International Journal of Advances in Engineering and Management (IJAEM)
Volume 4, Issue 11 Nov. 2022, pp: 206-217 www.ijaem.net ISSN: 2395-5252

Assesement of Hydrocarbon Potentials of Sokoto Basin using Airborne Radiometric Data by Thorium Normalisation method.

A. Jimoh[1], D.S. Bonde,[1]

1. Department of Physics, Faculty of physical Sciences, Kebbi State University of Science And Technology,Aleiro Kebbi State, Nigeria

Submitted: 01-11-2022 Accepted: 12-11-2022

ABSTRACT

A new exploration method, called Thorium Normalization Method used in exploring petroleum potentials in stratigraphic and structural traps in sedimentary basins was applied in Sokoto Basin Northwestern Nigeria.TheThorium Normalization technique is oriented towards suppressing the influence of the regional signatures. The separation of the radio spectrometric measurements over each lithologic unit and estimation of the characteristic statistics of these units were carried out. The analysis revealed the concentrations distribution patterns of primary radioelements: potassium (K), Thorium (eTh) and Uranium (eU) of the study area and this has shown a relatively low coefficient of variability (CV%) values for K, eTh and eU signify their high degree of homogeneity. The mean value of the radioelements (K ranging from 0.3 to 1.4%; Th ranging from 7.0 to 11.5 ppm and U ranging from 1.6 to 2.6 ppm) were

obtained from the statistical analysis correlates with the mean of natural radioelement (K ranging from 0.1 to 2.7 %; Th ranging from 0.4 to 11.2 ppm and U ranging from 0.1 to 3.7 ppm) content of sedimentary rocks which corresponds to shale, the main source rock for hydrocarbon accumulation in the study area. The DRAD (delineation of radioactive anomalies) results ranges from -1.1 to 2.6%. The positive DRAD values are indicators of favourable zones for the presence of hydrocarbon accumulations. Ten probable zones are identified and mapped over the study area grace to the application of the thorium normalization technique that might indicate a prospective possibility for feasible subsurface hydrocarbon accumulations and oil-bearing pay zones in Sokoto Basin.

Keywords: Airborne radiometric data, Sokoto basin, Hydrocasrbon accumulation, DRAD, Homogeneity, Radioelements.

I. INTRODUCTION

The Sokoto Basin is one of the Nigeria sedimentary Basins that is tectonically and paleogeographically related. It consists predominantly of a gently undulating plain with an average elevation varying from 250 to 400 m above sea-level. This plain is occasionally interrupted by low mesas. A low escarpment, known as the “Dange Scarp” is the most prominent feature in the basin and it is closely related to the geology. The study area is bounded by longitudes 4.00^0E to 7.00^0E and latitudes 12.00^0N to 13.50^0N in the Northwestern Nigeria.

The Sokoto Basin is the Nigerian sector of the larger Iullemmeden Basin. The Iullemmeden Basin itself is a broader sedimentary basin covering a part from north-western Nigeria, most parts of Niger Republic, Benin, Mali, Algeria and Libya with the major depocentres situated in Niger Republic. The Sokoto sector is an out-baying marginal basin with reducing sediment thickness and stratigraphic age from the thickest and oldest in Niger Republic while youngling towards Nigeria.

The search for hydrocarbon (oil and gas) in the Sokoto basin started decades ago and has drawn a lot of attention from different scholars who had used aeromagnetic and gravity data to determine the depth of Sedimentary thicknessfor possible hydrocarbon maturation and accumulation using spectral depth, Source parameter imaging,Wavelet analysis and Euler deconvolution. (Obaje;1987, Kogbe, 1981;Bonde et al.,2014, Ezekiel etal., 2019.).Hydrocarbon deposition in the earth’s crust influences the concentration and distribution of naturally occurring radioactive elements (K, Th and U) at the surface of the earth via combination groundwater, microseepage and electrochemical conventions cells (Walker et al., 2018). The naturally occurring radioactive elements (NOREs) produced beneath the earth manifest on the earth's surface through micro-fractures and microseep (Mazadiego 1994; Schumacher 2000; Yazdi et al. 2016; Bazoobandi et al. 2016; Mollai et al. 2019). Petroleum sources are commonly associated with high natural gamma-ray radiation. This creates an opportunity for the use of airborne radiometric data in the basin to detect areas within area with possible hydrocarbon presence. This study will guide the generation of prospects for potential hydrocarbon drilling in the Sokoto Basin by employing a simplified thorium normalization method. The success of the drilling will increase the number of inland sedimentary basins producing hydrocarbon and petroleum reserves in Nigeria.

