Original Research Article

Radiogenic Heat Production Due to Natural Radionuclides in Soil and Sediments of Coastal Communities of Okrika Local Government Area of Rivers State, Nigeria

Abstract

Thirty-six samples of soil and sediments were analyzed for radiogenic heat production due to three natural radionuclides from the Coastal communities of Okrika Local Government Area of Rivers state, Nigeria. The analysis was successfully carried out using NaI(Ti) Gamma-Ray Spectrometer to determine the radionuclides elementary composition of soil and sediment samples in terms of ^{40}K, ^{238}U and ^{232}Th respectively. The radiogenic heat production rate of soil ranged from 0.0058 µW/m^3 to 0.0245 µW/m^3 with a mean of 0.01255±0.02 µW/m^3, while for sediment it varied from 0.0030 µW/m^3 to 0.0131 µW/m^3 a mean value of 0.01255±0.02 µW/m^3. The result indicates that the coastal communities of Okrika had shown low radiogenic heat production rate. The soil and sediment samples from the coastal areas of Okrika shows low radiogenic heat production rate. The radiogenic heat production rate rate of soil and sediments was mostly from ^{238}U in the order of ^{238}U > ^{232}Th > ^{40}K. Therefore, the radiogenic heat production rate determined for the coastal communities of Okrika as presented in this study, serves as baseline data and the basis for further investigations/research of its impact in the study area, and also creates a facet for hydrocarbon and geothermal energy resource investigation of the region.

1. Introduction

Radiogenic Heat Production (RHP), in coastal sediments and soil samples is primarily dominated by the contributions from three radioactive elements which are ^{40}K, ^{228}U and ^{223}Th. These radionuclides are characterized by their long half-lives with respect to the age of the Earth, and their relative abundance is an essential aspect of heat-flow analyses, especially for the continental lithosphere [1-2]. The major source of RHP from the Earth's

interior is the heat produced as a result of decayed of radioelements. These major radionuclides, which are significantly abundant in rocks and their emissions are converted to heat from the Earth's interior. Study carried out by Pollack and chapman [3] indicates that the RHP contributes 45% of surface heat flow that is significant over the continents, while another studied carried out by Brady et al., [4] contributed that the magnitude of the RHP exponential decreases with depth. This decrease in magnitude indicates that RHP originated from the superficial layer of the Earth's crust 4-16 Km thick. The amount of RHP in radioactive samples depends on the amount of radionuclides present, rates of decay and their energy of emissions. During radioactive decay mass is converted to energy. The energy emitted by all of these decay processes, consisting of the kinetic energy of the emitted particles and the γ-radiation associated with the different decay processes, is absorbed in the rocks and finally transformed into heat. However, all naturally radioactive substance has the tendency to generate heat to a certain extent. Soil and sediment samples which .

characterized the geologic settings in coastal environment plays a significant role to determine the RHP and to understand the thermal history of and interpretation of continental heat flux data of a given environment [5].

Radionuclides present in the crust and mantle gave rise to the basis of several geophysics and geochemistry in different facets of applications. RHP by naturally radioactive elements in rocks plays a major role in geothermal studies, and very significant in interpretation of continental heat-flow density data. heat-flow density and RHP gives vital information of temperature field and the structure of the Earth's crust and geological settings [6-7].

In this paper, we present results of radioactive heat-production (RHP) measurements of soil and sediment samples of the primary radionuclides (^{40}K, ^{228}U and ^{223}Th) using gamma- ray spectroscopy. The samples were obtained from the coastal communities of Okrika Local Government Areain rivers State, Nigeria, and tthese data will be used to discuss the effects of the RHP rate to ascertain the thermal status of the coastal environment

