RADIOGENIC HEAT PRODUCTION IN THE CRUST USING HIGH RESOLUTION AERORADIOMETRIC (HRAR) DATA IN PARTS OF SOKOTO BASIN, NIGERIA

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Abstract

Measurement of radiogenic heat production has been carried out from the gamma ray spectroscopy of the high resolution aero radiometric (HRAR) data for parts of the Sokoto Basin in northwestern Nigeria. Ten sheets of total count map for the study area showing combine effects of ^{40}K, ^{238}U and ^{232}Th for the area were analyzed into potassium content map, uranium content map and thorium content map. The contribution and rate of heat production from the content maps were calculated. The results of the analyses show that the crustal radiogenic heat production (RHP) rate for the selected sections ranges from 0.07 to 5.48 µWm^{-3} with an average of 1.07 µWm^{-3} for 5,153 values. Some of the areas with radiometric anomaly, are lithologically consistent with limestone, granite and shale which are known to have the highest concentration of ^{40}K, ^{238}U and ^{232}Th. They are long lived isotopes of interest in the radioactive decay of the earth's crust. Using Rybach average of 2.25 µWm^{-3} for rocks and sedimentary formation as the standard. The Sokwoi Binji, Kaoje, and Konkwosso areas which have RHP values of 1.56 µWm^{-3}, 1.52 µWm^{-3}, 2.03µWm^{-3} and 1.79 µWm^{-3} respectively, may not be prospect areas for geothermal exploration. But the Kalmalo, Sokoto, Argungu, Dange, Birnin Kebbi and Giru with radiogenic heat production values of 3.62 µWm^{3}, 3.10 µWm^{-3}, 2.82 µWm^{-3}, 5.48 µWm^{-3}, 2.70 µWm^{-3} and 2.67 µWm^{-3} respectively, have RHP values found to be due to high heat production of ^{238}U are suggestive of anomalous geothermal conditions, may be good areas for geothermal exploration that can be tapped as an alternative to fossil fuel based energy in Nigeria and therefore are recommended for detailed ground radiometric survey and lab.tests.

Keywords: Aeroradiometric, Radiogenic, Geothermal, Sokoto Basin, Nigeria

Introduction

Airborne gamma ray spectroscopy (AGRS) measurement was used to carry out regional estimation of concentration of heat producing elements (HPE) in the Earth's crust in counts per second of the sedimentary rocks and igneous rocks of the crust. The decay of long life radioactive elements of interest for geothermal resources are ^{40}K, ^{238}U and ^{232}Th in the Precambrian basement that are largely covered by younger sedimentary and granitic rocks gives out geothermal heat that is radiogenic in nature. It is accompanied by the emission of radiation such as alpha particles, beta particles, gamma ray, neutron and proton. The gamma particles are high energy electromagnetic radiation with characteristic energy for each decay reaction. Their spectrum can be used to determine the concentration of different isotopes that decay (Gilmore, 2008).

The aeroradiometric survey counter that can be 80 -100 m above the surface could penetrate up to 0.005 km through rocks is mostly used for regional survey of gamma radiation emitted and penetrated close to surface of the crust. Hence, radiometric method is capable of yielding information only on what lies at the ground surface it provide regional information on geothermal resources by remote sensing Moxlami (1960). It is a fast and cost effective method because it is usually conducted with multiple sensor that can simultaneously measures radiometric, magnetic and electromagnetic data. Similarly, there is no limit accessibility to any part of the study area be it ocean, swampy, rocky magmatic mountain, valley etc one major disadvantage is that the cost of chartering air craft are not trivial.

The spectral radiometric measurement can be used to evaluate radiogenic heat production (RHP) rate, which is the amount of heat librated in unit time in unit volume of rocks by the decay of radiogenic isotopes, its unit is Wm^{-3}, but are only sensitive to a very thin surface layer of the earth's crust. The average RHP can be used to rank, to know the major element responsible for the RHP in the area, from airborne gamma ray data in space survey along a set of parallel flight lines profile 2 km apart. In the past AGRS has been used for uranium exploration, but following advancement in technology many instrument and field guideline, this method is now used as general mapping and exploration tool for several environmental and geosciences studies.