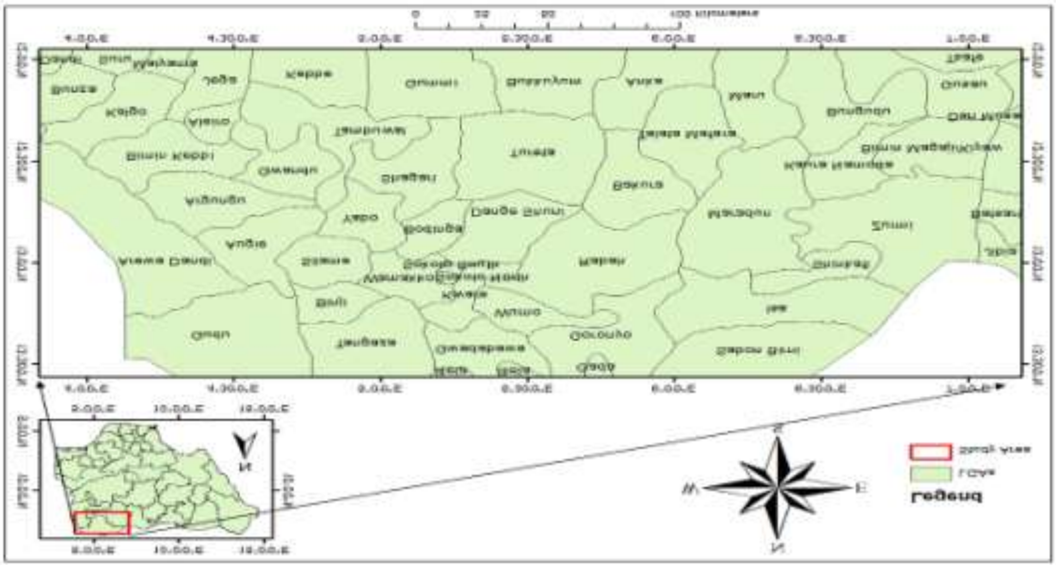

Fig 1. Location Map of the Study Area

The geology of the Sokoto Basin has been greatly explained by different scholars , such as Obaje 1987; Kogbe. 1981; the Sokoto Basin was extensively explained by Obaje et al 2013. The sediments of the Iullemmeden Basin were accumulated during four main phases of deposition. Overlying the Pre-Cambrian Basement unconformably, the Illo and Gundumi Formations, made up of grits and clays, constitute the Pre-Maastrichtian "**Continental Intercalaire**" of West Africa. They are overlain unconformably by the Maastrichtian **Rima Group**, consisting of mudstones and friable sandstones (Taloka and Wurno Formations), separated by the fossiliferous, calcareous and shaley Dukamaje Formation. The Dange and Gamba Formations (mainly shales) separated by the calcareous Kalambaina Formation constitute the Paleocene **Sokoto Group**. The overlying continental Gwandu Formation forms the Eocene **Continental Terminal**. These sediments dip gently and thicken gradually towards the northwest with maximum thicknesses attainable toward the border with Niger Republic.

II. METHOD

Data acquisition

Eighteen (18) half degree by half degree airborne radiometric data were acquired from the Nigerian Geological Survey Agency (NGSA) Abuja. The sheet numbers with their respective locations are; Sheet 8(Sakkwabe), Sheet 9(Binji), sheet 10(Sokoto), Sheet 11(Rabah), sheet 12(Isah), Sheet 13(Shinkafe), sheet 27(Leman), sheet 28(Arugungu), sheet 29(Dange), sheet 30(Gandi), sheet 31(Mafara), sheet 32(Kaura), sheet 49(Birnin Kebbi), sheet 50(Tambuwa), sheet 51(Gunmi), sheet 52(Ankah), sheet 53(Maru), sheet 54(Gusau). The aero-radiometric dataset was obtained as part of the airborne survey carried out between 2005 and 2009 by Fugro on behalf of the Nigerian Geological Survey Agency. The data were obtained at an altitude of 100 m along with a flight line spacing of 500 m oriented in NW-SE and a tie line spacing of 2000 m. The maps are on a scale of 1:100,000 and half-degree sheets.

The following steps were employed to achieve the aim and objectives of this study;

i. Assembling and knitting of the twenty-four aero-radiometric datasheets covering the study area to produce the equivalent concentration maps of Potassium (K), Thorium (eTh) and Uranium (eU) using Oasis Montaj software.

ii. Perform statistical analysis over each lithologic unit and determine the characteristic statistics of these units. The statistical parameters include the arithmetic mean (X), standard deviation (S) and coefficient of variability (CV %) to check the homogeneity and normality of distribution of the analysis for each rock unit.
iii. Determine the relative deviation of Potassium (KD%) and relative deviation of Uranium (eUD%).
iv. Using (iii) to determine DRAD, where DRAD = eUD% - KD%. Where positive DRAD values are favourable indicators for subsurface hydrocarbon accumulations in an area (Saunders et al. 1993; Al-Alfy 2009; Nigm et al. 2018).

2.1. Simplified Thorium Normalisation Method

In delineating radiometric signatures related to hydrocarbon accumulations in sedimentary basins, it is of necessity to develop a model to explain such signatures. Saunders et al. (1993) developed one of the most successful models called the 'Simplified Thorium Normalisation Method'. Saunders et al. (1987) started the use of thorium content as a lithological control to explain 'ideal' potassium and uranium value for samples. The basic assumption of this method arises from the fact that anything done to influence the apparent concentration of equivalent thorium also affects uranium and potassium concentration in the same vein and predictable ways. If hydrocarbons are not present, the radioactive elements (K, Th & U) should be in natural and constant proportions (Saunders et al. 1993; Al-Alfy 2009; Nigm et al. 2018). This method has proven helpful as a guide for delineating hydrocarbon accumulation and has further being used by different researchers as a guide for petroleum exploration (for example, Saunders 1989; El-Sadek 2002; El-Sadek et al. 2007; Al-Alfy 2009; Al-Alfy et al. 2013; Nigm et al. 2018; Skupio and Barberes 2017; Shawn et al. 2018; El-Khadragy et al. 2018; Salazar et al. 2018). Based on previous works, this present study attempts to use this method as a guide for delineating possible hydrocarbon accumulations within the study area of Sokoto basin.

Normalizing the thorium concentration will attenuate the lithological units and also affect the environment. This similarity in behaviour gives room for the use of thorium values to roughly predict the presence of uranium and potassium by determining their general relationships (Saunders et al. 1993). Significant variations between the predicted uranium and potassium concentration and the real values must be responsible for factors than lithology, soil moisture, vegetation or counting geometry. By knowing these secondary effects, possible hydrocarbon accumulation can be delineated (Saunders et al. 1991 and 1993). Adopting the Saunders et al. (1993) procedure, the equivalent concentration of uranium and potassium from the airborne radiometric spectral profiles of the study area can be normalised to the equivalent thorium data from the following; plots were made of the field measure Ks (%) versus Ths (ppm) and eU (pmm) versus Ths (ppm) values for all stations. Thereafter, various linear logarithm and second-order curve fitting procedures were tried and the simplest effective equations (1.0) and (2.0) relating these variables were determined to be linear and passing through the origin. The slopes of the lines were determined by the ratios of the mean K**s (%)** to the mean eThs (ppm), or the mean eUs (ppm) to the mean eThs (ppm). The equations are represented below:

$Ki=(meanKs/meaneTh\ s)eTh\ s$1

$Ui=(meanUs/meaneTh\ s)eTh\ s$2

where Ki is the calculated equivalent thorium defined potassium value from the station with actual thorium value of eThs, and Ui is the calculated equivalent thorium defined equivalent uranium value for that station.