2. Materials and Methods

2.1 Study Area

Okirika town island located in the southern part of Nigeria. It lies on the north bank of the Bonny River, 35 miles (56 km approximately) upstream from the Bight of Benin. It is also a port town were it can be accessed by vessels of draft of 29 feet (9 metres) or less. After the abolition of the slave trade in the 1830s, It then served as a port for the exportation of palm oil. The major source income of the inhabitants is fishing, with smaller industries including farming, speed boat transportation, and commercial commerce. The study area is lies within latitude: 40.43'44" N to 40.45'57" N and longitude range of 70.3'20" E to 70.6'42" E [8]. It has an estimated population of 222,285 with land mass of 223.487 km^2

(National Population Commission [9]. Okrika Local Government Area is bounded to the north, east, south and west direction by Port Harcourt City, Ogu-Bolo and Eleme, Bonny and Degema Local Government Area respectively. The town plays a host to the Port Harcourt Refining Company (PHRC), a subsidiary of Nigerian National Petroleum Corporation (NNPC) and other minor oil and gas companies within its environs. In addition, it has a jetty and terminal for loading and off-loading crude oil products. Geologically, the study area as well as the entire Rivers State, lies within the Niger Delta Sedimentary Basin. The surface topography in the area slants from the north towards the Atlantic Ocean in the

south. This gentle slope is a major feature of the Niger Delta region. Topographic heights rarely exceed 80 m within Okika town. Okrika area is drained by several creeks and rivers, and Bonny River been one of the major[10].

The map of Okrika town showing the sampled coastal communities which are; Ogan, Kalio, Ibuluya/dikibo, Okochiri, Abam, George, Okoro, Ekerekana-Ama and Main Okrika Island are shown in Figure 1

Fig 1: Study Area
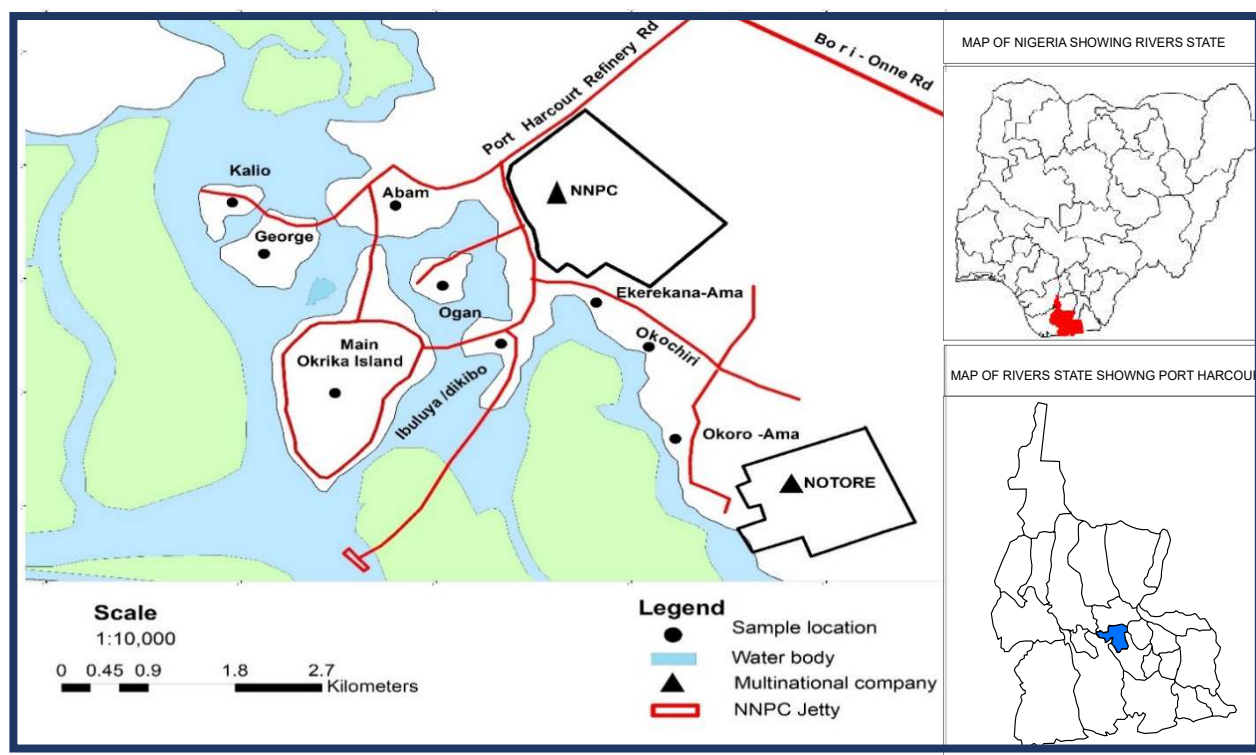
2.2 Sample Collection and Analysis