The Nigerian Geological Survey Agency (NGSA) carried out a nationwide airborne radiometric survey in 2009 with the aim diversifying the country's economy from mono product economy to other sector. Regional high resolution aeroradiometic (HRAR) data were acquired in Nigeria by Fugro Airborne Survey Limited for the NGSA between 2004 and 2009. The acquisition, processing and compilation of the new data were jointly financed by the Federal Government of Nigeria and the World Bank as part of the Sustainable Management for Mineral Resources Project (SMMRP). The airborne gamma ray spectrometer surveys, using Scintillation detector as counters with data recording interval of 0.1 seconds, were carried out by means of Fixed-wing aircrafts flown at mean terrain clearance of 80 m with 500 m line spacing and nominal tie-line spacing of 2 km. The flight line and tie-line trends were 135 and 45 degrees respectively. Unlike the preceding surveys that were done with the 1970's data, in an analogue paper map format from a flight height of 152 m with line spacing of 2 km and nominal tie-line spacing of 20 km; earlier studies with 1970's data such as (Ofoegbu, 1984; 1985; 1986; Nwachukwu, 1985.), they pointed out the need to shift from analogue to digital since 1970's, the stressful work of digitizing a map and the likely human error that could be introduced during the processing and correction of errors as problems.

These problems have all been eliminated because the HRAR data is in a digital format. Previous studies (Paoletti *et al.*,2005a and 2005b) showed that it provided an insights into the characterization of the buried, geological and outcropping volcanic structure of an area. It is rich in high frequency anomalies not shown in the previous regional low resolution data, and locate buried structures such as lineament, faults and volcanic and intrusive structures, hence it help in enhancing the knowledge given by previous low resolution studies. Thereby providing a better understanding of the buried, geologic, tectonic, geovolcanological and geothermal characteristics of an area. This new HRAR data is widely adjudged to be better and it is assumed that its analysis would provide better and improved geoscientific outcomes. Research in this topic on this area were lacking. This work aimed at identifying clean and renewable energy sources that can be a better alternative to burning fossil fuels that can lead to emission of green house gases. Green house gases trap heat (long wave radiation) in the atmosphere keeping the earth's surface warmer than it would be if they were not present. This can lead to global warming and climate change, it involves calculation of RHP from radioelements concentration of geothermal resources for possible generation of alternative energy sources to the traditional fossil fuel based energy in Nigeria, has fills the gap of lacking baseline geothermal data and avoids mistakes that have been previously made.

Location and geology of the study area

The Sokoto Basin is located in the northwestern part of Nigeria and is bounded by latitudes 10.00°N and 14.00°N and longitudes 3.50°E and 7.00°E (Fig. 1). It has a total surface area of about 111,925 km^2, which cuts across six provincial states in Nigeria, namely Kaduna, Katsina, Kebbi, Niger, Sokoto and Zamfara.

Sokoto basin, which has been extensively described by geologists (Kogbe, 1979; 1981; Obaje, 2009), constitutes the south-eastern portion of the Iullemmeden basin. Iullemmeden basin extends from Mali and the western boundary of Niger Republic through northern Benin Republic and north-west of Nigeria into eastern Niger Republic. The entire Iullemmeden basin covers an area of about 800,000 km^2. The rock unit are predominantly clay alternating with gritty sand unit, which are ill-stored, poorly consolidated with gravel overlying the precambrian basement and consist of a gentle undulating plain with an average elevation varying from 250 to 400m above sea-level (Kogbe, 1979).

