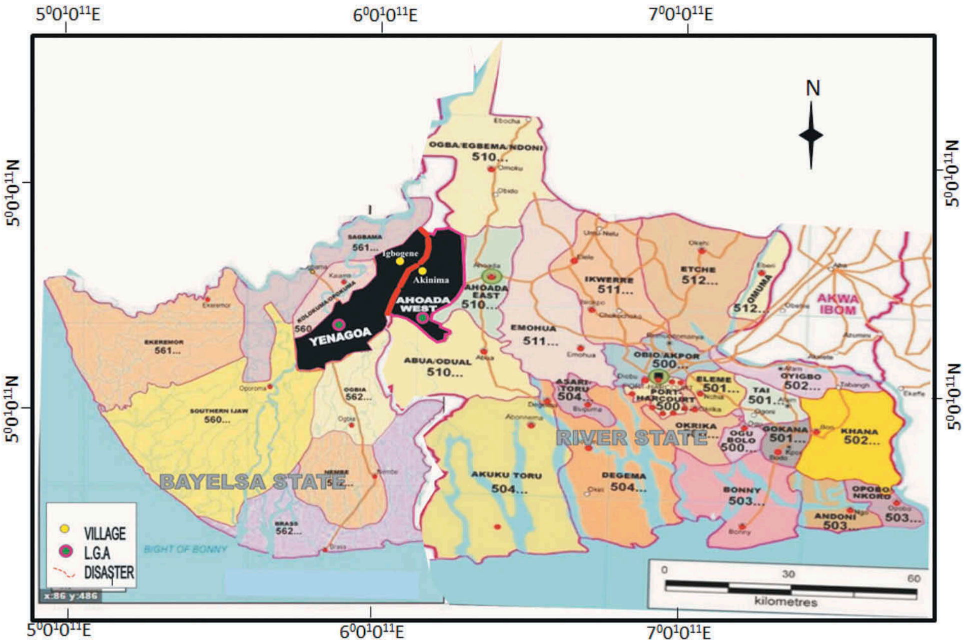

Figure 3. Map showing the Rivers–Bayelsa divide (dark red) and some major towns in the micro-earthquake/tremor sites.

during and after the earth tremor of 11 July 2016 in parts of Nigeria.

2. Location, geology and history of micro-earthquakes in Nigeria

The study area (Figure 3) lies within the Ahoada West Local Government Area (LGA) of Rivers State and Yenagoa LGA, Bayelsa State. The global positioning system (GPS) coordinates of Ahoada are 5°04'N and 6° 38'E while those of Yenegoa are 4°55'N and 6°15'E. The vibrations started from Akinima community and spread to Igbogene community. These communities are located within the oilfields operated by Shell Petroleum Development Company of Nigeria. The earth tremor makes people apprehensive within the affected communities of oil-rich Rivers and Bayelsa states. The vibrations occasioned by the tremor were felt between Akinima and Igbogene, in Rivers and Bayelsa states respectively, covering a distance of about 26 km.

In terms of geology, Nigeria is situated on rock of a Pre-Cambrian–Palaeozoic age, a basement terrain known to be stable and seismically safe. Alhough earth tremors (minor earthquakes) have been reported in Nigeria from 1933 to 2018, there is no history of devastating earthquakes. The first earth tremors in Nigeria were recorded in 1933, in a town known as Warri. Three years later, another tremor defaced and deformed the engineering construction of Lagos and its environs. Although some authors believed it was merely a movement of slope, in 1961, in an area within Ohafia in Imo State (now Abia State) experienced a tremor. In 1984, according to Ajakaiye et al.(1989), a more severe tremor accrued near Ijebu–Ode. Then, in 2000, Jushi Kwari town was struck with a micro earthquake, according to Eze (2007). Empirically and collectively, these series of repeated tremors reveal that Nigeria is not as aseismic as formerly believed. Significant inter-bedded devastating earthquakes are uncommon in Nigeria, and more minor occurrences are often not noticeable as high consequences in terms of people's safety and economic loss are never detected or felt. Recent intraplate seismic events have made people increasingly apprehensive, as the intensities of these seismic events range from 2 to 5 in Nigeria and 6 and above in adjoining countries, with devastating earthquakes, based on the Modified Mercalli Intensity Scale. Again, the instrumental magnitudes of the events of 1984 at Ijebu Ode, 1990 at Ibadan and 2000 at Jushi-Kwari were chronicled. According to Akpan and Yakubu (2010), the seismic body waves have magnitudes ranging from 4.3 to 4.5, local magnitudes ranged between 3.7 and 4.2, and surface wave magnitudes ranged from 3.7 to 3.9. Unfortunately, Nigeria had no functional seismological observatories when these events took place, and as a result no detailed information was documented. Presently, Nigeria has a limited and local seismographic network with four operational stations, established due to the emerging and clustering nature of the tremor signals. These observatory stations enabled detailed study of the latest tremor with respect to its origin, time and location, using standard seismological procedures.