36 samples of soil and sediments were collected from the coastal communities of Okrika. The location of the sampling points was taken by a Global Positioning System. The samples were packaged in polyethylene bags and transported to the Geology Department of the University of Ibadan. The collected samples were, air dried to remove moisture, pulverized into a fine powder for the greater surface area using a mini mortar and pestle before homogenized by sieving with a 2mm sieve [11]. Dried samples weighted 0.5kg were measured, packed into a white cylindrical plastic PVC container,

labelled accordingly, sealed and airtight with a paper tape. The containers were sealed and airtight for several weeks to ensure secular radioactive equilibrium[12-13,18], Joshua. The activity concentration measurement was determined using a thallium activated Canberra vertical high purity $2''\times2''$ Sodium iodide NaI(TI) detector connected to ORTEC 456 Digi base amplifier. The detector was connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes. The detector was shielded by 15cm thick lead on all four sides and 10 cm thick

3

on top. The energy resolution of 2.0 keV and relative efficiency of 33% at 1.33Mev was achieved in the system with the counting time of 10800 seconds. The detector limits of the sodium iodide detector used were 0.010, 0.027 and 0.006 Bq/kg for uranium, thorium and potassium respectively.

2.3 Radiogenic Element and Radiogenic Heat Production

The heat generated by long-lived radio-isotopes has been an important heat source during most of Earth's history. These radioactive isotopes must have a half-life comparable to the age of the Earth, the energy of its decay must be fully converted to heat and these isotopes must be sufficiently abundant on nature. The main radio isotopes as earlier stated are the conditions are ^{40}K ^{238}U, ^{232}Th respectively. The isotope 235U has a shorter half-life than 238U and release more energy in its decay,[18]. In this study, an attempt had been made to ascertain the RPH rate produced by the naturally occurring radionuclides present in soil and sediments of the coastal communities of Okrika Local Government Area of Rivers State.. According to [19] the elementary composition of the activity Concentration of ^{40}K ^{238}U, ^{232}Th in terms of ^{40}K(%),^{238}U(pmm) and ^{232}Th(pmm) were calculated using Equation 1- 4

$$1ppm =10^{-4}\% \qquad\qquad 1$$
$$1\%\ ^{40}K =318\ Bq/kg \qquad\qquad 2$$
$$1ppm\ ^{238}U = 12.35\ Bq/kg \qquad 3$$
$$1ppm\ ^{232}Th= 4.06\ Bq/kg \qquad 4$$

The total heat generation A of a rock (soil or sediment) is the sum of the activity concentration of ^{40}K ^{238}U, ^{232}Th indicated as A_k, A_U, and A_{Th} respectively[1, 14].

3. Results and Discussion

The RHP from sediment and soil was computed from the primarily radionuclides from ^{238}U, ^{232}Th, ^{40}K concentration using Equation 1 to 8 as presented in Tables 1 and 2 respectively. ^{232}U is the major elementary radioisotope which predominates in RHP rate. The radiogenic heat production from soil ranged from 0.0058 μW/m^3 at Abam to

$$A=\rho* (C_U A'_U + C_{Th} A'_{Th} + C_K A'_K\ ) \qquad 5$$

Where ρ sediment density

A' and C are the heat generation per mass and concentration of element in soil or sediment.