Adopting the approach discussed above, the equations were calculated directly from the data, and quick field evaluations may be made without preparing the plots and restoring to curve fitting. Deviation of the actual values from the calculated values for each station can be obtained from the given equation (Saunders et al. 1993):

$\mathrm{KD}\%=(\mathrm{K}s-Ki)/Ks$3

$\mathrm{eUD}\%=(eUs-eUi)/e$4

Where Ks and eUs are the measured potassium and equivalent uranium values at the station respectively. KD% and eUD% are the relative deviations expressed as a fraction of the station values. From experience, KD% yields small negative values and eUD% yields smaller negative or sometimes positive values over the hydrocarbon accumulations (Saunders et al. 1993). Emphasizing these two relationships, Saunders et al. (1993) defined a new parameter, called DRAD:

$DRAD=eUD\%-KD\%$5

Therefore, positive DRAD values are favourable indicators for subsurface hydrocarbon accumulations in an area (Saunders5 et al. 1993).

2.2. Statistical Evaluation of the Profile Data

A statistical evaluation was applied to the three variables (K, eTh and eU) for each rock unit with respect to the geological map (Fig. 2) of the study area. This statistical evaluation depends solely on the application of the coefficient of variability (CV) as shown in equation (6). For a certain variable in the study area, if the (CV %) is less than 100%, the variables tend to exhibit a normal distribution.

CV %=(SD/X)x106

Where SD is the standard deviation and X is the arithmetic mean.

The lower CV % corresponds to a higher degree of homogeneity. In this present study, the relatively lower values of CV % for K, eTh and eU mean a higher degree of homogeneity.

III. RESULTS

Figs. 4, 5 and 6 are the gamma-ray spectrometric maps that emphasize the nature of the radioelement distribution and are thus suited to the recognition of the geological features within the study area. These maps (K, eTh and eU) are characterized by a high, intermediate and low concentration and also reveal a general relation to the rock units in the study area. Fig 4 shows high concentration of potassium at the southeastern part, southwestern part and the Northeastern part corresponding to Gusau, Tsafe, Bungudu, Maru, Anka, Talata Mafara, Kaura Namoda, Birnin Magaji/Kiyawa,Argungu,Suru,Bunza and Isa respectively. While intermediate concentration at the central, western, northern part and southwestern partcorrespond to Bodinga, Sokoto Yabo, Shagari, Arewa Gandi, Maiyama, Jega and Aleiro respectively. The low concentration occurs in the northern part and northwestern part corresponds to Goronyo, Gudu, Tangaza and Binji respectively. The concentration value of potassium ranges from 0.2 % to 2.2 %. Fig 5 and 6 are the equivalent thorium and Uranium concentration maps respectively. The Fig 5 shows high concentration equivalent thorium at the southeastern part, northeastern part southwestern part, Northeastern part and the Northern part, corresponding to Gusau, Tsafe, Bungudu, Zumi, Maru,Bukkuyum, Anka,Talata Mafara Kaura Namoda, Birnin Magaji/Kiyawa, Jibia, Shinkafi, Suru,Bunza, Jega, Gumi, Aleiro Isa and Tangazia, respectively.While intermediate concentration at the central, eastern, southwestern and the northeastern part corresponds to Bodinga,Tureta, Batsani, Tambuwal and Isa respectively. The low concentration occurs prominently in the northwestern part of the study area which corresponds to Gudu. The concentration value of thorium ranges from 4.3ppm to 17.3ppm respectively.The Fig 6 shows high concentration of the equivalent uranium at the southeastern part, northeastern part, southwestern part, central and northern part corresponds to Bugudu, Talata Mafara, Anka, and Bukkuyum, Gada, Gumi, Bunza, Suru, Kalgo, Jega, Birnin Kebbi,Sokoto, Dange Shuni, Illela and Gwadabawa respectively. While intermediate concentration at the central, eastern, southeastern, northeastern and the northwestern part corresponds to Rabah, Tureta, Batsani, Tsafe, Gusau, Birnin Magaji/Kiyawa respectively. The low concentration occurs in the Binji and

Gudu areas of northwestern part of the study area. The concentration value of uranium ranges from 0.8ppm to 5.2ppm respectively.