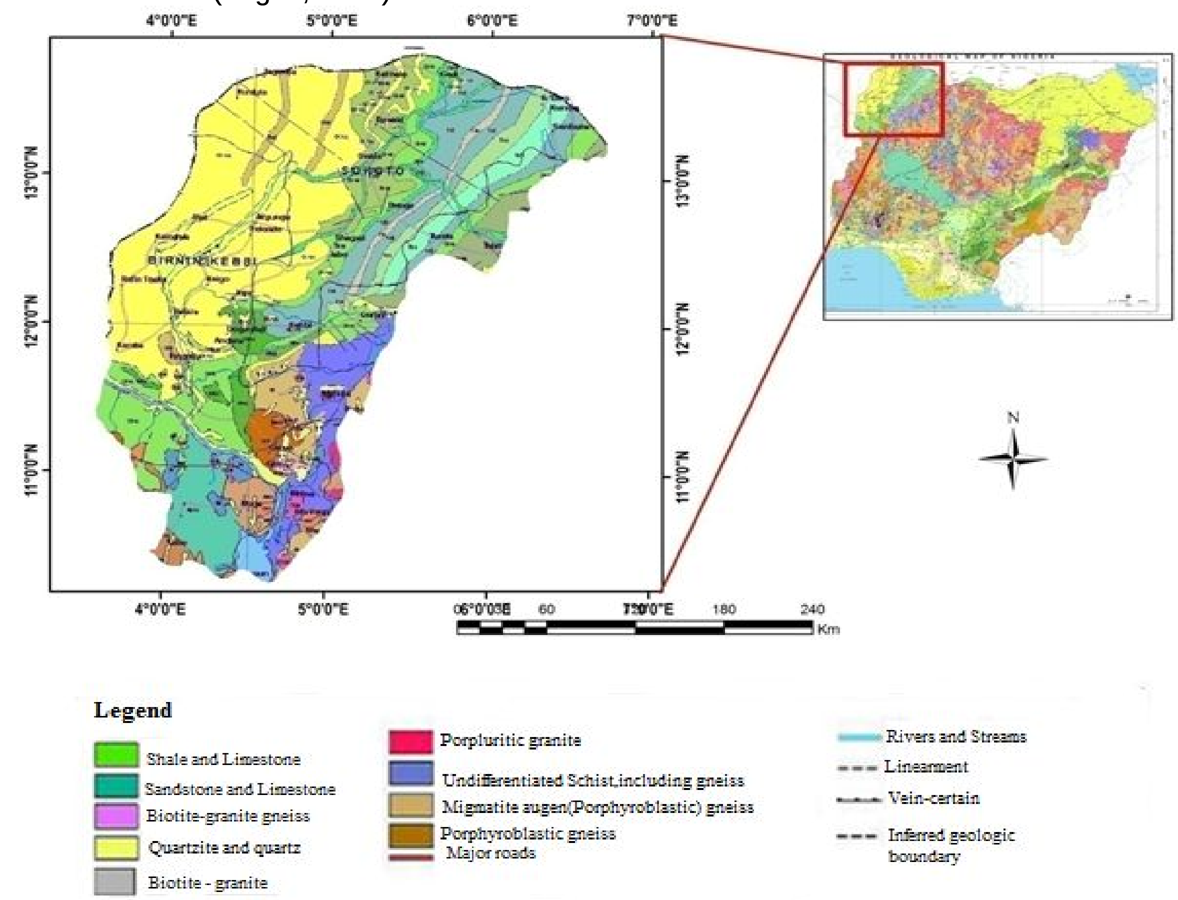

Fig. 1: Geologic map of Sokoto Basin (After Nigerian Geological Survey Agency, 2009)

The Nigerian sector of the basin is underlain to the east and south by precambrian basement rock consisting of igneous and metamorphic rocks, and to the north in the Tassaili and the Hoggar mountains by cambrian beds. The sediments of the Sokoto basin were deposited under varied environmental situations ranging from continental to marine events. The sedimentary rocks of the basin range in age from Pre-Maastrichtian to Eocene. (Fig. 2) have been classified under four major stratigraphic categories (Kogbe, 1979; 1981):

(i) The Illo and Gundumi formations overlying the precambrian basement unconformably, which is made up of grits and clays.
(ii) Maastrichtian Rima group, consisting of mud stone and friable sandstone called Taloka and Wurno formation separated by the fossiliferous and shelly Dukamaje formation.
(iii) The Dange and Gamba formation (mainly shale) separated by the calcareous kalambaina formation known as Sokoto group and is of marine origin.
(iv) The Gwandu formation forms the post-paleocene continental terminal, which occurs in the northwest and southern parts of Sokoto. This sediment dips gently and thickens gradually towards the northwest, with a maximum thickness of over 1,200 m near the frontier with Niger republic.

