Journal of Science Research and Reviews

PRINT ISSN: 1595-9074
E-ISSN: 1595-8329
DOI: https://doi.org/10.70882/josrar.2024.v1i1.7
Homepage: https://josrar.esrgngr.org

Original Research Article

Evaluation of the Seismicity Index for Nigerian Nuclear Installations

*[1]Lawal, Kolawole M., [2]Osumeje, Joseph and [3]Bello, Yusuf A.

[1]Department of Physics, Faculty of Science, National Open University of Nigeria, Abuja, Nigeria.
[2]Department of Physics, Faculty of Science, Ahmadu Bello University, Zaria, Nigeria.
[3]Department of Physics, Faculty of Science, Airforce Institute of Technology, Kaduna, Nigeria.
*Corresponding Author's email: kmlawal@noun.edu.ng

KEYWORDS
Fractal,
B-value,
Earthquake,
Seismicity.

ABSTRACT
Seismic Hazard Assessment (SHA) is a quantitative measure of assessing the seismic hazard or risk involved for a given site. The parameter computed for such an assessment is needed for building engineers or national decision makers especially when it concerns nuclear installations. Even though the International Atomic Energy Agency (IAEA) currently makes it mandatory to provide such an index before undertaking any form of development or construction of a nuclear installation, this computation has not been done for Nigeria. Data over long period of time is usually necessary for a quantitative seismic hazard assessment, but because such information is scarce in Nigeria a fractal approach is therefore used in this research. A SHA index called the b-value is evaluated by determining the fractal dimension of the network of locations of recorded past tremor events within Nigeria. In this work a b-value of 0.43 which quantitatively measures the seismic hazard or risk of a given region is computed for Nigeria. Aeromagnetic data was used in producing analytic signal maps that accurately mapped faults that could have been responsible for causing the earth tremors, and the coordinates of these faults or lineament were used in calculating the fractal dimension of the system of faults. The fractal dimension of 0.8568 was obtained by determining the slope of line of best-fit of the plot of the log of the average number of tremor locations <N(R)> within radius R of each location against log of radius R, which was in turn used to determine the b-value. A b-value of 0.43 obtained indicates that Nigeria is in a less seismically active region and this can be used in the IAEA safety guidelines for nuclear installations.

CITATION
Lawal, K. M., Osumeje, J. & Bello, Y. A. (2024). Evaluation of the Seismicity Index for Nigerian Nuclear Installations. *Journal of Science Research and Reviews*, *1*(1), 34-42. https://doi.org/10.70882/josrar.2024.v1i1.7

INTRODUCTION

The history of earthquakes in Nigeria actually dates back to the 1930's when tremors were felt in part of Warri in 1933 and Ibadan in 1939, and since then other events have occurred with the most recent being the one that occurred on the 5th of September, 2018 at the Mpape district of Abuja. A detailed report on the history of earthquakes in Nigeria can be found in Akpan and Yakubu (2010). The seismicity of an area is determined by the frequency of earthquakes in the past, as deduced from seismologic data collected on recent earthquakes that have occurred in the area and also from the location of active faults. Seismic hazard assessment is an effort by earth scientists to quantify seismic hazard and its associated uncertainty in time and space and to provide seismic hazard estimates for seismic risk assessment and other applications.

The Global Seismic Hazard Assessment Program (GSHAP) was launched in 1992 by the International Lithosphere Program (ILP) with the support of the International Council of Scientific Unions (ICSU). In order to mitigate the risk associated to the recurrence of earthquakes, the GSHAP promotes a regionally coordinated, homogeneous approach to seismic hazard evaluation; the ultimate benefits are improved national and regional assessments of seismic hazards, to be used by national decision makers and engineers for land use planning and improved building design and construction.

The International Atomic Energy Agency (IAEA) provides the global safety standards pertaining the Seismic Hazard Assessment (SHA) of a site meant for nuclear installation. In the IAEA Safety Standards Series SSG-9, Seismic Hazards in Site Evaluation for Nuclear Installations (IAEA, 2010) are classified into two groups: earthquakes occurring on identified seismotectonic structures, and earthquakes occurring in locations where no apparent correlation can be made with any specific geological structure. Nigeria falls in the second category and such earthquakes are referred to as diffuse seismicity. Nuclear installations have to be able to withstand earthquakes even if they are located in regions of low or diffuse seismicity. The recent earth tremor occurrences in Ikara, Kwoi and Abuja have repositioned the view about Nigeria's vulnerability to earthquakes. The Nigerian Research Reactor (NRR1) at the Centre for Energy Research and Training in Zaria is centred around these events. An important parameter needed in SHA is the *return-period*, which is an estimate of the interval of time between events like an earthquake, flood or river discharge flow of a certain intensity or size. It is a statistical measurement denoting the average recurrence interval over an extended period of time. This therefore requires data over a very long period in order to obtain accurate value and availability of such long period of data in Nigeria are either insufficient or not available. A more robust parameter often used is what is known as the b-value which is a dimensionless value that varies from 0.5 to 1.5 for an aseismic to a seismically active region respectively. A periodic computation such an index can also be used to reveal whether or not there is a build-up in seismic activity. This work is therefore aimed at calculating a b-value for Nigeria in order to quantify its present level of seismicity.