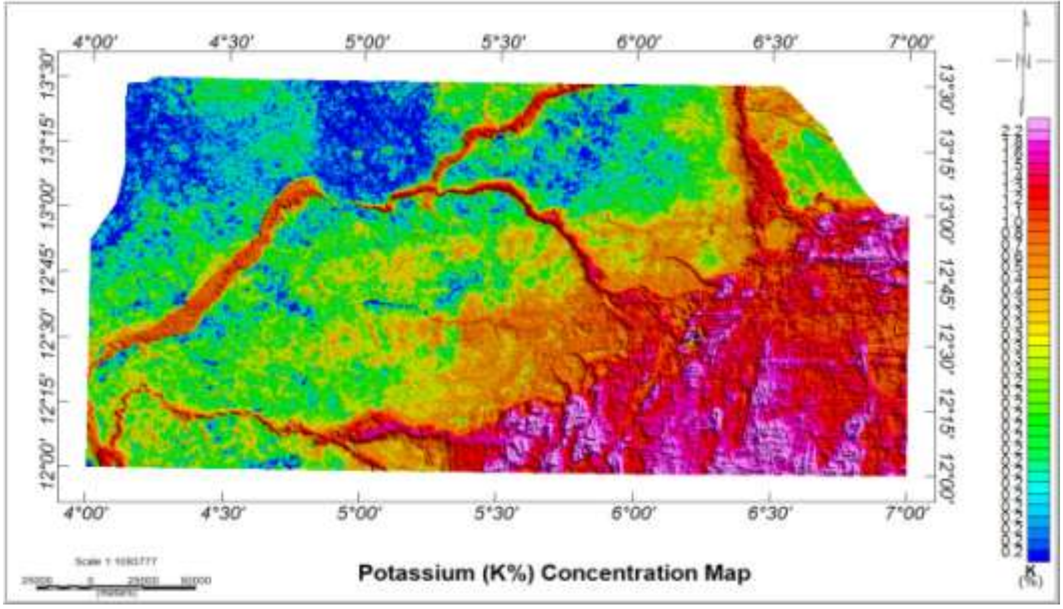

Fig 2. Potassium concentration (K %) map of the study area

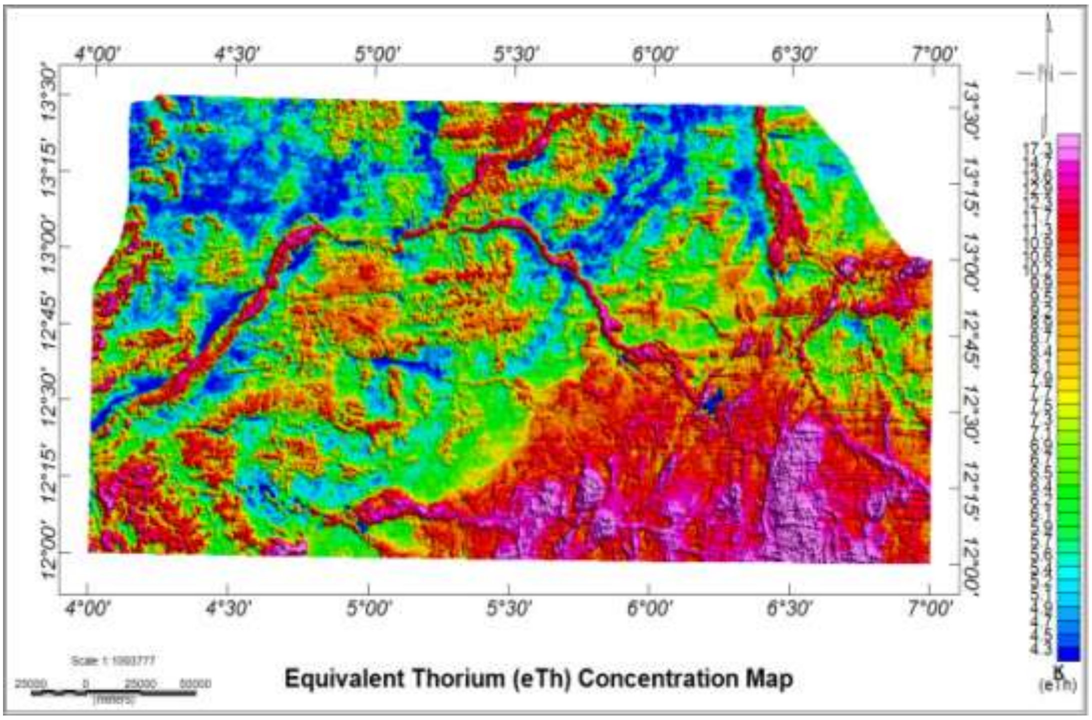

Fig 3. Equivalent Thorium concentration (eTh) map of the study area

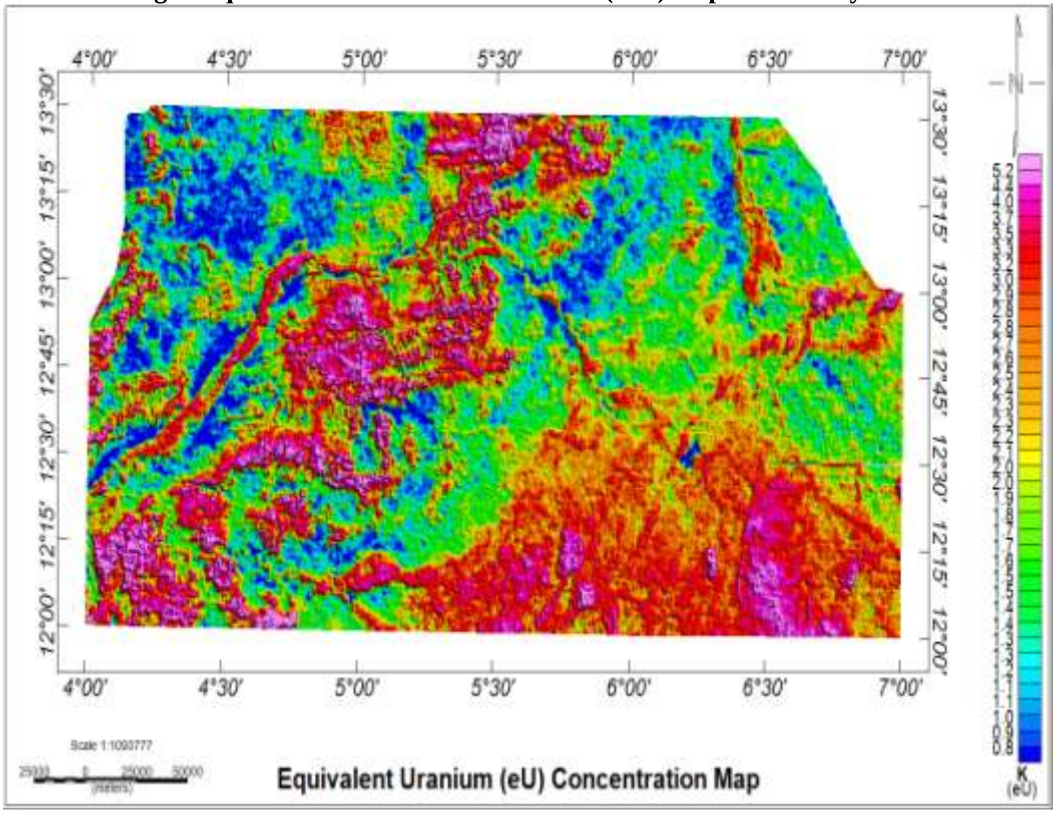

Fig 4. Equivalent Uranium concentration (eU) map of the study area

IV. INTERPRETATION

The quantitative interpretation depends principally upon the fact that, the absolute and relative concentrations of the radioelements (K, eU and eTh) vary measurably and significantly with lithology (Darnley and Ford, 1989). Table 1 summarizes the statistical results of the three variables over the five lithologic units of the study area. The study area comprises of Gwandu, Wurno, Dukamaje, Taloka and Illo/Gundumi formations (Fig 3). Statistical treatments were applied on the airborne gamma-ray spectrometric data in Sokoto Basin to display the distribution features of the K, eU, and eTh. These statistical studies were performed to calculate the minimum, maximum, arithmetic mean (X), standard deviation (S.D.) and coefficient of variability (CV %) which check the normality of each rock unit (CV % = (S.D./X) *100). According to Sarma and Kock (1980), if the (CV %) of a specific rock unit is less than 100%, the unit tends to exhibit a normal distribution. The data treated. Statistically, Table 1shows the results of this analysis.The coefficient of variability (CV %) of the three variables (K, eTh and eU) of each rock unit of the study area is less than 100 % except for Gwandu rock unit (100% in K). So, the rock units tend to normality in their distribution. The The Gwandu rock unit displays the highest values of CV% for the radiometric parameters (K%, eU, and eTh) with valuesof 100, 40.54 and 69.57 respectively, may be due to migration of the radioelements from the surrounding rock units. The relative lower values of CV % for the eTh and eU of other rock units within the study area show a higher degree of homogeneity.