Having known values of density of the dependent variables the radiogenic heat generation rate can be determined using Equation 2 [1,14]

$$A[\mu Wm^{-3}] = 10^{-5}\ x\ \rho[Kg/m^3]\ *(9.52*C_U\ [ppm] + 2.56*C_{Th}[ppm]+ 3.48*C_K[\%]) \qquad 6$$

Where concentration is given in weight-ppm, weight-ppm and weight-% for ^{238}U ^{232}Th and ^{40}K respectively. The density of the sediments and soil were 0.25 kg and diameter (6.5 cm) and height (6.0 cm) [1,14].

$$\text{Density of Sediment} = \frac{Mass}{Volume} \qquad 7$$
$$= \frac{0.25}{\pi r^2 h} \qquad 8$$

Where $\pi r^2 h$ is the volume of the sample collected, Equation 4 was used to generate the value of the density for each of the sediment/soil sample obtained from the coastal communities of Okrika Local Government Area of Rivers State.

0.0245 μW/m^3 at George-Ama with a mean of 0.01255±0.02 μW/m^3, while for sediment it varied from 0.0030 μW/m^3 at Kalio-Ama to 0.0131 μW/m^3 at Ekerekana-Ama a with an average value of 0.01255±0.02 μW/m^3. The computation of the RHP of soil and sediment computed from the coastal communities are is less than 1 μW/m^3 as displayed in Figure 2 to

3 for respectively. The contribution to RHP rates of both soil and sediment of the coastal areas of okrika is majorly ^{238}U followed by the least ^{40}K in the order of ^{238}U > ^{232}Th > ^{40}K. The results obtained from this study is similar to the study on heat production rate from radioactive elements of granite rocks and southern Arabia kingdom of Saudi Arabia (Abbay and Al-Ghamdi, 2019). Table 3 shows the comparison of other authors who carried out similar research on RHP rates.

Table 1. Mean **Concentration of ^{40}K, ^{238}U ,^{232}Th and Radiogenic Heat Production in Soil**

		MEAN ACTIVITY CONCENTRATION (Bq/Kg)			ELEMENTARY ANALYSIS			RHP
S/N	location	K-40	U-238	Th-232	^{226}U(ppm)	^{232}Th(pmm)	^{40}K(%)	A ($\mu W/m^3$)
1	Main Okika Island	73.63	2.60	4.59	5.9619	0.6404	0.0147	0.0073
2	Ogan-Ama	86.16	7.63	5.66	6.9765	1.8793	0.0181	0.0089
3	Kalio-Ama	129.86	7.78	5.29	10.5146	1.9150	0.0169	0.0131
4	Okochiri	118.12	8.03	6.72	9.5644	1.9778	0.0215	0.0120
5	Ibuluya/Dikibo	141.12	9.21	7.57	11.4263	2.2685	0.0242	0.0143
6	Abam/Igbiri	56.91	3.47	6.84	4.6077	0.8547	0.0218	0.0058
7	George-Ama	231.55	27.05	5.54	18.7486	6.6626	0.0177	0.0245
8	Okoro-Ama	128.18	11.02	7.24	10.3785	2.7143	0.0231	0.0132
9	Ekerekana-Ama	131.35	14.49	7.45	10.6352	3.5677	0.0238	0.0138
	Mean							**0.01255±0.05**

BDL = below detectable limit

Table 2. Mean **Concentration of ^{40}K, ^{238}U ,^{232}Th and Radiogenic Heat Production in Sediments**

|		MEAN ACTIVITY CONCENTRATION (Bq/Kg)			ELEMENTARY ANALYSIS			RHP
S/N	location	K-40	U-238	Th-232	^{226}U(ppm)	^{232}Th(pmm)	^{40}K(%)	A ($\mu W/m^3$)
1	Main Okika Island	56.00	4.93	2.60	4.5344	1.2143	0.0083	0.0058
2	Ogan-Ama	76.92	2.99	3.24	6.2283	0.7365	0.0104	0.0077
3	Kalio-Ama	22.88	10.15	3.37	1.8526	2.5000	0.0108	0.0030
4	Okochiri	79.44	8.61	4.02	6.4320	2.1195	0.0128	0.0083
5	Ibuluya/Dikibo	81.93	BDL	2.69	6.6328	BDL	0.0086	0.0079
6	Abam/Igbiri	64.70	1.97	2.99	5.2385	0.4852	0.0096	0.0064
7	George-Ama	98.78	6.32	2.90	7.9984	1.5554	0.0092	0.0100
8	Okoro-Ama	116.90	5.59	3.37	9.4652	1.3768	0.0108	0.0117
9	Ekerekana-Ama	130.35	6.90	3.83	10.5543	1.6983	0.0122	0.0131
	Mean							**0.00821±0.003**