MATERIALS AND METHODS

Many regions of the world have dense seismic networks that monitor earthquakes even as small as magnitude two or less. Various statistical correlations have been used to relate the frequency of occurrence of earthquakes to their magnitude, but the most generally accepted is the log-linear relation (Gutenberg and Richter, 1954):

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

where a and b are constants, the logarithm is to base 10, and N is the number of earthquakes per unit time with a magnitude greater than m occurring in a specified area. The frequency- magnitude relation (equation 1) is found to be applicable over a wide range of earthquake sizes both globally and locally (Ayodeji et al., 2020). The constant b or 'b-value' is a measure of the required level of seismicity and varies from region to region but is generally in the range 0.5< b < 1.5 (IAEA, 2010). Aki (1981) showed that the b-value is simply twice the fractal dimension. A fractal is any entity that is scale invariant (Mandelbrot,1985) meaning that it looks similar at a greater variety of scales, or sometimes referred to as being self-similar. Scale invariance of a geological phenomenon is of great importance in geology and are very useful when modelling natural phenomena.

The first step in determining the b-value is to catalogue the available past earth tremor events within Nigeria in terms of their dates and location and plot their positions on a map. This identify of the region of occurrences relative to one another. Using the Analytic signal technique aeromagnetic data would then be used in the mapping of major faults within these sites in order to provide more accurate locations of the structures or faults that may have triggered the tremors by repositioning the tremor locations. The Analytic Signal is given by:

$$A(x,y) = \sqrt{\left(\frac{\partial T}{\partial x}\right)^2 + \left(\frac{\partial T}{\partial y}\right)^2 + \left(\frac{\partial T}{\partial z}\right)^2} \quad (2)$$

where *T* is the observed field at *x* and *y* directions.

The analytic signal function is extremely interesting in the context of interpretation, as it is completely independent of the direction of magnetization and the direction of the inducing field. All bodies with the same geometry have the same analytic signal and the peaks of analytic signal functions are symmetrical and occur directly over the edges of wide bodies and directly over the centres of narrow bodies. Next, the fractal dimension of these locations is computed using the principle outlined by Lovejoy *et al.* (1986) and Lawal and Umego (2005). For each tremor location the number N(R) of other locations within various radii R from that location is determined. The log of its average <N(R)> over all the station is calculated and plotted against the log of radius R. The slope of the line of best-fit gives the fractal dimension of the seismic events within the whole region.

RESULTS AND DISCUSSION

The list of historical earth tremor occurrences in Nigeria as listed by Akpan and Yakubu (2010) is show in Table 1 and the locations of these tremors are shown in Figure 1. Aeromagnetic data over the locations of these earth tremors are obtained and interpretated for possible faults or lineaments. The aeromagnetic data are high resolution data acquired on row spacing of 500m with average topographic clearance of 80m. The data from the aeromagnetic anomaly map were given in the Universal Transverse Mercator (UTM) projections of coordinate system WGS84/UTM Zone 31N and were extracted from the map using GEOSOFT Oasis Montaj software as the maps were in GEOSOFT grid file format. Regional residual separation was conducted using a first order polynomial after which the residual field was subjected to enhancement and interpretation and using the method of Riedel (2008) the analytic signal technique was applied with the residual fields as input. The results shown in Figures 2-11 shows the Total Field Intensities (TMIs) and corresponding analytic signal results, also including the mapped lineament/fault lines (indicated as solid lines) which could have been responsible for the earth tremors. The coordinates of these lineaments rather than the geographical location of the towns where the tremors are felt represents a more accurate positioning of the sources of the tremors and are therefore used in the calculation of the fractal dimensions of the network. Using the method outlined above, Figure 12 shows the graph of the log of average number of tremor locations <N(R)> plotted against the log of radius R (radius of circle encompassing tremor locations) with the line of best fit representing the scaling behaviour of the network. The slope of the graph which represents the fractal dimension is 0.8568 and therefore gives a b-value of 0.43.

Since the b-value varies between 0.5 to 1.5, a value of 0.43 indicates that Nigeria can be said to be in in a less seismically active region. However, this is not to say that possibilities of future earth tremors or even earthquakes should be ruled out, as geological phenomena are known to be slow and buildup over time. Kadiri and Kijko (2021) calculated the b-value of 0.77 for the entire West African region using ground-motion-models (GMMs) obtained from seismic stations across the region. This value is obviously higher than that computed for Nigeria as countries like Ghana, Togo and Giunea have experienced earthquakes with higher magnitudes, and data used in their work also included those from the Cameroon Volcanic Line (CVL) which a very mobile and active region. The b-value computed for Nigeria is more localized and is therefore a better refection of the level of seismicity within the country.

