

Potential Applications of Marine Deposits Assessment Using Radiometric and Geochemical Data Integration in Arewa-Jantulu NW, Nigeria

Adamu, A.^{1*}, Abdulganiyu, Y.² and Attahiru, A.U¹

Page | 4220

¹Department of Applied Geophysics, Federal University Birnin Kebbi Nigeria

²Department of Geology, Federal University Birnin Kebbi Nigeria

Date Received: 20-09-2021

Date Accepted: 12-02-2022

DOI: <https://doi.org/10.48198/NJPAS/21.B15>

ABSTRACT

Exploration for uranium, thorium, potash, and manganese at this time can be seen as a magnitude that can settle into the immense economic benefit to the host community and the country at large. These minerals have transformed the economic landscape of many host countries and they can be mined to contribute significantly to the Nigerian economy. In this study In-situ measurements using Radiometric and trace element analysis of intercontinental deposits discovered by the paleomagnetic analysis were carried out in Arewa-Jantulu part of the Gwandu formation northwestern Nigeria. The present study was aim to measure and characterize the concentration of radioactive anomalies using radiometric and geochemical measurements. Uranium (U), Thorium (Th), and Potassium (%K) as well as the total count (TOT) gamma-ray concentration was measured with a portable Gamma-ray spectrometer. The results of the gamma-ray measurements shows spatial distribution plots of different levels of radioactivity over the studied area, which reflect contrasting radioelements contents for exposures to various rock types. The phase identification of marine soil sediment samples was determined from Atomic Absorption Spectrometry (AAS). While the study has shown the correlation plots of various trace elements versus radioelements concentration as well as the total concentration of some profiles of the study area. This study identified the need for the interpretation of geochemical data in this location to confirm the results obtained are meaningful. The study has also revealed the computed mean and standard deviation for trace elements analysis for ease assessment. For radioelements occurrences, the spatial distribution plots of activity of uranium (eU), thorium (eTh), and (K %) give an indication where high concentrations of thorium and uranium occur.

Keywords: Marine deposits; radiometric measurements; geochemical analysis; Arewa-Jantulu.

Introduction

Exploration for uranium, thorium, potash, and manganese at this time can be seen as a magnitude that can settle into the immense economic benefit to the host community and the country at large. These minerals have transformed the economic

landscape of many host countries and they can be mined to contribute significantly to the Nigerian economy. Despite the fact that we have some geoscience data on minerals, we are still heavily reliant on work done 30 to 50 years ago to assess

Corresponding Author: Adamu Abubakar

Department of Applied Geophysics, Federal University Birnin Kebbi Nigeria

Email: adamu.abubakar35@fubk.edu.ng



our reserve potential. There is the need to provide recent and more detailed investment-grade data to support investors. Data integration assessment of Solid mineral deposits in Nigeria will help diversify the economy into the rich mineral sector which will in no time accelerate the recovery of the Nigerian economy which has hitherto been stressed by dwindling revenue from oil. The sedimentary basin of northwestern Nigeria consists predominantly of a gentle Undulating plain with an average elevation varying from 250 to 400 meters above sea level. (Abdulganiyu, 2021; Obaje *et al.*, 2013; Kogbe, 1979). This monotonous plain is occasionally interrupted by steep-sided, flat-topped hills. A low escapement, which was named the “Dange Scarp” by earlier workers, is the most prominent feature in the basin and is closely related to the geology (Abdulganiyu, 2021; Obaje, 2013; Kogbe, 1979). The area to the east of this escapement consists predominantly of a gently undulating, sandy plain, which extends southwestwards to the basement complex boundary. The escarpment itself has undergone intensive erosion. The edge is marked with a high drainage density indicating active stream dissection resulting in deeply incised ravines with numerous mesas and outliers scattered on the plains to the east. The best outcrops of the Paleocene strata are confined to the face of the escarpment, the slope of its out liars and to the gentle dip slope facing westwards. The escarpment retain a marked NNE-SSW trend which appear parallels to the regional strike. In addition to the escarpments described above, numerous outliers and remnants of the Gwandu formation occur as tabular hills or low hummocks over the dip slope of the formations. The use of gamma ray spectrometry as a tool for geological mapping, environmental monitoring and exploring radioelement concentrations has found widespread acceptance over several decades and continues to be developed (Adamu & Ahmed, 2019; Ahmad, 2017; Henry & Jose-Maria, 2017; IAEA, 2010; Taufiq *et al.*, 2020). The radiometric Surveys

detect and map natural radioactive emissions (γ -ray) from rocks and soils. The gamma radiation takes place from the natural decay of elements like U, Th, and K. The radiometric method is capable of detecting these elements at the surface of the ground. The common radioactive minerals are uraninite (^{238}U), Monazite, Thorianite (^{232}Th), rubidium (^{87}Rb) in granite-pegmatite, Feldspars (^{40}K), Muscovite, Sylvite in acid igneous rocks, and radiocarbon (^{14}C) (Ademila *et al.*, 2018; Massimo *et al.*, 2010; Telford *et al.*, 1975). The objective of the present research work was to investigate and characterize the radioactive anomalies of marine sediments using ground radiometric and geochemical analysis in the Arewa-Jantulu area of Gwandu formation northwestern Nigeria.