BDL = below detectable limit
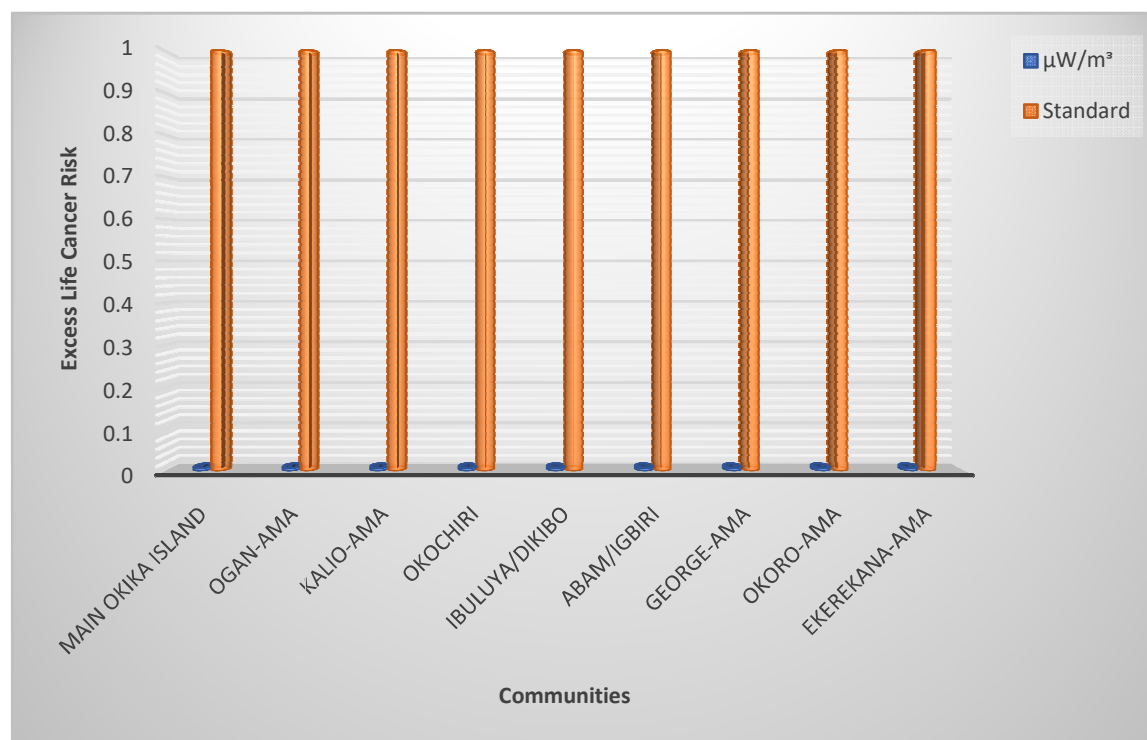
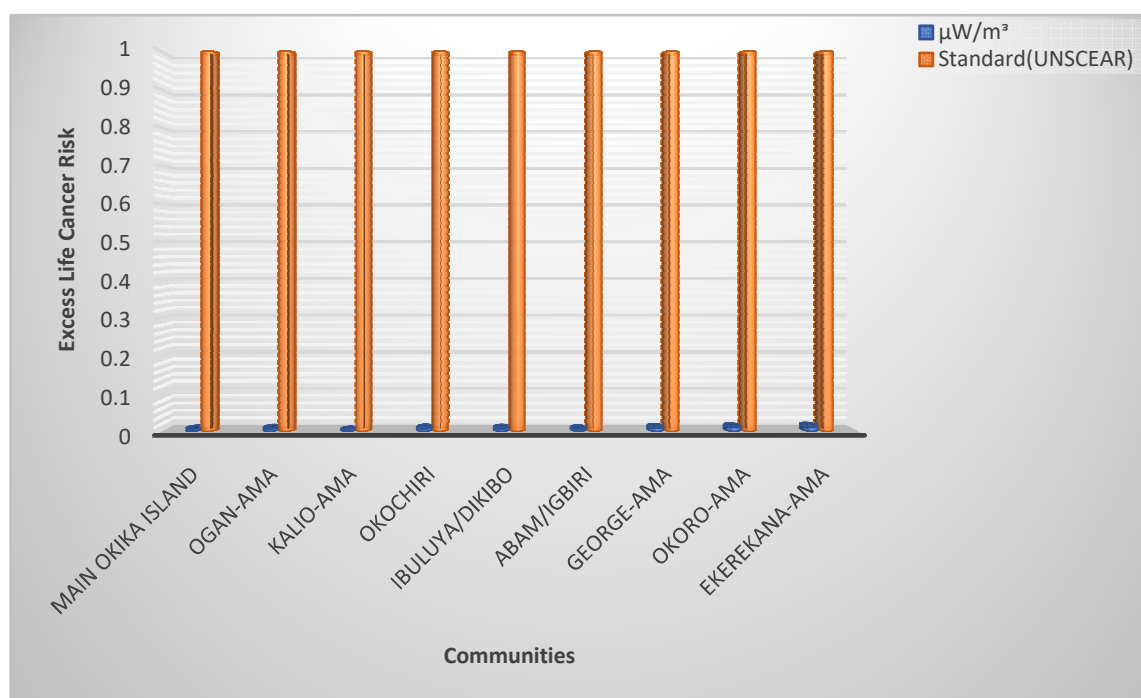Fig 2.   Heat Production in Soil in comparison with world standard average (UNSCEAR, 2000)