Comparative units of KD%, eUD% and DRAD were plotted after separation and statistical parameters were computed as a minimum, maximum, mean (X), standard deviation (SD), and (X+3SD) for each rock unit to illustrate the typical crossover anomalies over the expected hydrocarbon accumulations (Table 3). A conservative estimate of the statistical parameters is based on the samples derived from the population. The DRAD arithmetic means plus the three standard deviations (X+3δ) reaches 6.0, 1.7, -0.1, 1.6, and 2.9 over the Gwandu formation, Wurno formation, Dukamaje formation, Taloka formation and Illo/Gundumi formation respectively. The grand mean of DRAD (%) representing all the five lithologic units is 2.42. Any DRAD value for these rocks greater than 2.42 possesses a probability of 99.87% representing a valid anomaly that is not caused by random variations in the background values (Saunders 1989 & 1993; El-Sadek 2002; El-Sadek et al. 2007; Al-Alfy 2009; Al-Alfy et al. 2013; Nigm et al. 2018).The KD%, eUD% and DRAD anomaly maps of the study area (Fig 6 -8) reveal the residual KD%, eUD% content and DRAD anomalous zones over the study area (Sokoto Basin). These maps show eleven distinctive anomalies that may be indicative of probable hydrocarbon accumulation zones. According to Saunders(1993), hydrocarbon accumulations arecharacterized by negative KD and positive DRAD. These zones are clearly shown on the DRAD anomaly map (Fig 8 and 10). Anomalous values are expressed as positive numbers, where the more positive are the more anomalous. The possible hydrocarbon accumulation zones and their relation with the respective Rock units and their locations and corresponding locations are presented in Table 1.

Rock Type	Rock Units	Geological Ages	Radioelements	Min.	Max.	Mean	S.D	(CV%)
	Gwandu Formation	Eocene	K (%)	0.0	2.6	0.3	0.3	100
			eTh (ppm)	0.7	23.0	7.4	3.0	40.54
			eU (ppm)	-0.6	14.2	2.3	1.6	69.57
	Wurno Formation	Maastrichtian	K (%)	0.1	1.8	0.3	0.2	66.67
			eTh (ppm)	3.4	20.3	6.5	1.8	27.69
			eU (ppm)	0.4	7.3	1.6	0.6	37.50
	Dukamaje Formation	Maastrichtian	K (%)	0.3	4.2	1.4	0.7	50.00

Sedimentary Rock			eTh (ppm)	4.0	33.6	11.5	4.5	39.13
			eU (ppm)	0.3	6.2	2.6	1.0	38.46
	Taloka Formation	Maastrichtian	K (%)	0.1	1.7	0.4	0.2	50.00
			eTh (ppm)	3.0	14.7	7.0	2.4	34.29
			eU (ppm)	0.3	4.3	1.7	0.7	41.18
	Illo/Gundumi Formation	Pre-Maastrichtian	K (%)	0.0	1.7	0.3	0.2	66.67
			eTh (ppm)	0.3	17.3	7.0	2.5	35.71
			eU (ppm)	-0.6	14.1	1.9	1.2	63.16

Table 1. Statistical analysis of the variables in different lithologic units of the study area

Table 2. Mean of natural radioelement content of sedimentary rocks. (Adapted from Galbraith and Saunders 1983)

Rock Type	Th (ppm)	U (ppm)	K (%)
Evaporite	0.4	0.1	0.1
Carbonate	1.6	1.6	0.3
Sandstone	5.7	1.9	1.2
Shale	11.2	3.7	2.7

Table 3. Statistical analysis computed for the KD, eUD and DRAD for each rock unit to identify probable hydrocarbon accumulation zones in the study area

Rock Type	Rock Units	Geological Ages	Radioelements	Min.	Max.	Mean	S.D	X+3S.D
Sedimentary Rock	Gwandu Formation	Eocene	KD (%)	-5.1	0.6	-1.0	0.8	1.4
			eUD(%)	-3.5	51.5	-0.1	1.5	4.4
			DRAD(%)	-2.9	52.2	0.9	1.7	6.0
	Wurno Formation	Maastrichtian	K D(%)	-2.0	0.3	-0.4	0.4	0.8
			eUD(%)	-0.1	0.2	-0.2	0.2	0.4
			DRAD(%)	-1.1	2.0	0.2	0.5	1.7
	Dukamaje Formation	Maastrichtian	K D(%)	-0.1	0.7	0.5	0.1	0.8
			eUD(%)	-1.0	0.2	-0.2	0.1	0.1
			DRAD(%)	-1.6	0.3	-0.7	0.2	-0.1
	Taloka Formation	Maastrichtian	KD (%)	-2.1	0.6	-0.2	0.5	1.3
			eUD(%)	-0.8	0.1	-0.2	0.1	0.1

			DRAD(%)	-1.0	2.1	0.1	0.5	1.6
	Illo/Gundumi Formation	Pre-Maastrichtian	K (%)	-4.1	0.4	-0.6	0.6	1.2
			eUD(%)	-3.9	1.4	-0.2	0.3	0.7
			DRAD(%)	-3.3	4.4	0.5	0.8	2.9

Table 1. Probable hydrocarbon accumulation zones in the study area

S/N	Locations	Corresponding Locations	Exposed Rock Units	Indicative Anomaly.
1	Southwestern	Suru, Bunza and Maiyama	Gwandu & TalokaFormations	+ve DRAD and –ve KD
2	Southwestern	Jega, Aleiro and Kebbe	Gwandu & Taloka Formations	+ve DRAD and –ve KD
3	Western	Arewa Dandi	Gwandu Formation	+ve DRAD and –ve KD
4	Northeastern	Gudu	Gwandu Formation	+ve DRAD and –ve KD
5	Northeastern	Tangaza	Gwandu Formation	+ve DRAD and –ve KD
6	Northern	Illela	Illo/Gundumi Formation	+ve DRAD and –ve KD
7	Northwestern	Gada and Goronyo	Gwandu,Gundumi & Taloka Formations	+ve DRAD and –ve KD
8	Northwestern	Goronyo	Wurno,Taloka& Gwandu Formation	+ve DRAD and –ve KD
9	Northwestern	Gwadabawa	Gwandu & Gundumi Formations	+ve DRAD and –ve KD
10	Central West	Sokoto South	Gwandu Formation	+ve DRAD and –ve KD