3. Data acquisition and methodology

The materials used for this research were those that could screen the ionospheric–magnetospheric transition zone, which is the zone of interest. The ionosphere is the ionised part of the atmosphere, which contains free electrons as well as positive ions. These ions (positive and negative) are equally polarised, in such a way that the medium is, overall, electrically neutral. It plays a basic role in long-distance communication. The ionosphere is characterised by spatial and temporal variabilities which can cause atmospheric mishaps, leading to seismogenic activities worth studying. In the ionosphere, depression induces a time delay in a frequency range of 1.57542 GHz (L1) to 1.22760 GHz (L2). This affects transmissions from GPS satellites orbiting at a distance of up to 20,200 km. The interdependent delay in the ionosphere between these frequency signals increases with the total electron content (TEC), traversing the ray path occupied by TEC. According to Lanyi and Roth (1988), within the L1 and L2 frequencies, the delay in time measured can be converted to TEC traversing the ray path between the receiver and the satellite. TEC, which is one of the most important ionospheric quantities, gives the details of ionospheric ionisation and its practical applications. The TEC is the number of free electrons in a column of 1 square metre of cross-sectional area, spanning from the ground to the uppermost part of the ionosphere.

To this end, Nigerian Global Navigation Satellite System Reference Network (NIGNET) GPS data were downloaded for 10 days before and 5 days after the day of the tremor. NIGNET served principally as the fiducial network that defines and materialises a new reference frame based on space-geodetic techniques and links to African Reference France (AFREF). Presently, NIGNET is formed by nine Continuously Operating Reference Stations (CORS), covering the entire country. The data were obtained from the NIGNET GPS station with station code FPNO. The data were in compressed RINEX format, and the Gopi software was used to unzip and open it. The data were run in Matlab to obtain a daily average of vertical total electron content (VTEC) and contoured using the Surfer software progamme (Vender Velpen 1988). The values for the disturbance storm time (Dst) and Kennziffer planetary (Kp) geomagnetic indices were also downloaded within the same time frame and contoured.

4. Results and discussion

The analysed results shown in Figures 4–6 reveal day-to-day variability in GPS TEC values, and Kp and Dst geomagnetic indices, respectively. These figures are two-dimensional contour plots that have colour bars besides them. The colour distribution depicts the varying magnitude of TEC, Kp or Dst. The y-axis gives the time (Universal Time), while the x-axis shows days relative to the tremor. The tremor day is indicated as day zero, with days before and after having negative and positive signs, respectively. Figure 4 illustrates the daily variability

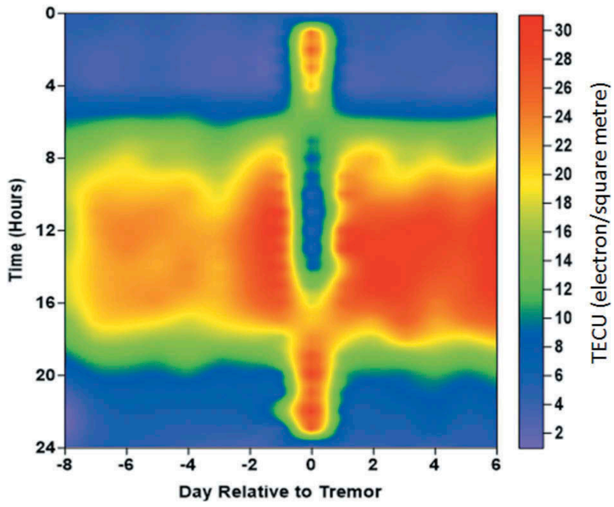

Figure 4. Contour map showing the vertical total electron content (VTEC) distribution, computed from 2 to 15 July 2016.