Fig 3.   Heat Production in Sediment in comparison with world standard average (UNSCEAR, 2000)

Table 3. Comparison of Radiogenic Heat in µW/m^3 obtained with others authors

Location	Sample	A($\mu W/m^3$)			Reference
		Minimum	Maximum	Average	
Bonny, Nigeria	Soil	0.0750	1.7958	0.7564±0.05	[14]
	Sediment	0.0286	2.5094	0.6002±0.06	
Ogun (Nigeria)	Sediment	0.28	0.91	0.48±0.1	[1]
Chad basin (Nigeria)	Sediment	0.17	1.90	0.90±0.01	[15]
Enugu (Nigeria)	Soil	0.39	1.9	0.95	[16]
Niger Delta Basin (Nigeria)	Soil	0.0000014	0.004	0.0006	[17]
Okrika, Nigeria	**Soil**	**0.0058**	**0.0245**	**0.01255±0.05**	**This work**
	Sediment	**0.0030**	**0.0117**	**0.00821±0.003**	**This work**

4. Conclusion

The RHP of soil ranged from 0.0058 $\mu W/m^3$ to 0.0245 $\mu W/m^3$ with a mean of 0.01255±0.02 $\mu W/m^3$, while for sediment it has maximum value of 0.0030 $\mu W/m^3$ and minimum value of 0.0131 $\mu W/m^3$ with a mean value of 0.01255±0.02 $\mu W/m^3$. The soil and sediment samples from the coastal areas of Okrika show low RHP rate. The RHP rate of soil and sediment was mostly from ^{238}U in the order of $^{238}U > {}^{232}Th > {}^{40}K$.

Therefore, the RHP rate determined for the coastal communities of Okrika as presented in this study, serves as baseline data and the basis for further investigations/research of the impact of radiogenic heat in the study area. This study also creates a facet for hydrocarbon and geothermal energy resource investigation of the study region.

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COMPETING INTERESTS DISCLAIMER:

8