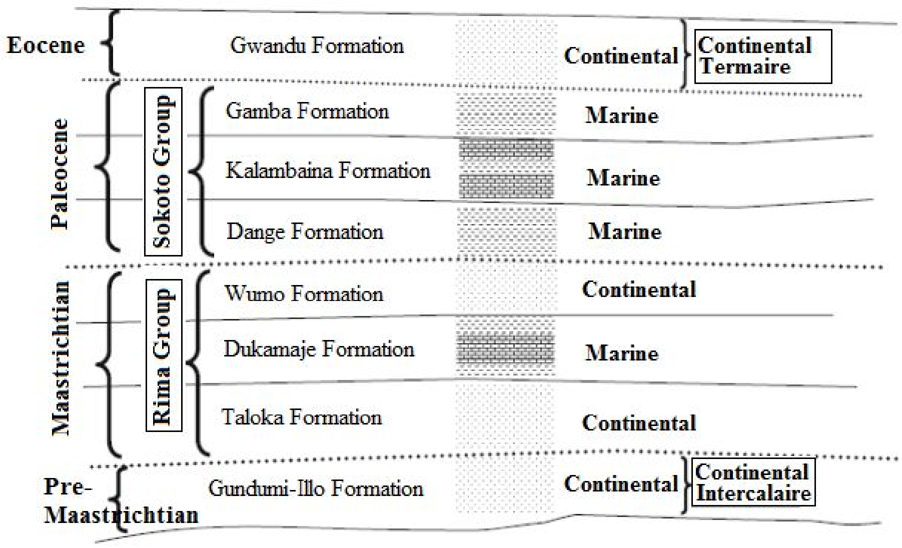

Fig. 2: Stratigraphic sequence of the Sokoto Basin (After Obaje, 2009)

Radiometric Method

The total count map for the study area showing combine effects of ^{40}K, ^{238}U and ^{232}Th for the area were analyzed into Potassium content map, uranium content map and thorium content map. The contribution and rate of heat production from the content maps were calculated. Using equation 1a, and consequently the RHP in rocks was evaluated

$$Q = \rho (0.035C_k + 0.097C_u + 0.026C_{th}) \quad \text{(Rybach } et\ al.\text{, 1988)} \qquad (1a)$$

Where C_u, C_{th} and C_k are concentrations of uranium, thorium and potassium respectively, and ρ is the rock density. Each of the radioelement concentrations were multiplied by a numerical constant. These constants reflect the differing contributions to the RHP of each radioelement in μWm^{-3} of rocks per unit of potassium, uranium and thorium. The constant for uranium is 0.097 which is about two times the constants for potassium (0.035) and thorium (0.026) these constants show that uranium play dominant role than thorium and potassium in radiogenic heat production.

The result of crustal radiogenic heat production (RHP) rate for the selected sections, was presented in tabular form showing the coordinate, concentration of ^{40}K, ^{238}U and ^{232}Th and RHP in (µ W / m^3). It has been established that the average radiogenic heat flow is 2.25 µ W / m^3 for granitic rock (Rybach 1981) value greater than this are anomalous which indicate feasibility of the geothermal energy.

Data acquisition and analysis

Ten (10) digital half degree HRAR colour maps each are having an area of 55 km x 55 km (sheet number 2 - 3, 9 – 10, 28 – 29, 49, 72, 95 and 117) on a scale of 1:100,000 with a total 2,748,653 data points were used in this work. The whole data, which were procured from the Nigerian Geological Survey Agency (NGSA) and assembled into total count map (Fig. 3), using a computer geophysical software Oasis Montaj version 6.4.2, the data range between 116979.90 and 5615.96 Cps with an average of 99489.16 Cps and a standard deviation of 41.212. The regions of pink to red indicates areas of high concentration of the three radioelements ^{40}K, ^{238}U and ^{232}Th while the blue region indicate areas of low concentration. This nationwide regional scale data (HRAR) has been processed and corrected by the NGSA before the eventual publication as HRAR colour Maps. The composite map was then analyzed into the content map of each of the radiogenic heat producing elements and 5,153 values of concentration were generated using Oasis Montaj Processing Software. Equation.2 was then used for calculating RHP from radioelement's concentration.