Table 1: List of historical Earth tremors in Nigeria (Modified after Akpan and Yakubu (2010)

Origin Time (GMT)		Felt Areas	Intensity	Magnitude
year-month-day	**h:min:s**			
1933	-	Warri	-	-
1939-06-22	19:19:26	Lagos, Ibadan, Ile-Ife	-	6.5(*M*L), 5.3(*M*S)
1963-12-21	18:30	Ijebu-Ode	V	-
1982-10-16	-	Jalingo, Gembu	III	-
1984-07-28	12:10	Ijebu-Ode, Ibadan, Shagamu, Abeokuta	VI	-
1984-08-02	10:20	Ijebu-Ode, Ijebu-Remo, Ibadan, Oyo Shagamu, Abeokuta	V	-
1984-12-08	-	Yola	-	-
1985-06-18	21:00	Kombani Yaya	IV	-
1990-06-27	-	Ibadan	-	3.7(*M*L)
1994-11-07	05:07:51		-	4.2(*M*L)
1997	-	Okitipupa	IV	-
2000-03-07	15:53:54	Ibadan, Akure, Abeokuta, Ijebu-Ode, Oyo	-	4.5(*m*b), 3.9(*M*S)
2000-05-07	11:00	Akure	IV	-
2005-03	-	Yola	III	-
2006-03-25	11:20	Lupma	III	-
2016-05-10	10:00	Ikara	-	-
2016-09-11	-	Kwoi	III	-
2019-09-05	-	Mpape, Abuja	-	-