Geology of the Study Area

The study area is well-drained by the Argungu River, Takalau, and other numerous branches flowing the north. The vegetation of the study area is of the tropical Sahel-Sudan savannah and the climate can be characterized by distinct wet and dry seasons. The study area is situated within the Gwandu Formation in Sokoto Basin. A basin is a sedimentary unit on the continental margin of the Iullemeden Basin, it extends from the major depo-centers in Niger Republic (Abdulganiyu, 2021; Obaje *et al.*, 2013; Kogbe, 1981). The geological map of the study area is presented in (Fig. 2). The Gwandu Formation Throughout the sedimentary basin of north-western Nigeria, the Tertiary marine sediments of the Sokoto Group are overlain disconformably by a thick series of deposits consisting predominantly of red and mottled massive clays, with sandstone intercalations. These sediments belong to the Gwandu Formation, with the type section and the type area in the Gwandu Emirate of northern Nigeria (Abdulganiyu, 2021; Obaje *et al.*, 2013; Kogbe, 1981). Outcrops of the formation cover almost 22,000 km² in north- western Nigeria. It contains a number of prominent ridges and groups

of flat-topped, steep-sided hills capped by ironstone. Other hills covered with ironstone debris occur in all stages of disintegration, rising out of the sandy plain over which the products of erosion have been distributed. The non-marine origin of the Gwandu Formation is certain, and the sediments can be correctly attributed to a continental environment, or more precisely, to a lacustrine environment (Adamu *et al.*, 2019; Obaje, 2009; Kogbe, 1976, 1978, 1979; Peters, 1976). The best outcrops of the Gwandu Formation occur around Birnin-Kebbi and Argungu. The sediments consist of massive white clays interbedded with coarse and medium-grained red sandstones and mudstones with occasional peat bands. The type section proposed for the formation by Kogbe (1979) shows the typical lithologic characteristic of the formation. Beneath the lateritic capping is a hard ferruginous sandstone layer which is easily eroded into a network of gullies. These are underlain by red sandy clays and white massive mudstones, which are invariably, stained pale brown or pink. The mudstone with sandstone intercalations extends monotonously throughout the sections. Also, similar sections of the Gwandu Formation occur on the slopes of the Gwandu outliers within the Kalambaina Formation on the outskirts of Sokoto Township near the cement factory. The sands at the surface are quite red in colour, often showing colour banding and poor stratification. The mudstones often show a nodular structure with nodules suggestive of local turbulence in the depositional environment. By correlation with palynomorphs from tropical Tertiary deposits earlier mentioned, the age of the Gwandu Formation was tentatively put as Eocene-Miocene (Adamu *et al.*, 2019; Obaje, 2009; Kogbe, 1976, 1978, 1981; Kogbe *et al.*, 1972b; Peters, 1976).

Page | 4222

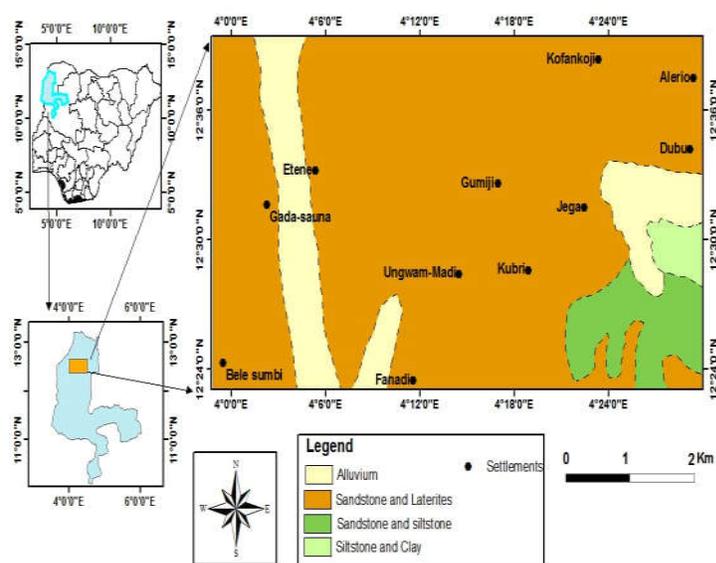


Figure 1: Geological map of the Study Area (Modified after Obaje, 2009)

Materials and Methods

Field Procedure and Data Collection

The study area is located in Arewa-Jantulu of Dendi Local Government Area of Kebbi State. It lies within latitudes 12° 24' N and 12° 36' N longitudes 4° 00'E and 4° 24' E and with an average elevation of 240 m above mean sea level. Argungu-Arewa and Duku-Makera are the closest major towns to the study area (Fig. 2) (Abdulganiyu, 2021; Obaje *et al.*, 2013; Kogbe, 1981). A detailed gamma-ray spectrometric survey of the study area was carried out. This involves taking readings, on the surface on a square grid of 20 m intervals. A total of 400 m by 400 m was covered. Ten profiles were established at the interval of 20 m each in the study area. The readings include total gamma activity due to the equivalent radioelements eU, eTh, and ^{40}K as well as total count (TOT count) at each station. The gamma activity was recorded with a *Sim-Max - G 411* portable field gamma-ray spectrometer. The procedure for taking readings involved placing the spectrometer on the ground at each station and readings were taken for each window. The acquired eU (ppm), eTh (ppm) and K (%) data were therefore

computed and plotted through Microsoft Excel to determine their respective profile signatures. Figure 2 shows the location and distribution of profile lines respectively. These maps give foresight thoughts to what the results of the study area would be based on the distribution of ^{238}U and ^{234}Th in the country with known geology. As discussed earlier in the method of data collection, treatment of data to obtain element concentration from counts was also detailed in the same section (after Adamu *et al.*, 2020). As sequel to the aforementioned above the results obtained is analyzed to characterize the spatial distribution of radioelements uranium (U), thorium (Th), and potassium (K %) occurrence in the area of study. Soil samples were collected from 5 cm deep in the study area. Twenty (20) samples were collected and analyzed for their uranium (U), thorium (Th) content, and other elements commonly associated with, Iron (Fe), Silicon (Si), Copper (Cu) Chromium (Cr), Aluminum (Al), Nickel (Ni), Zinc (Zn) and Magnesium (Mn) content of the samples and other elements was determined.