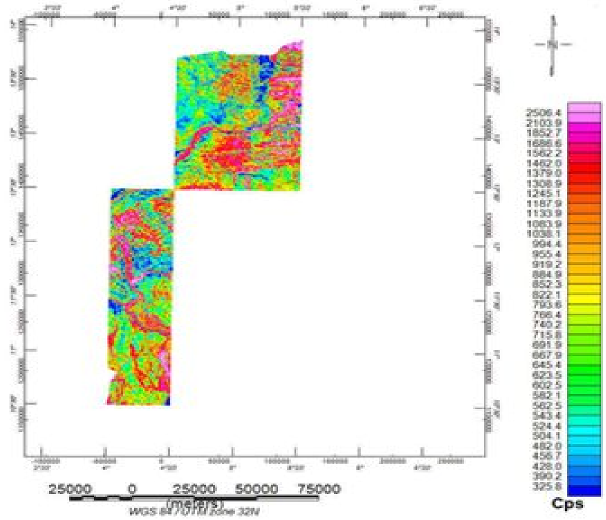

Fig. 3: Total Count Map of parts of Sokoto Basin

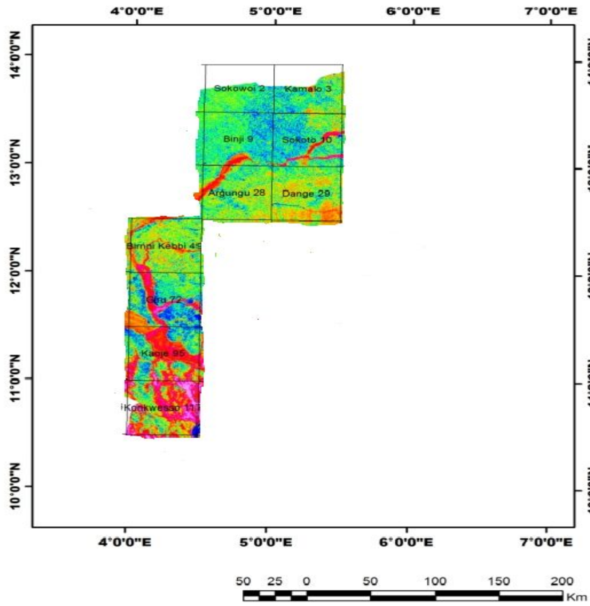

Fig. 4: Potassium concentration map of parts of Sokoto Basin

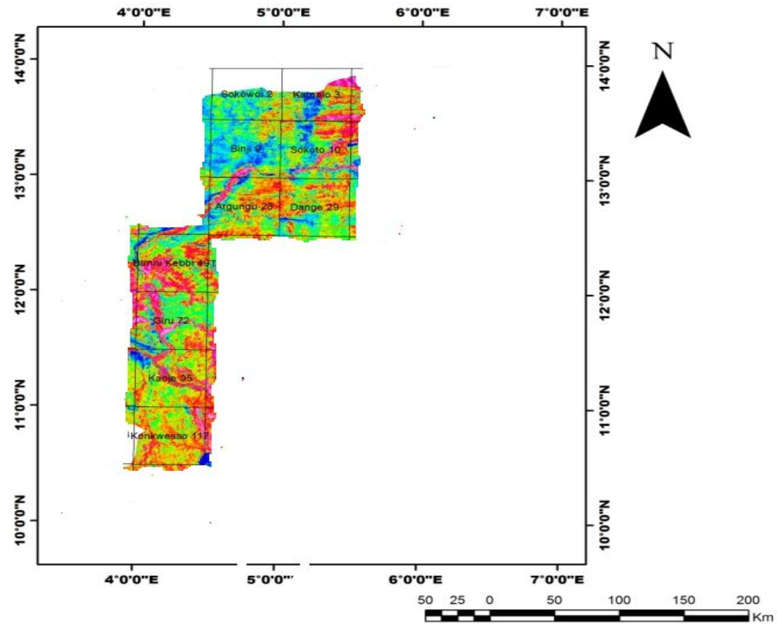

Fig. 5: Thorium concentration map of parts of Sokoto Basin

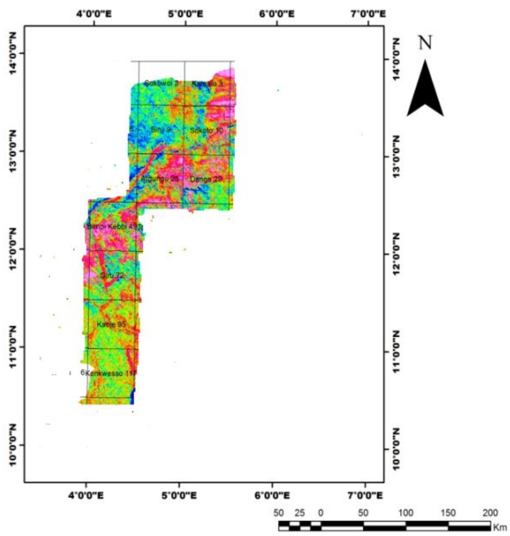

Fig. 6: Uranium concentration map of parts of Sokoto Basin

Radiogenic Heat Production (RHP) Estimation

The radiogenic near surface heat generated by heat producing elements from the radioactive decay in the earth's crust is calculated by summing the contribution of each radioactive element with the following formula (Rybach, 1988)

$H = 10^{-11}\, \rho\, (3.48C_k + 2.56C_{th} + 9.52C_u)$ (Rybach *et al.*, 1988) (1b)

In sokoto basin the average upper crustal density (ρ) is 2700 kgm^{-3} (Aku *et al.*, 2013), using a constant value for the upper crustal density will lead to overestimating the RHP of sedimentary bedding whose average density is approximately 20 % lower than that of crystalline rocks, this together with heat production constant (3.48, 2.56, and 9.52) was used to estimate RHP for each of the heat producing elements in the soil and rocks of the crust while A is total geothermal heat produced due to the three elements A(µWm^{-3}) was evaluated as:

$A = 0.094\, C_k + 0.069\, C_{th} + 0.257\, C_u$ (2)

Several different formulae have been adopted over the years in physics that account more precisely for the energy of the neutrinos with negligible difference ((<5%), but for the sake of consistency between data sets, we have used the standard values of the geophysicist and geologist. Table1 shows locations coordinate of points with highest RHP values of the total 5,153 values.

Table 1: Summary of radiogenic analyses and evaluated RHP parameters

Location	Long (°E)	Lat (°N)	K (%)	Th (ppm)	U (ppm)	Potassium (µWm^{-3})	Thorium (µWm^{-3})	Uranium (µWm^{-3})	Total/RHP (µWm^{-3})
Sokwoi	4.90	13.57	0.101	9.419	3.507	0.010	0.650	0.901	1.56
Kalmalo	5.47	13.85	0.198	17.073	9.410	0.019	1.178	2.418	3.62