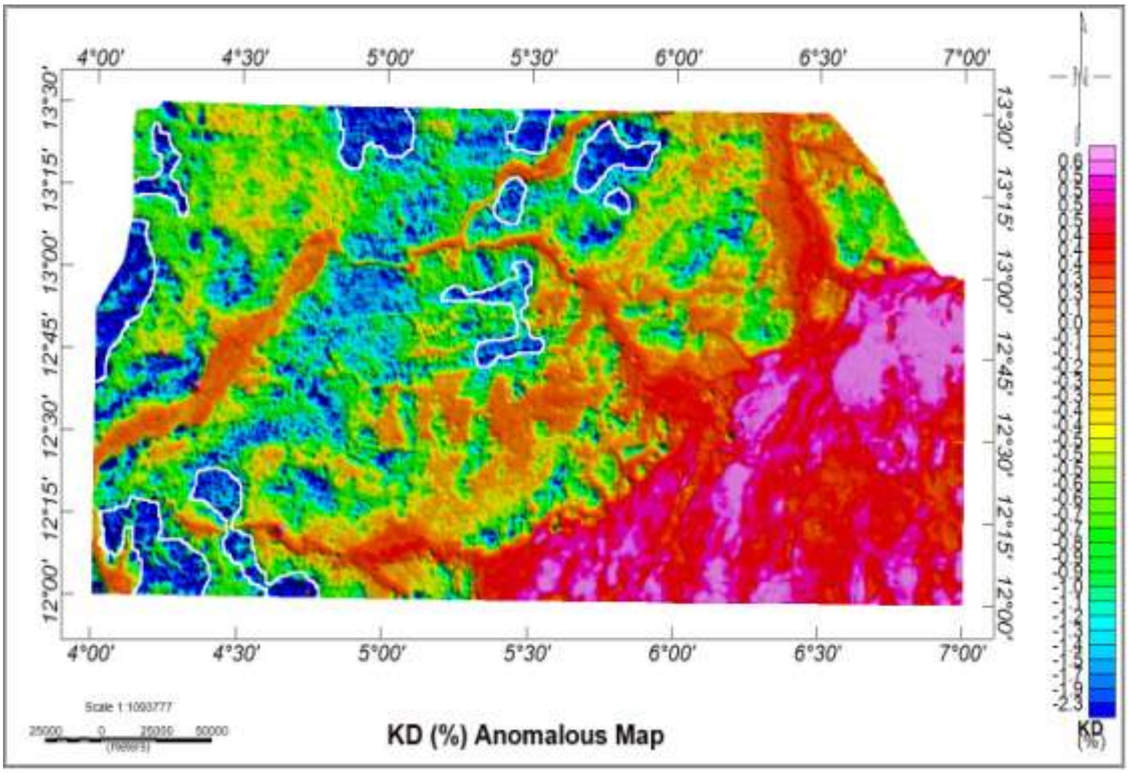

Fig 7. KD% Anomaly of the study area

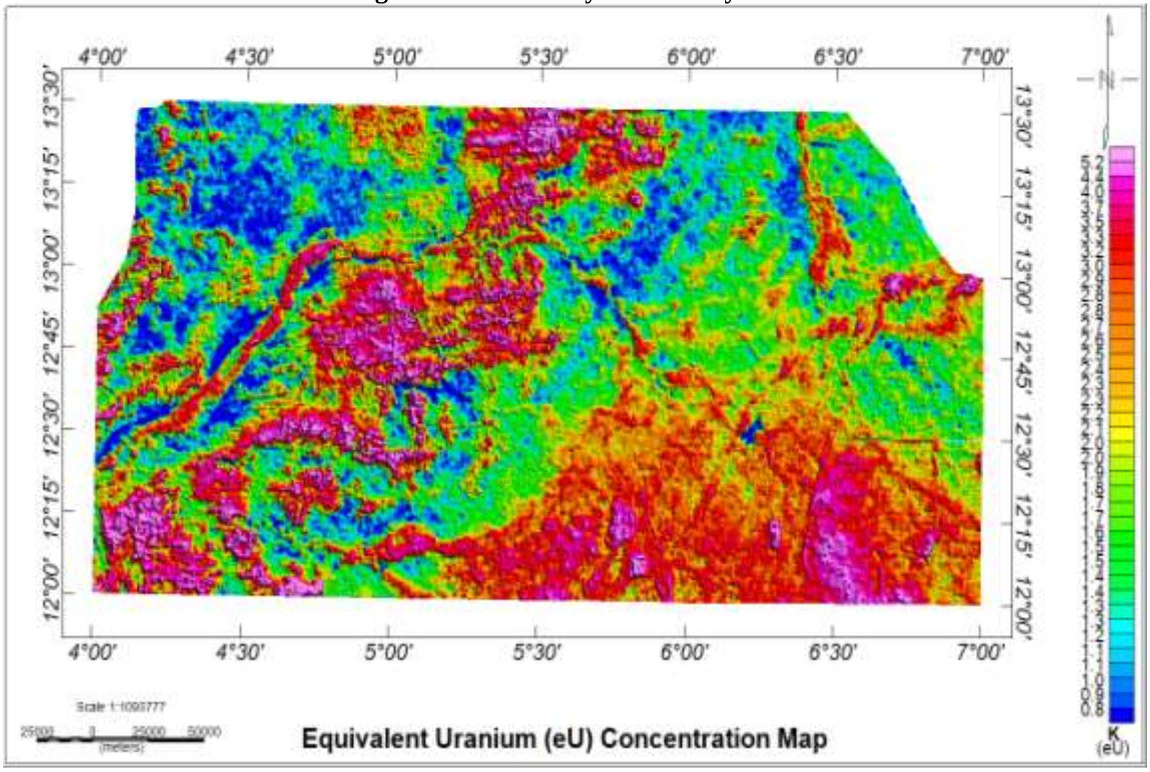

Fig 8. eU% Anomaly of the study area

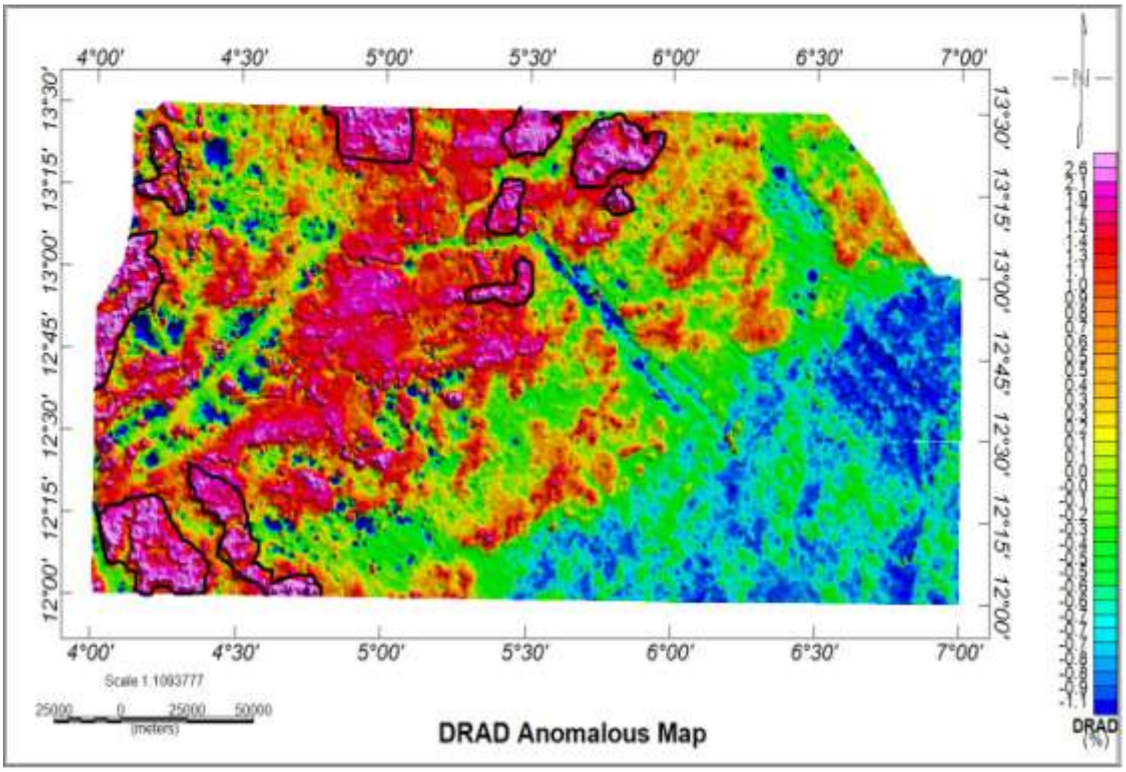

Fig 6. DRAD% Anomaly of the study area

V. CONCLUSION

Thorium normalization technique was applied on the airbone radiometric data of Sokoto Basin where K, eTh, eU data were plotted for five rock units to delineate favourable zones for hydrocarbon accumulations within the study area. The statistical treatment was applied for each rock unit. According to Sarma and Koch (1980), if the (CV %) of a specific rock unit is less than 100%, the unit tends to exhibit a normal distribution. So, all rock units in the study area tend to normality in their distribution for the three radio-elements (K, eTh and eU) except for K in Gwandu rock unit (100% in K).The mean values of the radioelements obtained from the statistical analysis correlate with the mean of natural radioelement content of sedimentary rocks adapted from Galbraith and Saunders (1983) which corresponds to shale, the main source rock for hydrocarbon maturation in the study area. The DRAD arithmetic mean plus the three standard deviations (X+3SD) for the data set were computed and the grand mean of DRAD (%) representing all the five rock units is 2.42. Any DRAD value for these rocks greater than 2.42 possesses a probability of 99.87% representing a valid anomaly that is not caused by random variations in the background values (Saunders 1989 & 1993; El-Sadek 2002; El-Sadek. 2007; Al-Alfy 2009; Al-Alfy et al. 2013; Nigm et al. 2018). This led to the identificationof ten stations in DRAD map over the investigated area that are statisticallyconsistent, and show reliable anomalies that, might demonstrate prospectivehydrocarbon accumulations in the study area.It can therefore be concluded in this study that the preliminary information obtained from the thorium normalization method will guide the exploration of hydrocarbon in the Sokoto Basin.