Sample Preparation

Twenty (20) samples were collected and analyzed for their elemental concentration commonly associated with heavy metal, Fe, Mn, Cu, Ni, Si, Al, Zn and Cr contents. The samples were dried at 40°C, then homogenized, quartered and passed through a 180 μm plastic sieve. Representative 0.5 g subsamples were digested with a mixture of $\text{HNO}_3 + \text{HClO}_4 + \text{HF}$. Solutions were analyzed for Zn, Ni, Co, Cr, and Cu using Atomic Absorption Spectrometry (Perkin-Elmer 2380, air-acetylene flame). The 20 collected soil samples were ground in a mechanical agate grinder until fine particles (< 200 μm) were obtained for the analysis by means of the acid digestion method (Kelly, 2010; Abbey, 1968, 1972). About 0.250 g of the soil samples were weighed and placed into Pyrex test tubes. Concentrated nitric acid (4.0 ml) and 1.0 ml concentrated perchloric acid were added. The mixtures were heated in an aluminum block until

complete dryness. After the test tubes were cool, 5% (0.8M) nitric acid was added and heated at 60°C for 1 h with occasional mixing. Upon cooling, the mixtures were decanted into polyethylene tubes and centrifuged at 3500 rpm for 10 min. Heavy metal concentrations of the solutions were measured using Atomic Absorption Spectrometry (AAS). Atomic absorption spectrometry (AAS) is an analytical technique that measures the concentrations of elements. Atomic absorption is so sensitive that it can measure down to parts per billion of a gram (μgdm^{-3}) in a sample (Angino and Billings, 1972; Kelly, 2010). The technique makes use of the wavelengths of light specifically absorbed by an element. They correspond to the energies needed to promote electrons from one energy level to another, higher-energy level.

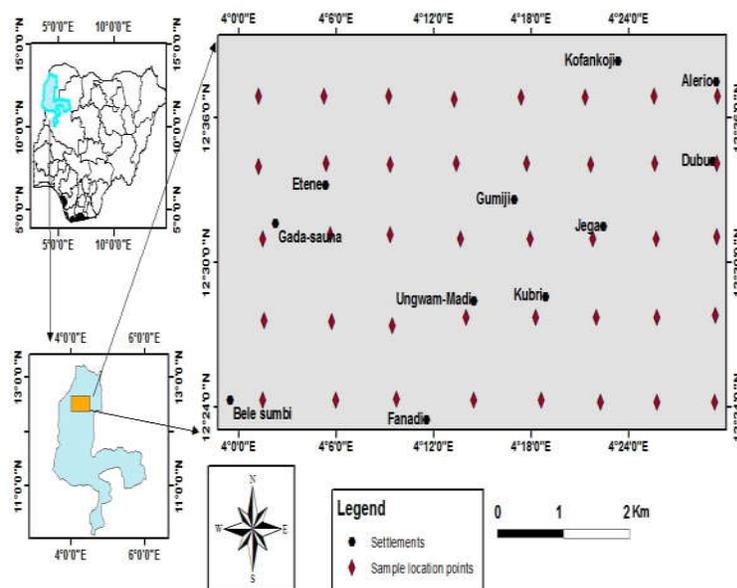


Figure 1: Location map of the Study Area (Adopted from Google Earth, 2018)

Results and Discussion

Radiometric Data Analysis

The activity concentrations of equivalent uranium, eU, thorium, eTh, Potassium (%K) and *TOT* count

determined from the spectrometer readings were plotted based on histogram spatial distribution and scattered concentrations (Figures. 3, 4, 5, 6 & 7) in order to actually characterize the anomaly considered in terms of its radioelement's contents.

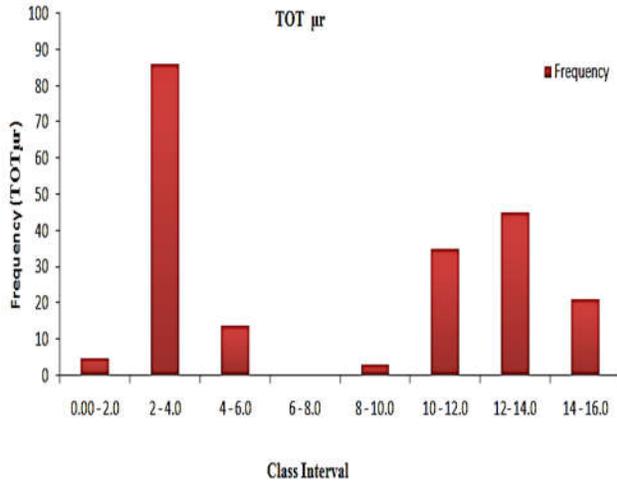


Figure 3: Spatial distribution for total count (TOT) of gamma activity concentration contents

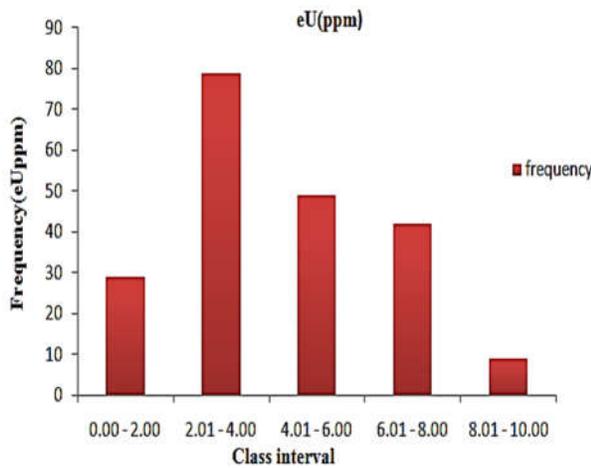


Figure 4: Spatial distribution for eU (ppm) of gamma activity concentration contents