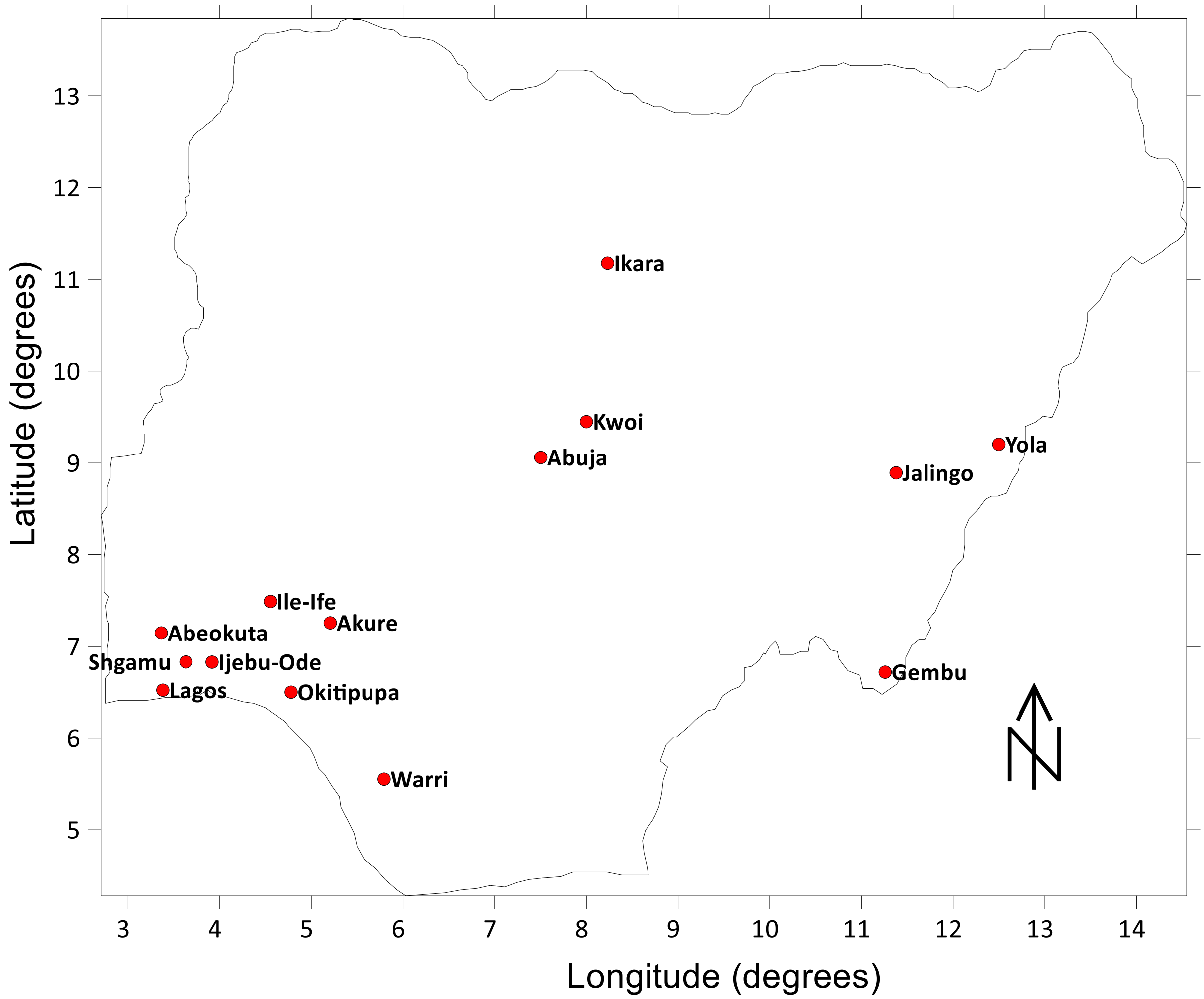

Figure 1: Map of Nigeria showing locations where earth tremors were felt

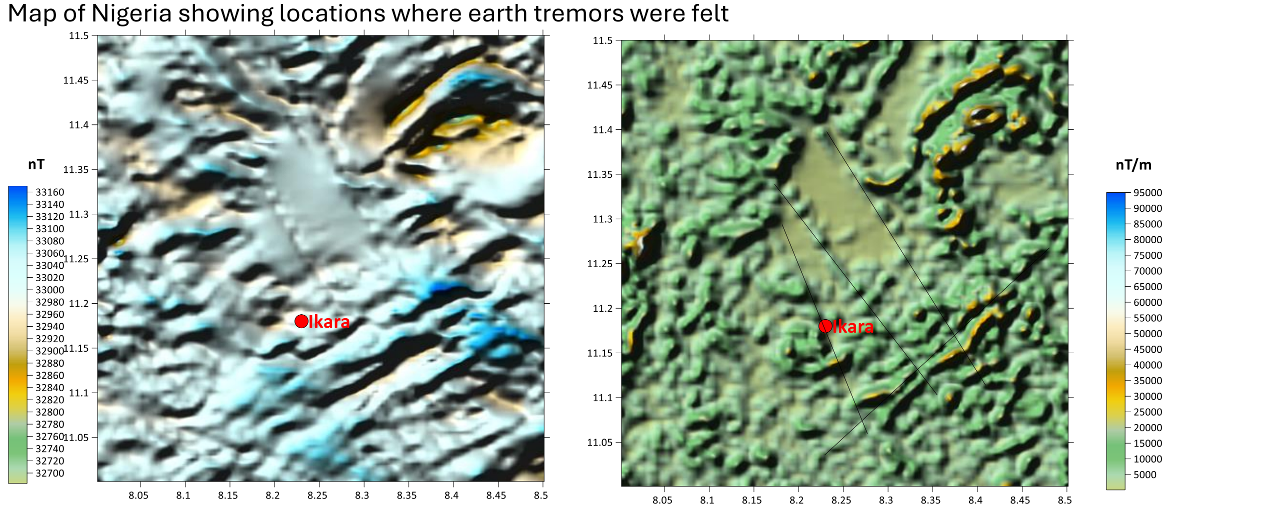

Figure 2: Total magnetic intensity map of Sheet 103 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

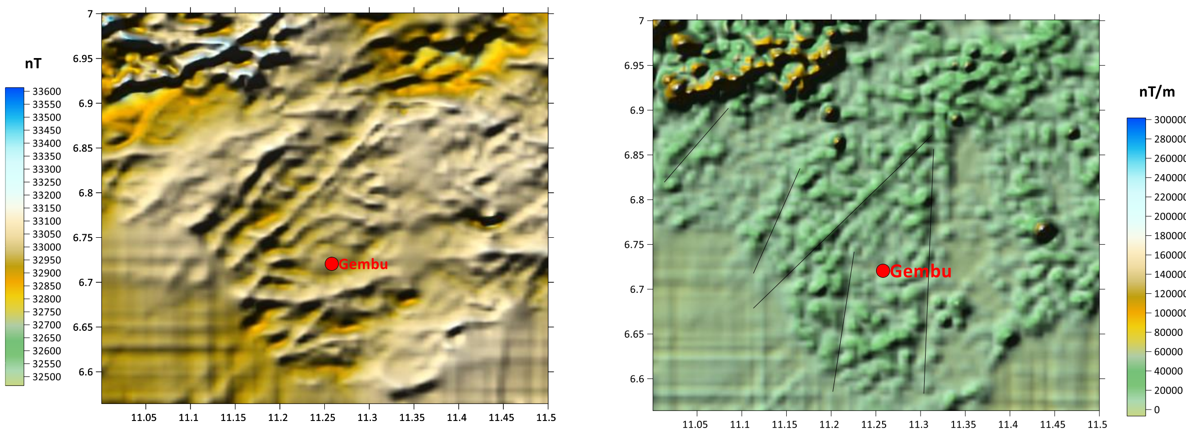

Figure 3: Total magnetic map of Sheet 295 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