Binji	4.93	13.23	0.200	7.677	3.763	0.019	0.530	0.967	1.52
Sokoto	5.41	13.37	0.207	13.329	8.411	0.019	0.920	2.162	3.10
Argungu	4.91	12.71	0.309	10.874	7.935	0.029	0.750	2.039	2.82
Dange	5.18	12.71	0.360	15.084	17.134	0.034	1.041	4.403	5.48
BirninKebbi	4.25	12.24	0.176	13.396	6.862	0.017	0.924	1.764	2.70

Giru	4.25	12.00	0.199	15.019	6.277	0.019	1.036	1.613	2.67
Kaoje	4.25	11.48	1.077	14.157	3.709	0.101	0.977	0.953	2.03
Konkwesso	4.25	10.73	1.001	10.585	3.753	0.094	0.730	0.965	1.79

Results and Discussions

It has been established that the average radiogenic heat flow is 2.25 μWm^{-3} for younger sedimentary and granitic rocks (Rybach 1981), value greater than this are considered as radiometric anomalies indicating feasibility of geothermal potential that is purely crustal origin with no mantle input. Table 1, indicates selected areas with high RHP of 5,153 values too large to be published. Some of the areas with RHP anomalous correspond to areas that are lithologically consistent with limestone, granite and shale which are known to have the highest concentration of ^{40}K, ^{238}U and ^{232}Th are long lived isotopes of interest in radioactive decay in the earth's crust. The, Kalmalo, Sokoto, Argungu, Dange, Birni Kebbi and Giru has RHP anomalous values of 3.62 μWm^{-3} 3.10 μWm^{3}, 2.82 μWm^{-3} , 5.48 μWm^{-3}, 2.70 μWm^{-3}, 2.67 μWm^{-3}, respectively may be good areas for geothermal exploration and therefore are recommended for detailed ground-based radiometric survey and lab tests. The Sokwoi, Binji, Kaoje ,and Kwonkosso areas with low RHP values of 1.56 μWm^{-3}, 1.52 μWm^{-3} 2.03 μWm^{-3} and 1.79 μWm^{-3} may not be prospect areas for geothermal exploration. Figure 7 shows that the RHP contour map is trending NE – SW with the highest value of RHP in the northern part of the study areas while the southern parts characteristically have low RHP and hence low geothermal potential except for Birnin Kebbi and Giru which correspond to areas with occurrence of phosphate. The map shows a clear correlation with the geology of the area.