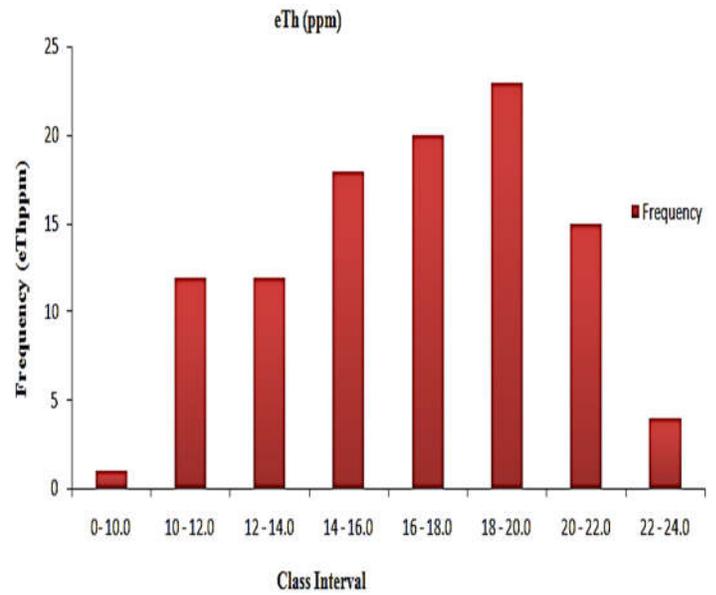


Figure 5: Spatial distribution for eTh (ppm) of gamma activity concentration contents

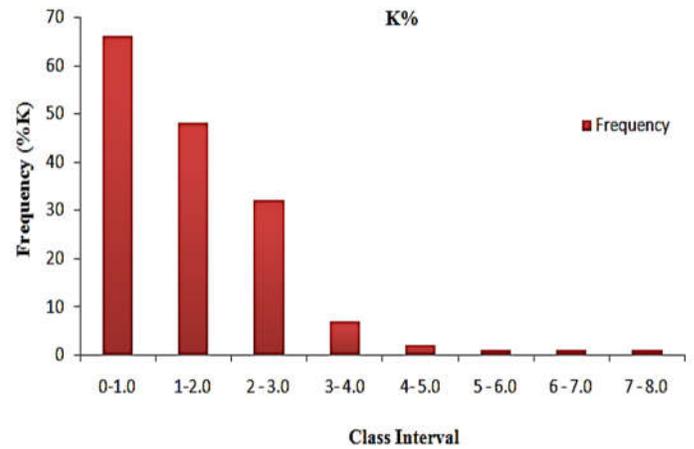


Figure 6: Spatial distribution for potassium (K %) of gamma activity concentration contents

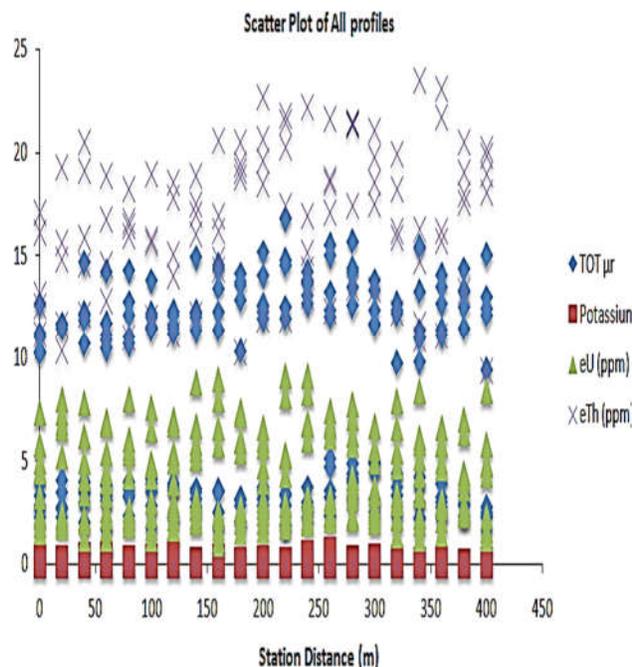


Figure 7: Scattered plot concentration of radioelements and total count for all profiles

Geochemical Analysis

The summary of the composition of elemental concentration of major elements (%) determined specifically, Fe, Mn, Si, Cr, Al, Cu, Ni, and Zn as well as other radioelements (ppm) in the clay of sites 1 and 2 are presented in Table 1 and 2. As reported by (Adewole *et al.*, 2020; Yang *et al.*, 2007; Zhang *et al.*, 2011; Mohammed *et al.*, 2011), SiO₂ was the most abundant major oxide in the clays varying between 63.22 - 67.90% (avg. 66.11%) in banded gneiss derived clay, 51.91-55.46% (avg. 53.17%) and 38.6 - 46.03 % (avg. 42.12 %) in sedimentary clay. Iron (Fe) was the major abundant in concentrations with a significant high value of 2500.3 (ppm) (average of 1664.75 ppm). The trace elements Fe, Mn, is relatively high in weathered lateritic clay (2500.3 ppm, 183.1 ppm), Cu is relatively high in Kaolinitic-clay from Red molted Iron with (224.3 ppm) but relatively low in sediments from sedimentary rock (168.25 ppm). Zn are 90.3 ppm and 38 ppm in weathered lateritic soil and sandy-clay, respectively. The

average concentrations of various trace elements in the soils derived from laterite deposits, clay deposits as well as Kaolinitic are 379.5 ppm and 116.5 ppm. Trace elements such as Cu, Zn, Si, Fe, and Mn were observed to be enriched in the sedimentary clays (Petters, 1976; Taylor, 1966, 1968; Kelly, 2010).

Table 1. Elemental concentration of Site A

S/N	Fe	Mn	Si	Cr	Al	Cu	Ni	Zn
1	946.1	62.6	40.1	50	10.2	112.2	20.3	38
2	1225.1	35.3	50.2	96	126	200.1	86.5	90.3
3	1320.5	41.1	151.3	118.2	64.1	187.5	20.8	77.4
4	829.2	26.5	79.8	60.5	20.7	224.3	36.2	81.4
5	2500.3	183.1	220.3	69.3	88.3	167.2	91.2	50.3
Min	829.2	26.5	40.1	50	10.2	112.2	20.3	38
Max	2500.3	183.1	220.3	118.2	126	224.3	91.2	90.3
Mean	1664.75	104.8	130.2	84.1	68.1	168.25	55.75	64.15
SD	359.325	21.1	45.05	17.05	28.95	28.025	17.725	13.075