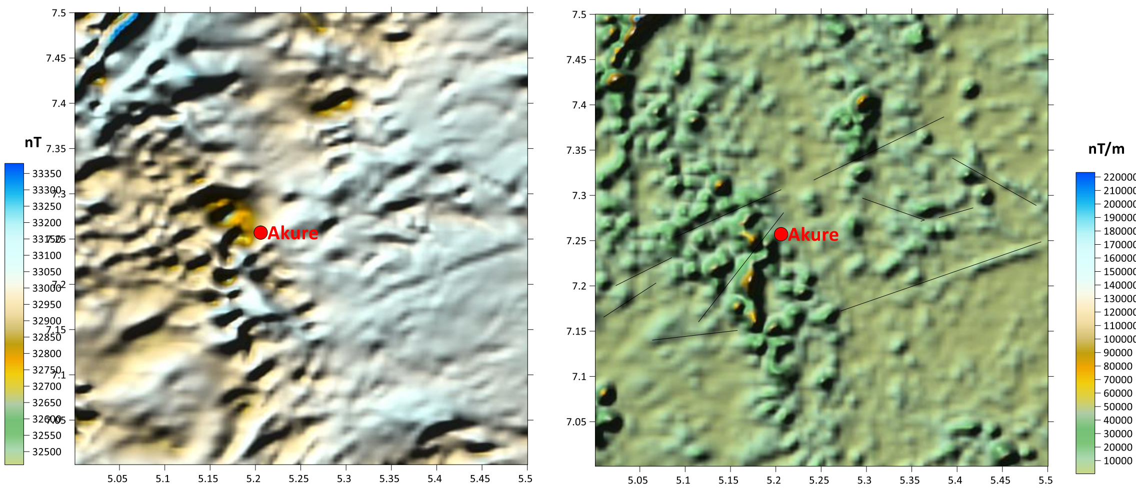

Figure 4: Total magnetic map of Sheet 264 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

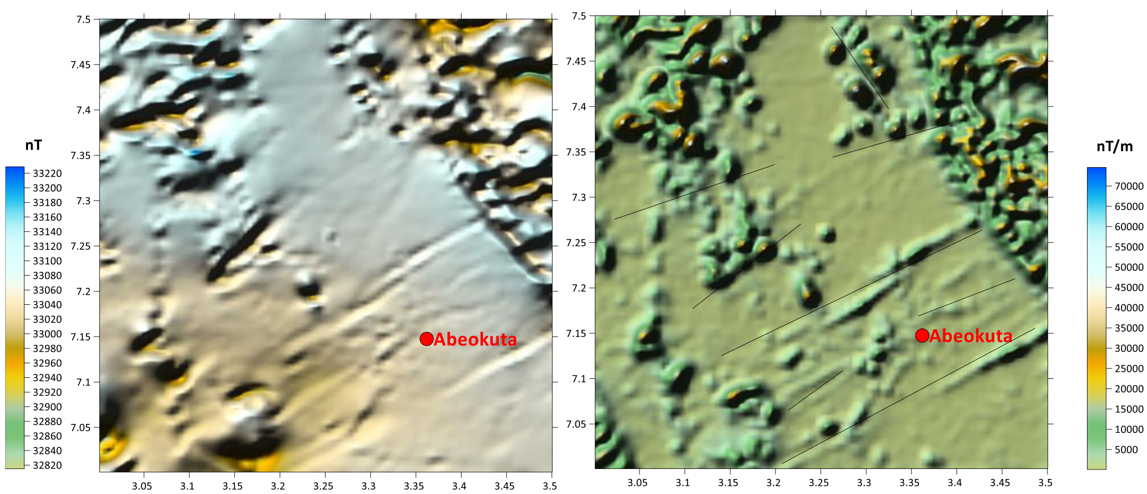

Figure 5: Total magnetic map of Sheet 260 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

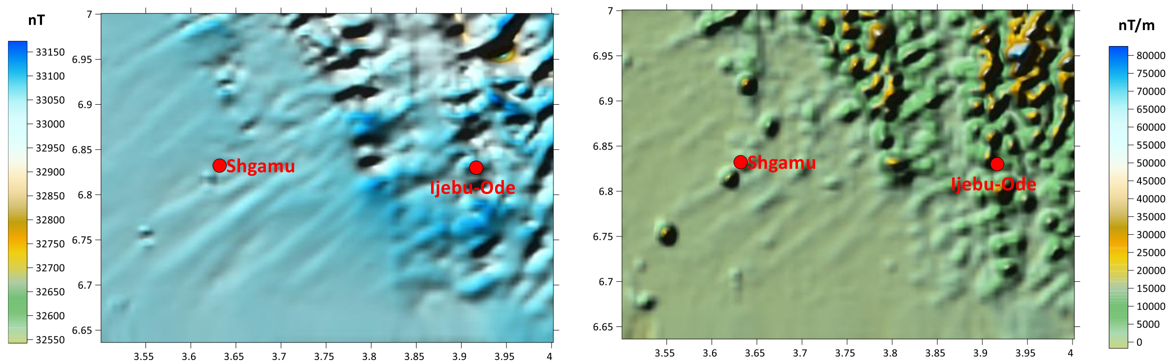

Figure 6: Total magnetic map of Sheet 250 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