REFERENCES

[1]. Adler, H. H., 1974, Concepts of uranium ore formation in reducing environments in sandstones and other sediments: Proc., Formation of uranium ore deposits, Internat. Atomic Energy Agency, 141-168.

[2]. Al-Alfy IM (2009) Radioactivity and reservoir characteristics of lower Miocene rocks in Belayim marine oil field. Ph.D. Thesis, Faculty of Science, Zagazig University, Zagazig, Egypt, p 174.

[3]. Al-Alfy IM, Nabih MA, Eysa EA (2013) Gamma ray spectrometry logs as a hydrocarbon indicator for clastic reservoir rocks in Egypt. Applied Radiation Isotope 73:90–95.

[4]. Annual Statistical Bulletin 2019, www.opec.org/opec_web/en accessed on 10/12/2019.

[5]. Armstrong, F. E., and Heemstra, R. J., 1973, Radiation halos and hydrocarbon reservoirs: A review: U.S. Bureau of Mines Information Circular 8579.

[6]. Bazoobandi MH, Arian MA, Emami MH, Tajbakhsh G, Yazdi A (2016) Petrology and Geochemistry of Dikes in the North of Saveh in Iran, Open journal of marine science 6(02): 210-222.

[7]. Bonde, D.S., Udensi, E.E. and Rai, J.K. (2014) Spectral Depth Analysis of Sokoto Basin. Journal of Applied Physics , 6, 15-21.

[8]. Branson, D.O., 1950, Blackfoot Field, Anderson County, Texas: Bull., Am. Assn. Petro Geo!., 34, 1750-1755.

[9]. Bruno, L., Roy, D. L., Grinsfelder, G. S., and Lomando, A. J., 1991, Alabama Ferry Field U.S.A., East Texas Basin, Texas.

[10]. Darnely AG, Ford KL 1989. Regional airborne gamma –raysurveys, a review. In: Garland GD, edited by. Proceedings ofExploration, 87; Third Decennial Inter –nationalConference on Geophysical and Geochemical Explorationfor Minerals and Groundwater; Ontario, Canada:Geological Survey of Canada, Special V.3. p. 229–240.

[11]. El-Sadek MA (2002) Application of thorium-normalized airborne radio-spectrometric survey data of Wadi Araba area, Northeastern Desert, Egypt, as a guide to the recognition of probable subsurface petroleum accumulations. Applied Radiation Isotope 57:121–130.