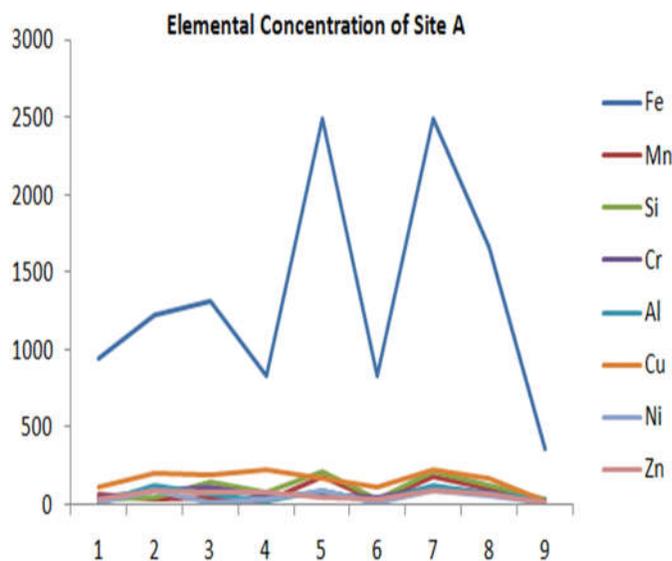


Figure 8: Spatial distribution plot of Elemental Concentrations of trace elements for site A

Table 2: Elemental concentrations of site B

S/N	Fe	Mn	Si	Cr	Al	Cu	Ni	Zn
1	2056.9	496.1	56.1	26.3	47	150.6	56.2	22
2	2138.1	670.3	33.2	113.6	56.1	116.4	33.1	110.1
3	1066.3	88.7	190.1	180.2	80	59.3	40.7	84.2
4	1692.1	180.2	44.04	232.3	10.3	60.86	20.8	141.4
5	2500.3	260.1	120.3	44.1	27.5	112.2	17.1	10.3
Min	1066.3	88.7	33.2	26.3	10.3	59.3	17.1	10.3
Max	2500.3	670.3	190.1	232.3	80	150.6	56.2	141.4
Mean	1783.3	379.5	111.65	129.3	45.15	104.95	36.65	75.85
SD	136.8	58.3	27.775	51.5	0.925	22.825	9.775	26.925

Correlation between Radioelements and Heavy metals Concentrations

In a geochemical measurements, it's unusual to analyze only a single element in a given set of samples. More likely, the correlation between the concentrations of radioelements and trace elements determined for a number contents. Since certain groups of elements respond more or less similarly to a given set of environmental conditions, it follows that mutual correlations between different elements serve to identify more clearly the variations present in the geophysical and geochemical landscape. Associations of some elements may lead directly to an interpretation of the type of deposit likely to be present in the area. As reported from the investigation the correlation between the uranium, thorium and the iron (Fe) contents observed statistically significant correlation in uranium-iron contents between the two different media. The correlation coefficient was 0.62, the spatial association is shown in (Fig. 10 (a - n)).

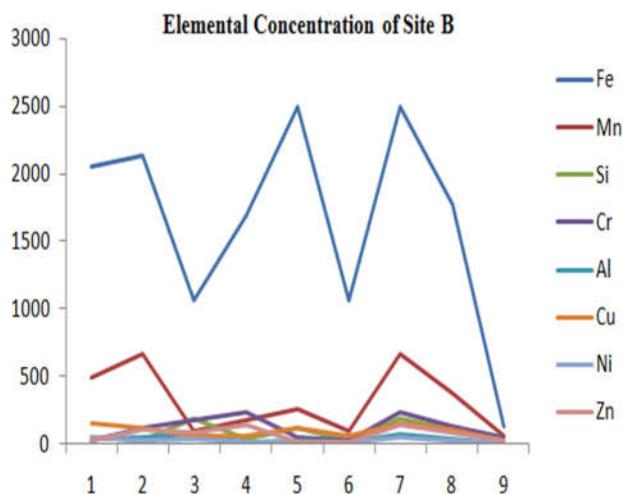
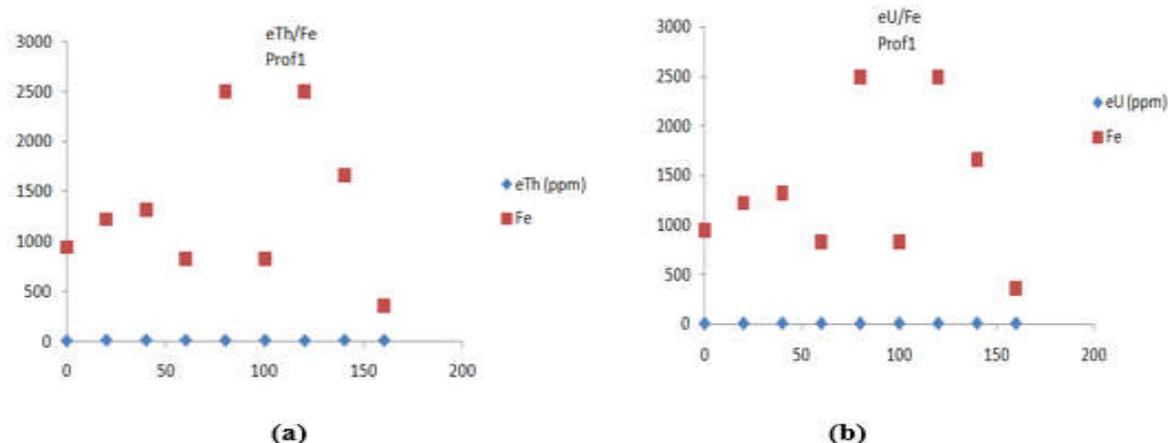
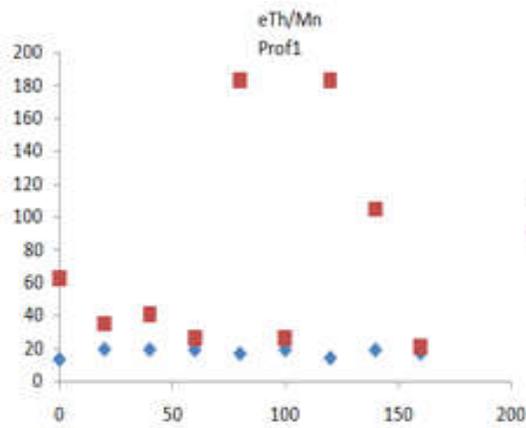
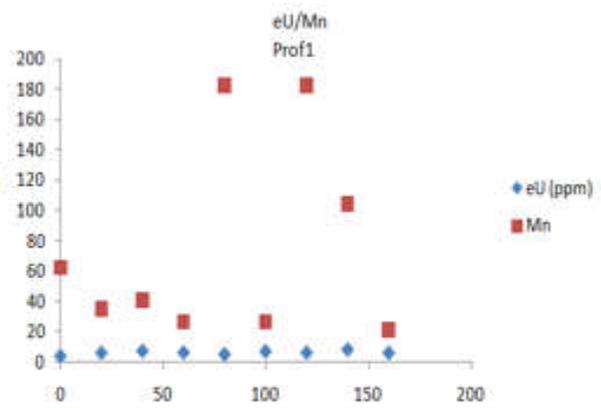