The results agree with Uwa (1984) and Ofor (2014). This study fills the gap of the lacking baseline geothermal data and avoids mistakes that have been previously made.

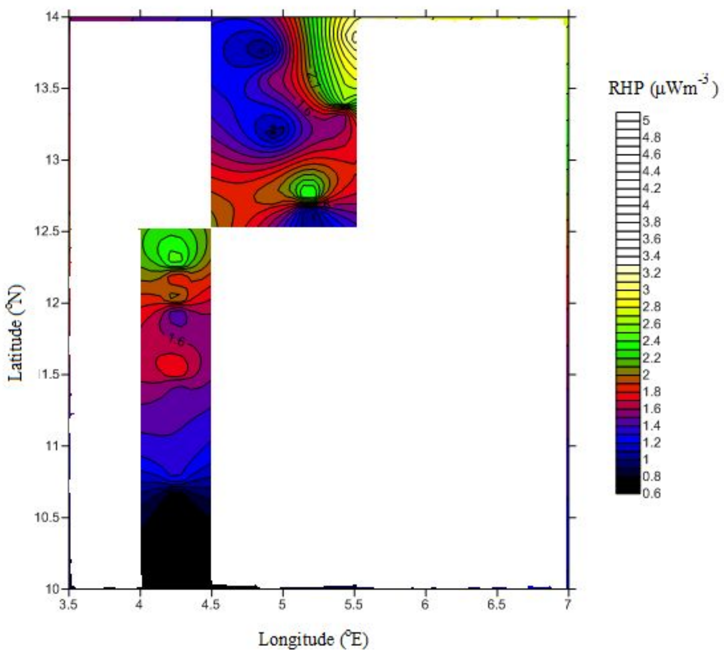

Fig. 7: Contour map of RHP of parts of Sokoto Basin (Contour interval 0.1 μWm^{-3})

Conclusions

The results show of crustal radiogenic heat production (RHP) rate for the selected sections ranges from 0.07 to 5.48 µWm^{-3} with an average of 1.07 µWm^{-3} for 5,153 values. Some of the areas with radiometric anomaly, are lithologically consistent with limestone, granite and shale which are known to have the highest concentration of ^{40}K, ^{238}U and ^{232}Th. Low RHP values are observed at Kaoje, Konkwosso, Sokwoi and Binji areas, may not be prospect areas for geothermal exploration. RHP results higher than Rybach average of 2.25 µWm^{-3} observed at Dange, Kalmalo, Sokoto, Argungu, , Birni Kebbi and Giru associated with highest heat production of ^{238}U in each value are suggestive of anomalous geothermal conditions may be good areas for geothermal exploration and therefore are recommended for detailed ground-based radiometric survey and Lab tests. ^{238}U is the major radioelement, which predominates in the geothermal energy potential parts of the study areas that can be tapped as an alternative to fossil fuel based energy in Nigeria.

Acknowledgments

The authors are grateful to the Nigerian Geological Survey Agency (NGSA) for releasing the HRAR data on a subsidised rate. The authors are also grateful to the Federal University of Technology, Minna, Nigeria for granting one of the authors a study fellowship and the University of Ilorin, Nigeria for the facilities made available for the research work.

References

Aku, M. O., Umego, M. N. & Musa, A. O. (2013). Gravity study of rocks in the Schist belts of Northwest Nigeria. *Nigerian Journal of Physics*, 24, 83 – 90.

Alabi, O. O., Akinfuyi, F. O., Ojo, M. O. & Adebo, B. A. (2007), Radiogenic heat production of rock from three Rivers in Osun State of Nigeria. *Journal of Applied Sciences*, 7, 1661- 1663

Catherine, P., Phaneuf, B. & Jeanclaude, M. (2014). Estimating concentrations of heat producing elements in the crust near the Sudbury Neutrino Observatory, Ontario, Canada. *Elsevier Journal of Tectonophysics,* 622, 135-144.