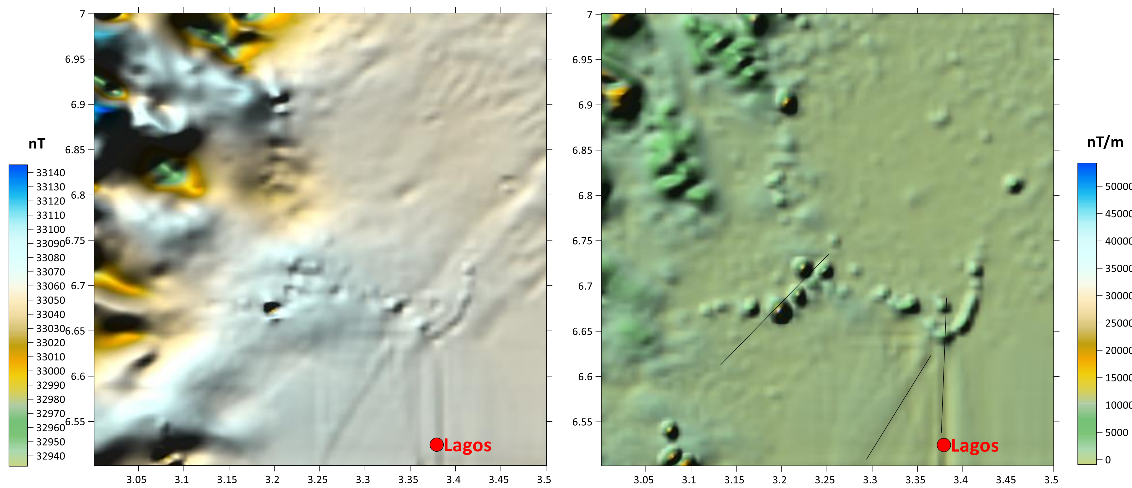

Figure 7: Total magnetic map of Sheet 279 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

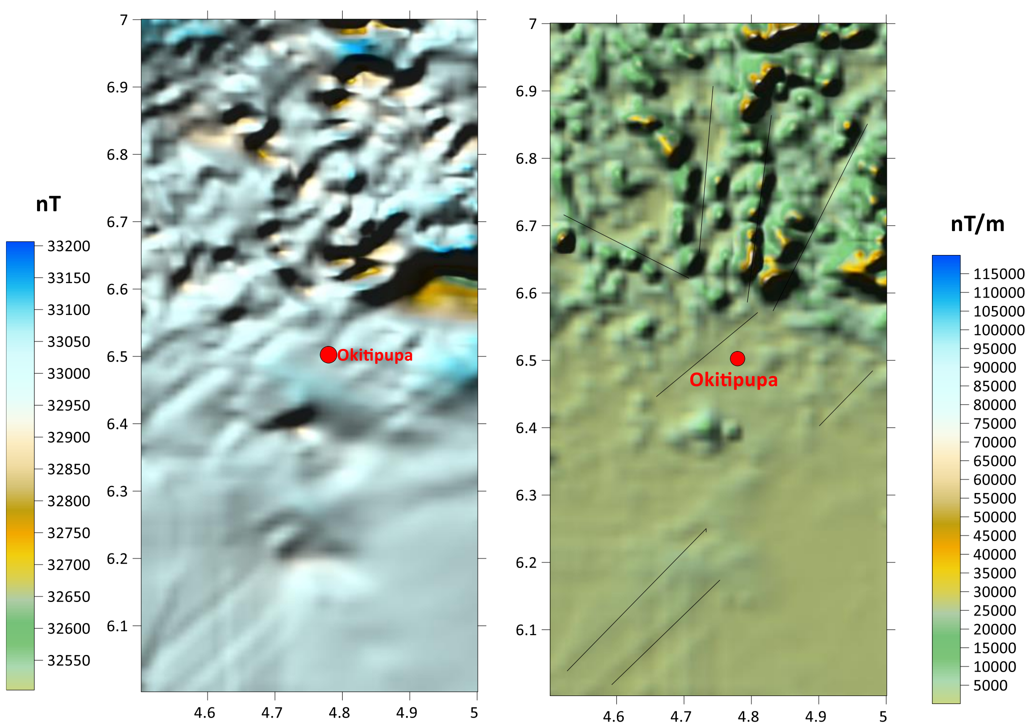

Figure 8: Total magnetic map of Sheets 282 and 296 combined (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