Figure 9: A plot of Elemental Concentrations of trace elements for site B

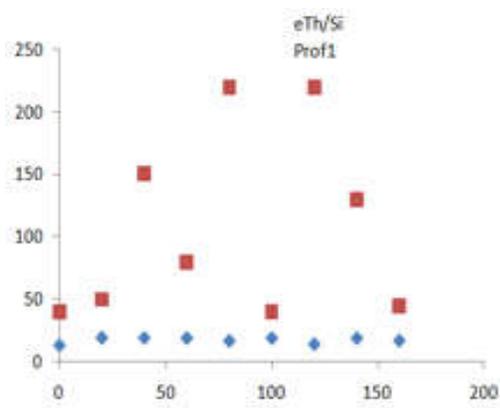




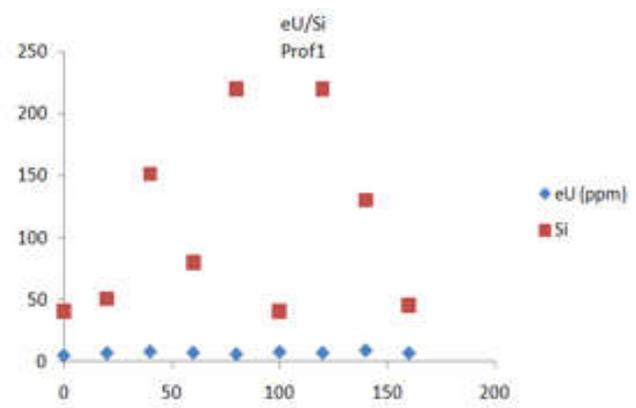
(c)



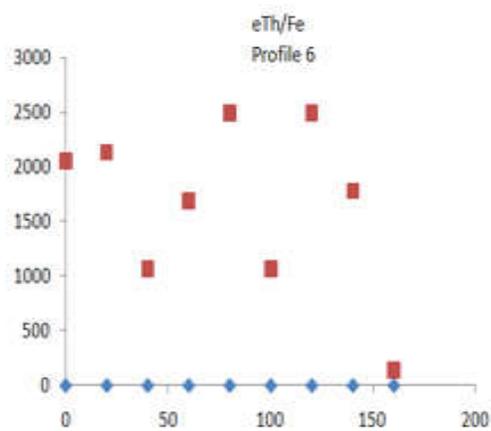
(d)



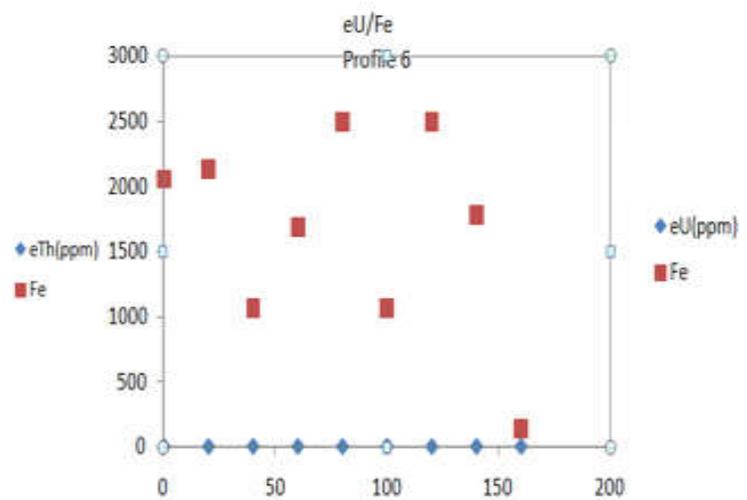
(e)



(f)



(g)



(h)

