Journal of Physics: Conference Series

PAPER • OPEN ACCESS

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To cite this article: T.A. Adagunodo *et al* 2019 *J. Phys.: Conf. Ser.* **1299** 012074

Radiogenic Heat Model in the southern axis of Ogbomoso, SW Nigeria

T.A. Adagunodo [1], O.G. Bayowa [2], A.I. Ojoawo [3], M.R. Usikalu [1], M. Omeje [1]

[1] Department of Physics, Covenant University, Ota, Nigeria
[2] Department of Earth Sciences, Ladoke Akintola University of Technology, Ogbomoso, Nigeria
[3] Department of Physics, University of Ibadan, Ibadan, Nigeria

Corresponding email: taadagunodo@yahoo.com; obayowa@lautech.edu.ng

Abstract. This study is aimed at estimating the radiogenic heat model in the southern part of Ogbomoso, Nigeria. In-situ measurements of activity concentrations of radioelements are randomly taken at seven locations. The individual data point is measured four times, while the average was recorded for accuracy. The results showed that the radiogenic heat produced per radionuclide varies from 28.71 to 143.55 ρW kg^{-1} for ^{238}U; 89.60 to 217.60 ρW kg^{-1} for ^{232}Th; 0.0010 to 0.0063 ρW kg^{-1} for ^{40}K; with mean values of 73.83, 151.04 and 0.0033 ρW kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively. The total radiogenic heat production in the study area varies from 136.23 to 303.73 ρW kg^{-1}, with mean value of 224.87 ρW kg^{-1}. It is shown that thorium is the major contributor to the total heat generated in the study area. The study area is characterized by low heat production potential, which could be attributed to depletion of thorium and uranium in the geological rocks in the environs. Comprehensive radiometric survey to cover the entire city is recommended. This will help in characterization of the radiogenic heat produced per geological unit.

Keywords: Radiogenic heat model, Geodynamic process, Decayed radioelements, Geogenic heat, Ogbomoso

1. Introduction

The major source of heat from the Earth's interior is the heat produced as a result of decayed radioelements. During decay process of radioisotopes in rock and soil, there is emission of alpha, beta and gamma particles, which in turn generates the radiogenic heat experienced in the Earth's interior [1]. This source of geogenic heat is responsible for all the geodynamic processes [2]. The rate of radiogenic heat production (that is, amount of radiogenic heat per unit time) only depends on the concentrations of radioelements presents in soil and/or rock, and independent of the sock/soil parameters, such as pressure and temperature [3].

Thermal assessment of the lithosphere is important, because it helps to understand the heat generating potential of the Crust and the nature of the Mantle. The fundamental elements that are mostly responsible for this terrestrial heat flow and Earth's internal heat are the ^{238}U, ^{232}Th and ^{40}K isotopes [4]. The radiogenic heat is produced when the kinetic energy emitted during the decay processes of the long-lived radioactive elements is absorbed internally by the rocks (and its weathering products), which later results to geogenic heat. The assessment of radiogenic heat produced in an environment will shed light on the geothermal systems within than region.

In this study, in-situ radiometric survey of ^{238}U, ^{232}Th and ^{40}K concentrations in the southern axis of Ogbomoso, SW Nigeria were measured using Super-Spec Gamma Ray Spectrometer. Assessment of the heat produced by the decayed radioelements within the Crust in the study area will assist to understand the geothermal potential of the environment.

2. Geological Settings of the study area

Ogbomoso is bounded by latitude 8° 2´– 8° 11´ N and longitude 4° 7´– 4° 22´ E. In this study, the southern part of the city is considered (latitude 8° 3´– 8° 7´ N and longitude 4° 12´– 4° 16´ E). The study area resides within the Basement Complex rocks of SW Nigeria (Figure 1), which are of Precambrian in age [5-20]. These SW rock units have been classified by Rahaman in 1988 as Migmatite-Gneiss-Quartzite complex [21]. As reported by [22], the rocks have been resolved into granite-, banded-, agmatite- and augen- gneisses, as well as schistose quartzite unit (Figure 2). The gneisses are of syenogranite to granodiorite in origin, while the quartzites appear as elongated ridges in NW-SE orientation [22]. The quartzites in Ogbomoso are mostly schistose, with micaceous minerals, which at some points appear as quartzofeldspar. These appearances dominate the southern part of Ogbomoso. Another dominant rock unit in Ogbomoso south is the variation of migmatite and agmatite gneisses. Evidences of tectonic activities are revealing in the outcrops around the study area.