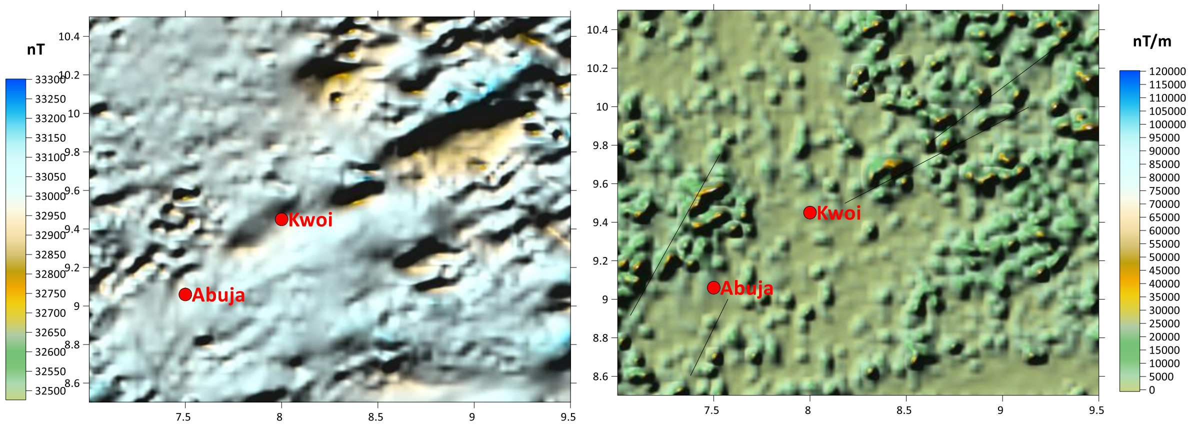

Figure 9: Total magnetic intensity map of Sheets covering Abuja and Kwoi (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

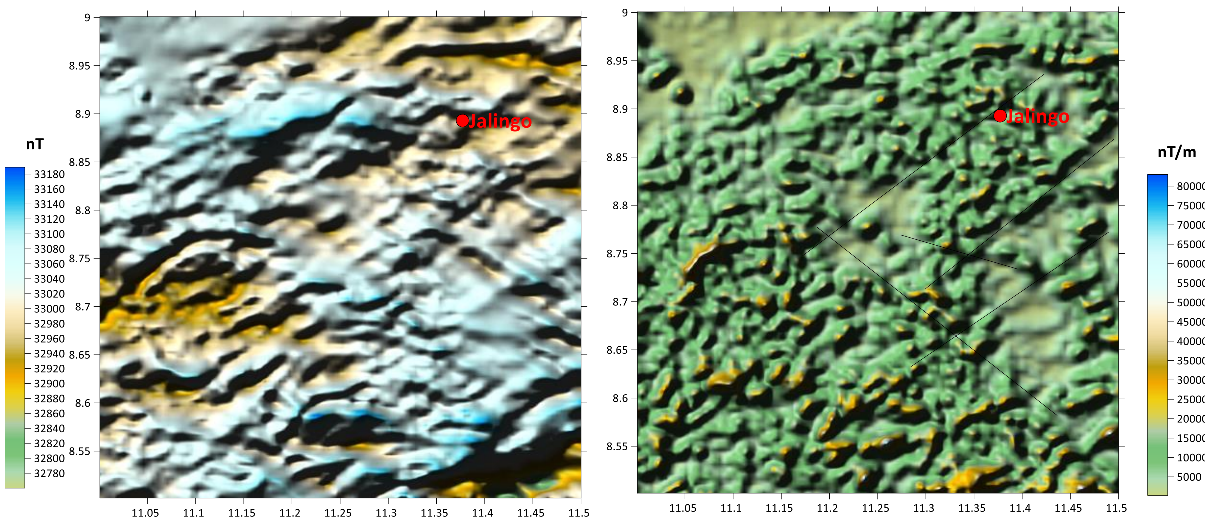

Figure 10: Total magnetic intensity map of Sheet 215 (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

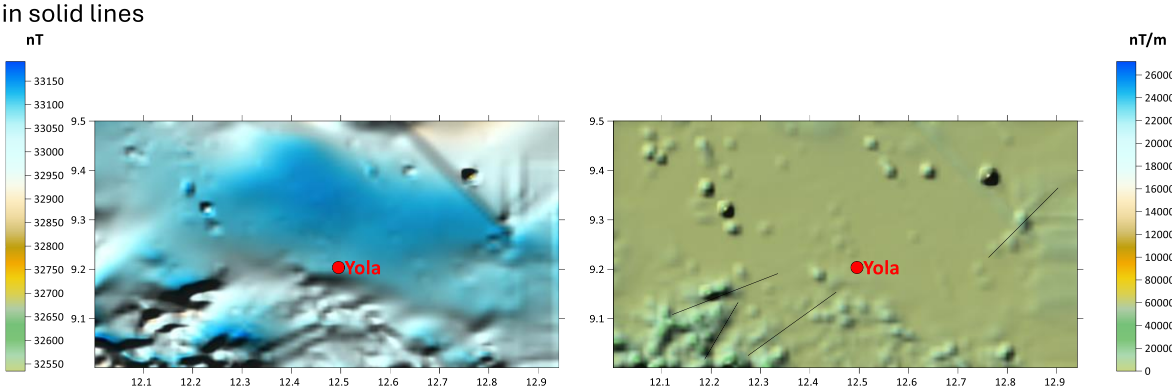

Figure 11: Total magnetic intensity map of Sheets 196 and 197 combined (a) with the corresponding Analytic signal map (b) Mapped faults are shown in solid lines