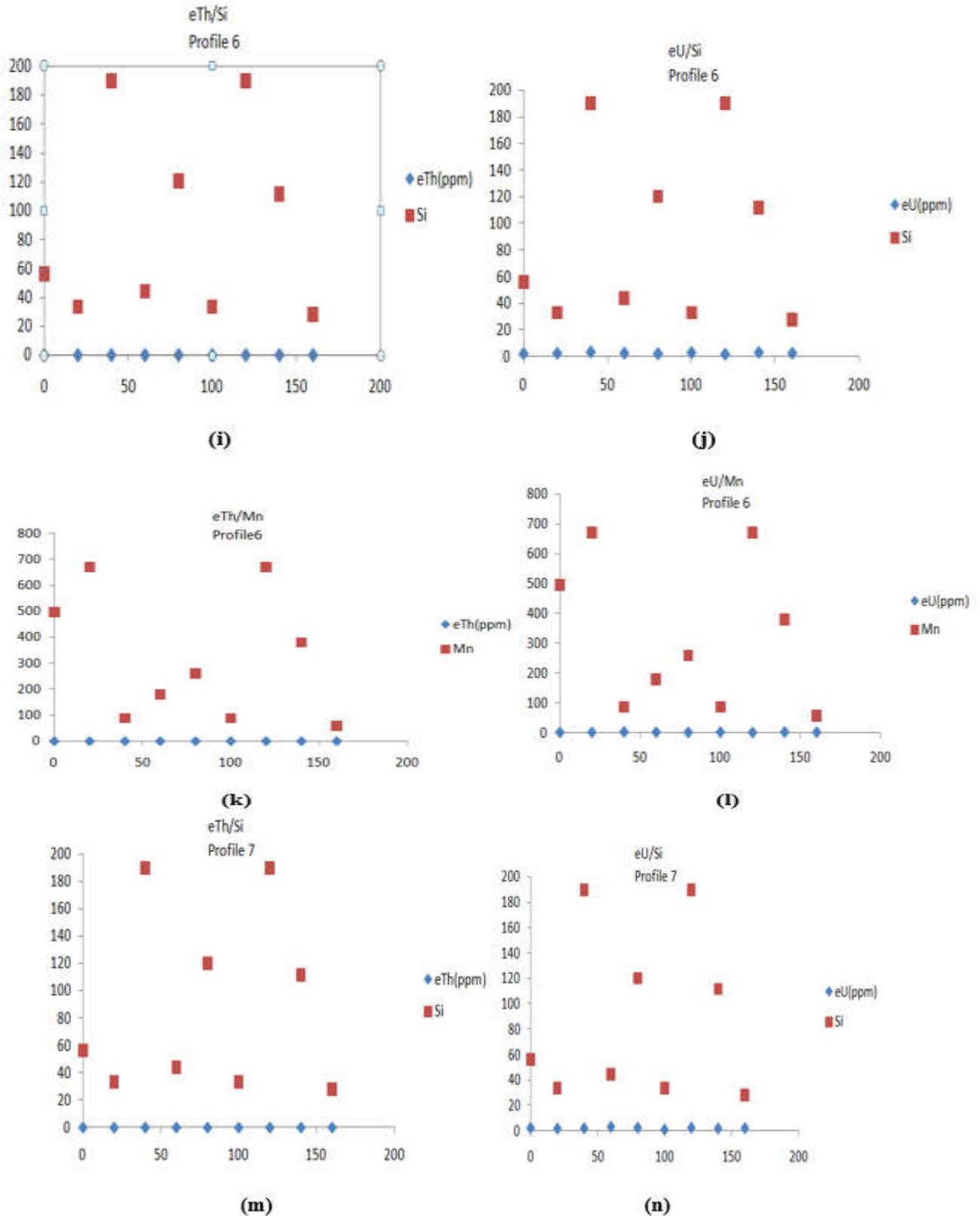


Figure 10 (a – n): Correlation plots of radioelements with trace elements contents of clay soil sediments in some profiles of the study area.

Conclusions

This study has shown that radiometric and geochemical measurements can be used to identify and analyze anomalous concentrations for both radioelements (U, Th, K %) as well as trace elements (Fe, Mn, Cu, Zn, Si, Ni, Cr and Al). The distribution of toxic elements such as Uranium and Chromium were clearly shown as capture in (table 1 & 2). Although the study has shown the correlation plots of trace elements versus radioelements concentration as well as the total concentration within the various profiles of the study area. This study identified the need for the interpretation of geochemical data in a geological setting to ensure the results obtained are meaningful. The study has shown that the data point for trace elements based on their mean and standard deviation within the geological settings display the geochemical analysis in the best way. For the analysis of radioelements occurrences, the spatial distribution plots of uranium (eU), thorium (eTh) and (K %) give an indication of high activity concentration of thorium and uranium were present.

Recommendation

The survey data can be used in conjunction with other factors of mineral deposits in the Gwandu formation of Sokoto Basin in a GIS based analysis of mineral prospectively. Further methods can be carried out for Baseline geochemical mapping for regolith and surficial sediments.

Acknowledgments

The authors are grateful to the Department of Applied Geophysics, Federal University Birnin Kebbi, for allowing us to use their equipment for data collection.

Conflict of interests

The authors declare that they have no conflict of interest.

References

- Abdulganiyu, Y., (2021). Stratigraphy and Sedimentology of Maastrichtian to Palaeocene Stratigraphic Succession of Gada Sheet4, Sokoto Sheet 10 and Rabah Sheet 11 South-western Sector of Iullemeden (Sokoto) Basin Northwestern Nigeria. *Unpublished Ph.D thesis*, Department of Geology, Ahmadu Bello University Zaria, Nigeria.
- Abbey, S. (1968). Analysis of rocks and minerals by atomic absorption spectroscopy. *Geol. Surv. Canada Paper* 68-20.
- Abbey, S. (1972). "Standard samples" of silicate rocks and minerals – a review and compilation. *Geol. Surv. Canada Paper* 72-30.
- Adewole, J.A., Adeyemi, M.O., and Omojola, D.I. (2020). Geochemical and Mineralogical Characteristics of Clay deposits at Ijesha-Ijebu and its Environs, Southwestern Nigeria. *Global Journal of Pure and Applied Sciences*, Vol. 26 (1) pp 119 – 130. DOI: <https://dx.doi.org/10.4314/gjpas.V26i2.4>, www.globaljournalseries.com.
- Ademila, O., Akingboye, A.S., and Ojanomi, A.I. (2018). Radiometric Survey in Geological Mapping of parts of Basement Complex Area of Nigeria. *Vietnam Journal of Earth Sciences*, 40(3), 288-298, Doi: 10.15625/0866-7187/40/3/12619.
- Adamu, A., Ologe, O., Ahmed, A.L., and Sunusi, A.Y. (2020). Characterization for Radioelements over an Escarpment Feature(s): A Case Study of the Duku-Tarasa Gwandu Ridge Area of Birnin Kebbi NW Nigeria. *International Journal of Geosciences*, 11, 529-543. <https://doi.org/10.426/ijg.2020.118028>.