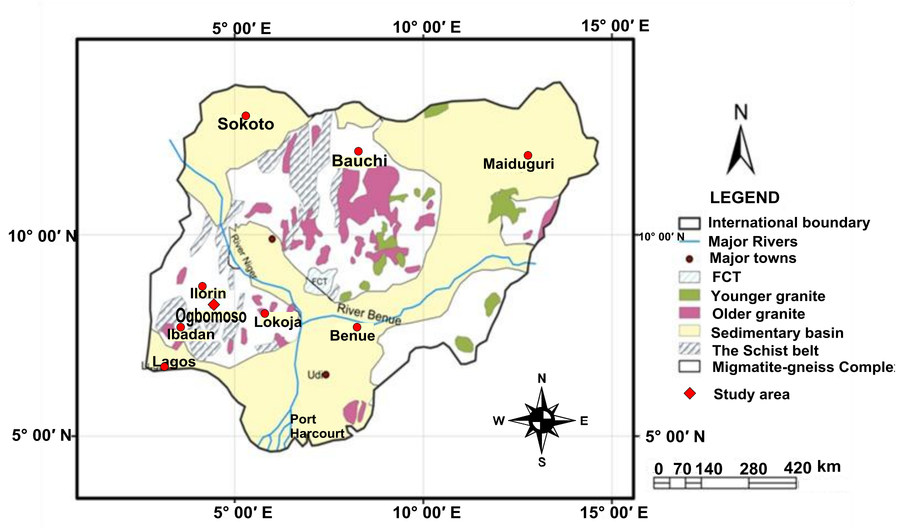

Figure 1: Geologic map of Nigeria (Adapted and modified from [15] and [24])

3. Material and Methods

In-situ radiometric survey to measure the concentrations of uranium (eU), thorium (eTh) and potassium (K) was carried out in the southern part of Ogbomoso, SW Nigeria. The data were randomly taken at seven locations in the southern part of the city using Super-Spec gamma ray spectrometer. The data were acquired in December, 2017. The equipment used is capable to detect the major three radioisotopes (^{238}U, ^{232}Th and ^{40}K) in the Crust at 1 m above the earth's surface. The measurements at a spot were done four different times (which culminate to a total data point of twenty-eight), whereby the mean value of these readings represent the measurement at that location. The equipment was manufactured by Canadian Geophysical Institute. It is an electronic device with, an inbuilt detector, large storage capacity, digital display unit, high sensitivity, and accuracy of about 95%. This device displays the measured eU and eTh in part per million (ppm); and K in percentage concentration (%). Additional record about the working principle and data acquisition mode of this equipment has been reported by [25] and [26]. The radiogenic heat (Q) produced by subsurface radioactivity with concentrations of uranium (C_U), thorium (C_{Th}) and potassium (C_K) can be determined by Eq. (1) as proposed by Rybach [27]. This equation has been as applied by [4] and [28]. Hence, the obtained radioactivity data were used to model the radiogenic heat produced in the southern part of Ogbomoso, SW Nigeria.