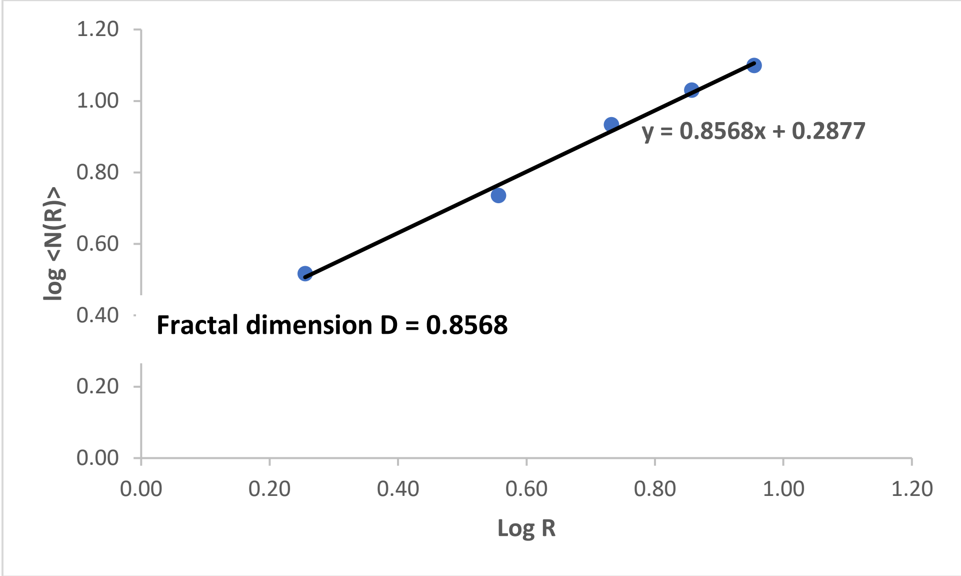

Figure 12: Plot of the log of average number of tremor locations <N(R)> plotted against the log of radius R (radius of circle encompassing tremor locations).

CONCLUSION

A b-value of 0.43 indicates that Nigeria is in a less seismically active region and this represents an index which can be used by regulatory bodies to quantify risk levels or qualify the level of seismicity in respect to sensitive infrastructures such as nuclear power stations within the country. Also due to the simplicity and direct mode of computation of the b-value periodic updates can easily be done so as to observe or investigate the gradual buildup the region from being aseismic to becoming seismically active.

ACKNOWLEDGEMENT

The Authors would like to thank the Tertiary Educational Trust Fund (TETFund) for providing the grant which was used in funding this research. Our gratitude also goes to the reviewers of this work whose inputs have added value to this work.

REFERENCES

Aki, K. (1981): A probabilistic synthesis of precursory Phenomena, in Earthquake Prediction. In: D. W. Simpson and P. G. Richards Ed., 566 – 574, American Geophysical Union, Washington, D. C.

Akpan OU, Yakubu TA (2010). A review of earthquake occurrences and observations in Nigeria. Earthq. Sci., 23(3): 289-294.

Ayodeji A. E., Ibitoye F. I. and Saurabh B. (2020): Preliminary analysis of probabilistic seismic hazard assessment for nuclear power plant site in nigeria, Scientific African, Vol. 8, 1 – 12.

Fedi, M. and Rapolla A ., (1995). Vertical gravity and magnetic soundings: Forward problem formulation and data inversion. Boll. Geof. Teor. Appl., 37,199-205.

Gutenberg, B. and Richter, C. F. (1954). Seismicity of the Earth and Associated Phenomenon, 2nd edition, Princeton University Press, Princeton.

IAEA (2010). Seismic Hazards in Site Evaluation for Nuclear Installations, IAEA Safety Standards Series No. SSG-9, Vienna.

Kadiri U.A. and Kijko A. (2021): Seismicity and seismic hazard assessment in West Africa. Journal of African Earth Sciences 183(28):104305. DOI:10.1016/j.jafrearsci.2021.104305

Lawal K.M. and Umego M.N. (2005). A Fast Method of Digitizing Aeromagnetic Maps, Nigerian Journal of Scientific Research, 5 (No. 1): 28 - 33.

Lovejoy, S., Schertzer, S., and Ladoy, P., (1986). Fractal characterization of homogeneous geophysical measuring network. Nature, 319, 43-44.

Mandelbrot, B. B. (1985). Self-affine fractals and fractal dimension. Physica Scripta, 32, 257-260.

Prihadi S, Darharta D. and Hendra G. (2018): A Note on the Use of the Second Vertical Derivative (SVD) of Gravity Data with Reference to Indonesian Cases, Journal of

Engineering and Technological Sciences, Vol. 50, 127 – 139.

Riedel, S. (2008). Airborne-Based geophysical investigation in Dronning Maud land Antarctica. Dissertation, Christian Albrechts Universitat Zu Kiel, Kiel.

Sari, E. P and Subakti, H. (2015): Identification of Baribis fault - West Java using second vertical derivative method of gravity, IP Conference Proceedings, Vol.1658,DOI: 10.1063/1.4915024

Wei D. and Yangyang Z. (2021): The Calculation of High-Order Vertical Derivative in Gravity Field by Tikhonov Regularization Iterative Method, Mathematical Problems in Engineering, p 1-13.