- Adamu, A., and Ahmed, A.L. (2019). Investigation on Radioelements Occurrences in Rocks within the Northwest, Nigeria. *Global Journal of Pure and Applied Sciences*, 25, 167-174. <http://www.globaljournalseries.com>, <https://doi.org/10.4314/gjpas.v25i2.6>
- Ahmad, M.A. (2017). Ground Gamma-ray Spectrometric studies of El-Sahu Area, Southwestern Sinai, Egypt. *NRIAG Journal of Astronomy and Geophysics*. www.elsevier.com/locate/nrjag. ScienceDirect; Vol. (6), pp 361 – 367.
- Angino, E.E., and Billings, G.K. (1972). *Atomic Absorption Spectroscopy in Geology* (2nd edition). Elsevier.
- Henry, M.M., and Jose-Maria, J.M. (2017). Magnetic and Radiometric Signatures in Soils above Hydrocarbon Accumulation, Toqui and Mana Fields Tolima, Colombia. Extended Abstract Based on Oral Presentation given at AAPG International Conference and Exhibition, Bcelona Spain, 3-6th April, 2016.
- International Atomic Energy Agency (IAEA), (2010). Radioelement Mapping. IAEA Nuclear Energy Series, No. NF-T-1.3, Vienna, Austria; 108p.
- Kelly, S.D., (2010). Uranium Chemistry in Soils and Sediments, Synchrotron-Based Techniques in Soils and Sediments: Elsevier, Argonne, Illinois, p.411-466.
- Kogbe, C.A. (1979). Geology of Southeastern Portion of the Iullemeden Basin (Sokoto Basin), *Bull. Dept. Geology*, Ahmadu Bello University, Zaria, Nigeria, 2, 420p.
- Kogbe, C.A. (1981). Cretaceous and Tertiary of the Iullemeden Basin in Nigeria (West Africa), *Cretaceous Research* 2, 129-186p.
- Kogbe, C.A., (1978). Geology of the Northwestern Nigeria Basin (a review) (1974) *Geology of Nigeria*, Kogbe C.A. (Ed.) Elizabethan Publishing Co. pp. 331 – 338.
- Kogbe, C.A., LE Calvez, Y., Mehes, K., and Grekoff, N., (1972b). Microbiostratigraphy of Lower Tertiary Sediments from the Southeastern Flank of the Iullemeden Basin (N.W. Nigeria), *Proc. Vth African Micropal. Coll. Addis Ababa and Revista Espanola de Micropaleontologia*, ser.7, no. 3, pp. 523 – 538.
- Li, X., and Thornton, I. (1993). Arsenic, antimony and bismuth in soil and pasture herbage in some old metalliferous mining areas in England. *Environ. Geoch. and Health*, 15, 135-144.
- Lu, S. G. and Bai, S. Q. (2012). Study on the correlation of magnetic properties and heavy metals content in urban soils of Hangzhou City, China. *J. App. Geophys.*, 60, 1–12.
- Mohamed, E.B., Mohamed, S., Ahmed, B., and Samir, N. (2011). Heavy metal pollution and soil of Beni Mellal City (Morocco), *Environ Earth Sci* (Berlin: Springer) 2011 <https://doi.org/10.1007/s12665-011-1215-5>.
- Obaje, N.G. (2009). *Geology and mineral resources of Nigeria: Lecture Notes in Earth Sciences*, Springer, Berlin Heidelberg.
- Peters, S., (1976). The Marine Maastrichtian and Paleocene Sediments (of northwestern Nigeria) – The Dukamaje Formation and the Sokoto Group. *Geological Guide to Some Nigerian Cretaceous-Recent Localities: 7th African Micropal. Coll. Ile-Ife, Nigeria*, pp. 75-87.

- Taufiq, S, Nneka, O.F., Daniel, O.N., Sani, T.U. (2020). Review of Combined Magnetic and Radiometric Methods of Geophysical Survey in Nigeria. *Int J Earth Sci Geophys* 6:032
- Tauson, L.V., and Kozlov, V.D. (1973). Distribution functions and ratios of trace-element concentrations as estimators of the ore-bearing potential of granites. *Geochemical Exploration 1972*, pp. 37 – 44. IMM. London.
- Tauson, L.V., Ovchinnikov, L.N., Polikarpochkin, V.V., and Grigoryan, S.V. (1971). The use and development of geochemical prospecting methods for ore-deposits in the U.S.S.R. *Geochemical Exploration. CIM Spec. Vol. 11*, pp. 42 – 43. IMM. London.
- Taylor, R.M., and McKenzie, R.M. (1966). The association of trace elements with manganese minerals in Australian soils. *Austral. J. Soil Res.* 4, 29 – 39.
- Taylor, R.M. (1968). The association of manganese and cobalt in soils – further observations. *J. Soil Sci.* 19, 77-80.
- Timperly, M.H., Brooks, R.R., and Peterson, P.J. (1970). Prospecting for copper and nickel in New Zealand by statistical analysis of biogeochemical data. *Econ. Geol.* 65, 505 – 510.
- Tissot, B., Califet-Debyser, Y., Deroo, G., and Oudin, J.L. (1971). Origin and evolution of hydrocarbons in early Toarcian shales, Paris basin, France. *Amer. Assoc. Petrol. Geol. Bull.* 55, 2177 – 2193.
- Wang, X. S. and Qin, Y. (2005). Correlation between magnetic susceptibility and heavy metal in urban topsoil: a case study from the city of Xuzhou, China. *Environ. Geol.*, 49, 10-18.
- Yang, T., Liu, Q., Chan, L., and Cao, G. (2007). Magnetic investigation of heavy metals contamination in urban topsoils around the East Lake, Wuhan, China. *Geophys. J. Int.* 171:603–12.
- Zhang, C.X., Qiao, Q.Q., Piper, J.D.A. & Huang, B.C., (2011). Assessment of heavy metal pollution from a Fe-smelting plant in urban river sediments using environmental magnetic and geochemical methods, *Environ. Pollut*, 159, 3057–3070.