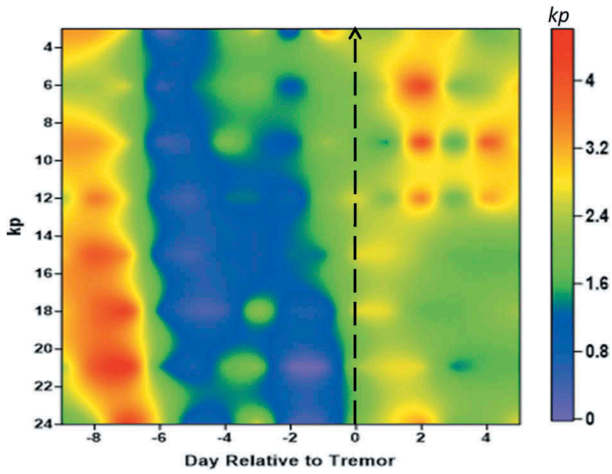

Figure 5. Analytical results from the planetarische Kennziffer (Kp) geomagnetic index, from 2 to 15 July 2016.

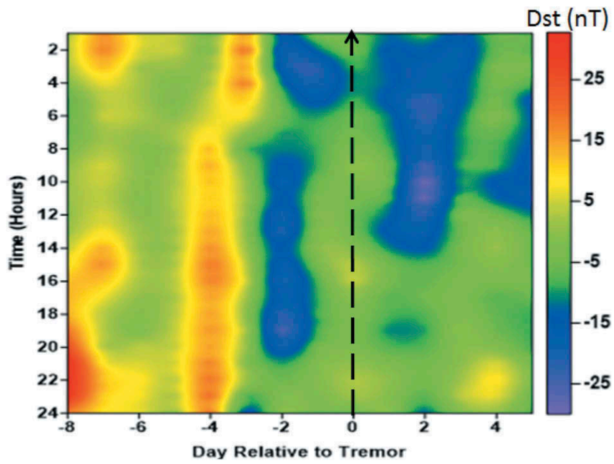

Figure 6. Analytical results from the disturbance storm time (Dst) geomagnetic index, from 2 to 15 July 2016.

of VTEC values estimated from 2 to 15 July 2016 using GPS ground stations close to the epicentre of the event. However, due to technical difficulties with the receiver, no data were available for the –10th day. By visual inspection of the VTEC contour plot, a striking anomaly was detected on day zero (the tremor day). It is important to note that pre- and post- variations were absent. Because the ionospheric equatorial storm time and ring current during solar-terrestrial disorders creates substantial disorders in geomagnetic fields, as noticed on the ground surface, the investigated parameter could exhibit variations in the absence of seismic activity. Hence, to distinguish seismo-ionospheric alarms from geomagnetic turbulence, the geomagnetic indices Dst and Kp (http://spider.ngdc.noaa.gov) were cross referenced. According to Mayaud (1980) and Ondoh (2008), the Kp index (Figure 5) discriminates the terrestrial event on a global scale, whereas the Dst index records the activity of current variabilities in the equatorial ring (Figure 6). According to Pulinets et al. (2003), the effect of the ionosphere in a geomagnetic storm has a worldwide impact, while the seismic effect is noticed at stations within approximately 2000 km of the probable potential epicentre. In the current study, the distance between the GPS station and the affected communities is 121.1 km. The Kp is active when its value is ≥ 3.0, according to Poole and Poole (2002), while Dst is stormy at ≤ –30 nT (Xinzhi et al. 2014). The 3-hourly Kp and the 24-hourly Dst indicated no geomagnetic storm on the tremor day, as displayed in Figures 5 and 6. From the results of our investigations, it is clear the tremor that occurred in parts of Rivers and Bayelsa states of Southern Nigeria on 11 July 2016 presented a strong perturbation in VTEC values, which was purely localised.