[12]. El-Sadek MA, Ammar AA, Omraan MA, Abuelkeir HM (2007) Exploration for hydrocarbon prospects using aerial spectral radiometric survey data in Egypt. Kuwait Journal of Science Engineering 34(2A): 133.

[13]. Elkins, T. A., 1940, The reliability of geophysical anomalies on the basis of probability considerations: Geophysics, 5, 321-336.

[14]. Eshhati, Muhamed A. (2001) the organization of petroleum exporting countries (OPEC): foundations of a strategic approach.(PhD thesis), Kingston university, uk.bl.ethos.368864

[15]. Foster, N. H., and Beaumont, E. A., Eds., Stratigraphic traps II, Treatise of petroleum geology, Atlas of oil and gas fields: Am. Assn. Petro Geol., 1-27.

[16]. Galbraith, J. H., and Saunders, D. F., 1983, Rock classification by characteristics of aerial gamma-ray measurements: J. Geochem. Exp!, **18,47-73.**

[17]. Gingrich, J. E., and Fisher, J. C., 1976, Uranium exploration using the track etch method, Proc., Exploration for uranium ore deposits,Internat. Atomic Energy Agency, 213-227.

[18]. Hahn, A., Kind, E. G., and Mishra, D. C. (1976). Depth estimates of magnetic sources by means of Fourier amplitude spectra. Geophy. Prosp., **24**: 278-308.

[19]. Kiran., K. T. (2002). 2D and 3D land Seismic Data Acquisition and Seismic Data Processing. Shell Petrophysics Training Manual. 45-90.

[20]. Kisswani, Khalid M, “Economics of oil prices and the role of OPEC (2009). Doctorate Dissertations. AA13367363. https://opencommons.uconn.edu/dissertations/AA13367363

[21]. Kogbe, C.A Geology of Nigeria, Elizabeth pub.co, Lagos (1976), pp.337-353.

[22]. Nigerian Geology Survey Agency. (1976). Geology Map of Nigeria, Scale 1:2,00 000. Geology Survey of Nigeria, Kaduna, Nigeria (Oasis Montaj Software Inc.).

[23]. Nigm AA, Youssef MAS, Abdelwahab FM (2018) Airborne Gamma-ray Spectrometric data as a guide for probable hydrocarbon accumulations at Al-Laqitah area, central eastern desert of Egypt, Applied Radiation and Isotopes 132: 38 – 46.

[24]. Mazadiego L (1994) Desarrollo de Una Metodologia Para La Prospecting Geoquimica En Suoerficie de Combustible Fosiles. Tesis de Doctorado. Madrid: 1-353.

[25]. Mollai M, Dabiri R, Torshizian HA, Pe-Piper G, Wang W (2019) Cadomian crust of Eastern Iran: evidence from the Tapeh Tagh granitic gneisses, International Geology Review, 1-21.

[26]. Obaje., N. G. (2009). Geology and Mineral Resources of Nigeria. Springer-Verlag Berlin Heidelberg.

[27]. Obaje, N. G; M. Aduku and I. Yusuf , 2013. The Sokoto Basin of Northwestern Nigeria: A Preliminary Assessment of the Hydrocarbon Prospectivity. Journal of Canadian Petroleum Technology .

[28]. Oppenheim, A. V., and Schafer, R. W. (1975). Digital Signal Processing Practice, Hall International Inc., New Jersey, pp. 1227-1296

[29]. Philip., K., Michael B., and Ian H. (2002). Introduction to Geophysical Exploration. Blackwell Science Ltd.

[30]. Reeves, C. (2005);Aeromagnetic Surveys; Principles, Practice and Interpretation, Training Programme, NGSA, Nigeria.

[31]. Saunders, D.F., 1989. Simplified evaluation of soil magnetic susceptibility and soil gashydrocarbon anomalies. Bull. Assoc. Pet. Geochem. Explor. 5, 30–48.

[32]. Saunders, D.F., Branch, J.F., Thompson, C.K., 1994. Tests of Australian aerial radiometric data for use in petroleum reconnaissance. Geophysics 59, 411–419.

[33]. Saunders, D.F., Burson, K.R., Branch, J.F., Thompson, C.K., 1993. Relation of thoriumnormalizedsurface and aerial radiometric data to subsurface petroleum accumulations.

[34]. Geophysics 58 (10), 1417–1427.

[35]. Saunders, D.F., Burson, K.R., Thompson, C.K., 1991. Relationship of soil magnetic susceptibility and soil gas hydrocarbon measurements to subsurface petroleum accumulations.

[36]. Bull., Am. Assn. Pet. Geol. 75, 389–408.

[37]. Saunders, D.F., Terry, S.A., Thompson, C.K., 1987. Test of national uranium resource evaluation gamma-ray spectral data in petroleum reconnaissance. Geophysics 52, 1547–1556.

[38]. Salazar S, Castillo L, Montes L, Martinez F (2018) Utilizing the radiometric and seismic methods for hydrocarbon prospecting in the Rancheria sub-basin in Colombia. Applied Radiation and Isotopes140: 238-246.

[39]. Sarma, D.D., Kock, G.S., 1980. A statistical analysis of exploration geochemical data for uranium. Math. Geol. 12 (2), 99–114.

[40]. Schumacher D (2000) Surface geochemical exploration for oil and gas: new life for an old technology. The Leading Edge 19(3): 258-261.

[41]. Skupio R, Barberes GA (2017) Spectrometric gamma radiation of shale cores applied to sweet spot discrimination in Eastern Pomerania, Poland, Acta Geophys 65:1219–1227.

[42]. Taiwo A. (2020) Interpretation of airborne radiometric data for possible hydrocarbon presence over Bornu basin and its environs, Northeast Nigeria using thorium normalisation method. Iranian Journal of Earth Sciences Vol. 13, No. 3, 2021, 161-172.

[43]. Unlocking Nigeria’s Potential in Natural Gas, www.shell.com.ng accessed on 12/12/2019.

[44]. Walker S, Harmen K, Donovan D (2018) Airborne Gamma-ray surveying in Hydrocarbon Exploration. GeoConvention, Canada.

[45]. Yazdi A, ShahHoseini E, Razavi R (2016) AMS, A method for determining magma flow in Dykes (Case study: Andesite Dyke). Research Journal of Applied Sciences, 11(3), 62-67.