Chapman, D. S. & Furlong, K. P. (1992). Thermal state of continental lower crust. In: Fountain, D. M., Arculus, R., Kay, R. W. (Eds.), Continental lower crust. Amsterdam: Elsevier Science, 179-199.

Glimore, G. (2008). Practical Gamma ray Spectroscopy, 2nd edition. UK: Wiley

Joshua, E. O. & Alabi, O. O. (2012). Pattern of radiogenic heat production in rock samples of Southwestern Nigeria. *Journal of Earth Sciences and Geotechnical Engineering*, 2(2), 25 – 38.

Kogbe, C. A. (1979). *Geology of the South-Eastern (Sokoto) sector of the lullemmeden basin.* Department of Geology, Ahmadu Bello University Zaria Bulletin, 32,142.

Kogbe, C. A. (1981). Cretaceous and tertiary of the Iullemmeden Basin of Nigeria (West Africa). *Cretaceous Res*, 2, 129–186.

Megwara, J. U., Udensi, E. E., Olashehinde, P. I., Daniyan, M. A., & Lawal, K. A. (2013). Geothermal and radioactive heat studies of Southern Bida Basin, Nigeria and the surrounding basement rocks. *International Journal of Basic and Applied Sciences*. 2(1), 125 – 139.

Moxiami, R. M. (1960). Airborne radioactive surveys in geological exploration. *Geophysics,* 25(2), 408 – 432.

Nwachukwu, J. I. (1985). Petroleum prospects of Benue Trough Nigeria. *The Ame. Asso. of Petro Geology Bulletin*, 69(4), 601– 609.

Obaje, N. G., Wehner, H., Scheeder, G., Abubakar, M. B. & Jauro, A. (2004). Hydrocarbon prospectivity of Nigeria's Inland Basins from the Viewpoint of organic geochemistry and oganic petrology. *Am. Assoc. Pet. Geol.,Bull.,* 88(3), 325– 353.

Obaje, N. G. (2009). *Geology and mineral resources of Nigeria.* Lecture Notes in Earth Sciences. Springer, Berlin Heidelberg.

Ofor, N. P. (2014). *Determination of curie point depth and assessment of geothermal potential of the Sokoto Basin, Nigeria. Using Aeromagnetic and Aeroradiometric Data.* Ph.D. Thesis Federal University of Technology Minna-Nigeria. 115pp.

Paoletti V., Secomandi, M., Florio G., Fedi, M. & Rapolla, A. (2005a). The integration of remote senIng magnetic data in the Neapolitan volcanic district. *Geosphere,* 1,2, 85-96.

Pipan, M. (2009). *Remote sensing and geophysical methods for geothermal exploration.* A paper presented at the School on Geothermics, organized by ICTP, ICS-UNIDO and IAEA, Trieste, Italy.

Rahaman, M. A. (1989). *Review of the basement geology of Southwestern Nigeria in geology of Nigeria.* Rock View Nigeria Limited, 39 – 56.

Rybach, L. & Buntebarth, G. (1981). Relationships between the petrophysical properties density, seismic velocity, heat generation, and mineralogical constitution. *Earth and Planetary Science Letters*, 57, 367-376.

Rybach, L., Hokrick, R., & Eugester, W. (1988). *Vertical earth heat probe measurement and prospects in Switzerland.* Communication and Proceedings,1, 167 – 372.

Umego, M. N. (1990). *Structural interpretation of gravity and aeromagnetic anomalies over Sokoto Basin, Northwestern Nigeria.* Unpublished Ph.D. Thesis, Ahmadu Bello University, Zaria, Nigeria.

Uwah, E. J. (1984). *Investigation of radiometric anomalies by nuclear and other methods. A case Study of the Sokoto Basin, Nigeria.* Ph.D. Thesis. Ahmadu Bello University, Zaria Nigeria.

Wright, J. B., Hastings, D., Jones, W. B. & Williams, H. R. (1985). *Geology and mineral resources of West Africa.* London: George Allen and Urwin.Pp. 90 – 120.

Zhanxue, S., Andongm W., Jinhui, L., Baoqun, H. & Gongxin, C. (2015). Proceeding *World Geothermal Congress.* 19 – 25.