5. Conclusion

This is a preliminary study on the use of NIGNET GPS data to investigate ionospheric conditions before, during and after an earthquake – in this case, the 11 July 2016 earth tremor in parts of Rivers and Bayelsa states, Nigeria. Our results revealed striking perturbations in TEC during quiet geomagnetic conditions, which suggests a micro-seismic event. The affected communities play host to rich oilfields where exploration activities are ongoing. These activities introduce a pressure differential which may have triggered the tremor.

Acknowledgements

NIGNET is greatly acknowledged for providing the data used in achieving the results in this paper.

Disclosure statement

No potential conflict of interest was reported by the authors.

References

Afegbua KU, Yakubu TA, Akpan OU, Duncan D, Usifoh ES. 2011. Towards an integrated seismic hazard monitoring in Nigeria using geophysical and geodetic techniques. Intl J Phys Sci. 6(28):6385–6393.

Ajakaiye DE, Daniyan MA, Ojo SB, Onuoha KM. (1989). Southwestern Nigeria earthquake and its implications for the understanding of the tectonic structure of Nigeria. In Wassef AM, Boud A, Vyskocil P, Editors. Recent crustal movements in Africa, J. Geodynamics. 7:205–214.

Akpan O, Yakubu T. 2010. A review of earthquake occurrences and observations in Nigeria. Earthuake Sci. 23(3):289–294.

Burke K. 1969. Seismic areas of the Guinea Coast where Atlantic fracture zones reach Africa. Nature. 222 (5194):655–657.

Eze CL. 2007. Tsunami: facts and figures for nigerian coastal dwellers and tourists. Port Harcourt: Transparent Earth Nigeria Limited; p. 50.

Ibanga JI, Akpan AE, George NJ, Ekanem AM, George AM. 2018. Unusual ionospheric variations before the strong Auckland Islands, New Zealand earthquake of 30th September, 2007. NRIAG J Astron Geophys. 7 (1):149–154. doi:10.1016/j.nrjag.2017.12.007.

Kogbe CA. 1989. The Cretaceous and Paleogene Sediments of Southern Nigeria. Geology of Nigeria 2nd Edition. Rock View (Nig) Ltd, pp. 325–334.

Kogbe CA, Delbos L. 1984. The recent Guinea earthquake: probable origin and geographic implications. Pangea. 2:17–19.

Lanyi GE, Roth T. 1988. A comparison of mapped and measured total ionospheric electron content using global positioning system and beacon satellites observations. Radio Sci. 23(4):483–492.

Mayaud PN. 1980. Derivation, Meaning and use of geomagnetic indices, Geophysical monograph, no. 22. Washington (DC): American Geophysical Union.

Ondoh T. 2008. Investigation of precursory phenomena in the ionosphere, atmosphere and groundwater before large earthquakes of M >6.5, Advance. Space Res. 43:214–223.

Poole AWV, Poole M. 2002. Long-term trends in foF2 over grahamstown using neural networks. Annals Of Geophysics. 45:155–161.

Pulinets SA, Legen AD, Gaivoronskaya TV, Depuev VK. 2003. Main phenomenological features of ionospheric precursors of strong earthquakes. J Atmos Solar Terr Phys. 65:1337–1347.

Tsalha M, Lar U, Yakubu T, Kadiri U, Duncan U. 2015. The review of the historical and recent seismic activity in Nigeria. IOSR J Appl Geol Geophys (IOSRJAGG). 3:48–56.

Vender Velpen BPA. 1988. A computer processing package for D.C. Resistivity interpretation for an IBM compatible. ITC J. 4. The Netherlands.

Wilson MP, Davis RJ, Foulger GR, Julian BR, Styles P, Gluyas S, Almond JG. 2015. anthropogenic Earthquake in the UK. A National baseline prior to Shale exploitation. Mar Pet Geol. 68:1–17.

Wilson MP, Foulger G, Gluyas JG, Davis RJ, Julian BR. 2017. HiQuake: the human -induced Earthquake Database. Bull Seismolo Soc.

World CBS News. 2011. The Richter scale – how earthquakes are measured. tttp//www.cbsnews.com

Xinzshi W, Junhui J, Dongjie Y, Fuyang K. 2014. Analysis of Ionospheric VTEC disturbances before and after the Yutian Ms 7.3 earthquake in Xinjiang Uygur autonomous region. Geod Geodyn. 5(3):8–15.