$$Q = 0.00348\,(C_K) + 95.2\,(C_U) + 25.6\,(C_{Th}) \tag{1}$$

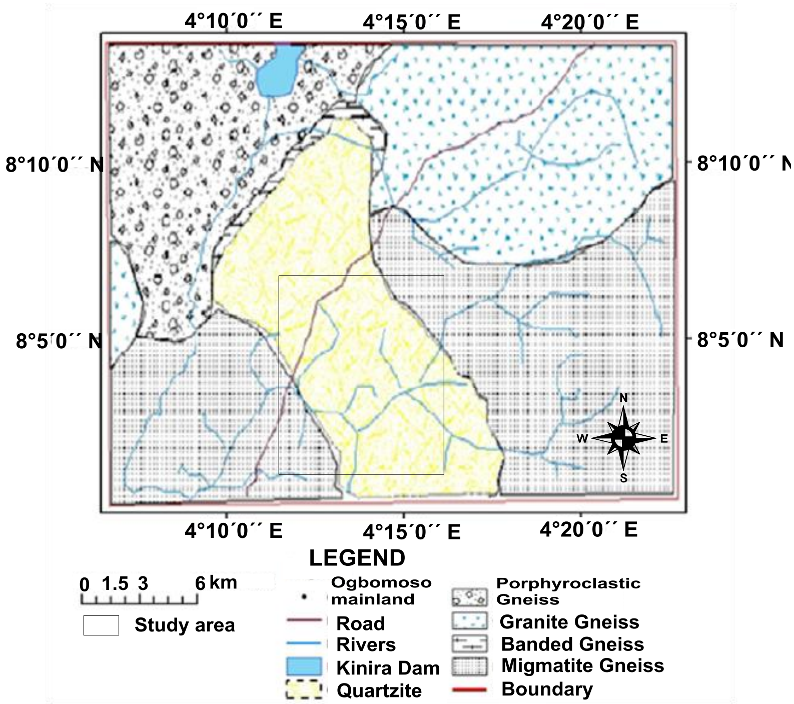

Figure 2: Geological map of Ogbomoso (Adapted from [23])

4. Results and Discussion

The concentrations of radioisotopes and the heat produced as a result of individual contributions of ^{238}U, ^{232}Th and ^{40}K in the southern part of Ogbomoso are presented in Table 1. The activity concentrations of ^{238}U varied from 0.3 to 1.5 ppm, with mean value of 0.77 ppm; ^{232}Th varied from 3.5 to 8.5 ppm, with mean value of 5.90 ppm; and ^{40}K varied from 0.3 to 1.8%, with mean value of 0.96%. The radiogenic heat production by the three radioisotopes in the southern part of Ogbomoso varied from 28.71 to 143.55 ρW kg^{-1} for ^{238}U; 89.60 to 217.60 ρW kg^{-1} for ^{232}Th; 0.0010 to 0.0063 ρW kg^{-1} for ^{40}K; with mean values of 73.83, 151.04 and 0.0033 ρW kg^{-1} for ^{238}U, ^{232}Th and ^{40}K respectively. The total radiogenic heat production (Q) in the southern part of the city varied from 136.23 to 303.73 ρW kg^{-1}, with mean value of 224.87 ρW kg^{-1}. Since $Q < 750$ ρW kg^{-1}, the study area is characterized by Low Heat Production Potential (LHPP) [29].

IOP Conf. Series: Journal of Physics: Conf. Series **1299** (2019) 012074 doi:10.1088/1742-6596/1299/1/012074

As revealed in Figure 3, the percentage distribution of radioelements in the study area showed that ^{238}U and ^{232}Th shared 32.8 and 67.2% of the radiogenic heat produced, while contribution from ^{40}K is negligible. This revealed that thorium is the major contributor to Q in the study area. This is in agreement with the studies of [29] and [30], which were carried out in the Benue Trough of Nigeria and Ogun River axis, south-west Nigeria. Unusual high concentration of a particular radionuclide does not imply high radiogenic heat production rate [31], the generation of Q in an area is as a result of contributions from the three radioisotopes.

The total radiogenic 2D model of the study area in Figure 4 revealed that there is an outward flow of Q in SW-NE trend. Though the entire study area is characterized by LHPP, increase in trend is experienced in the upper half of the study area. By comparing the geological map of the city (Figure 2) to the total radiogenic map in the study area (Figure 4), it could be inferred that Quartzite and Migmatite Gneiss produced emission of decayed radioelements equally (Figure 5). This emission has generated the low radiogenic heat in the study area. The LHPP in the study area could be as a result of thorium and uranium depletion (homogeneity) in the geological formations of the study area. Only granitic rocks that are consolidated after the thermal peak in the last metamorphism are associated with high Q [30].

Table 1: Radioactivity concentrations and potential radiogenic heat production in the southern part of Ogbomoso

Location	Radioactivity concentrations			Heat produced per radioelement			Total heat produced (Q)
	^{238}U (ppm)	^{232}Th (ppm)	^{40}K (%)	^{238}U (ρW kg^{-1})	^{232}Th (ρW kg^{-1})	^{40}K (ρW kg^{-1})	(ρW kg^{-1})
RHM 1	0.5	8.4	1.8	47.85	215.04	0.0063	262.90
RHM 2	1.2	3.5	0.7	114.84	89.60	0.0024	204.44
RHM 3	1.5	5.1	1.5	143.55	130.56	0.0052	274.12
RHM 4	0.5	7.2	1.0	47.85	184.32	0.0035	232.17
RHM 5	0.9	8.5	0.9	86.13	217.60	0.0031	303.73
RHM 6	0.5	4.4	0.5	47.85	112.64	0.0017	160.49
RHM 7	0.3	4.2	0.3	28.71	107.52	0.0010	136.23
Mean	0.77	5.90	0.96	73.83	151.04	0.0033	224.87

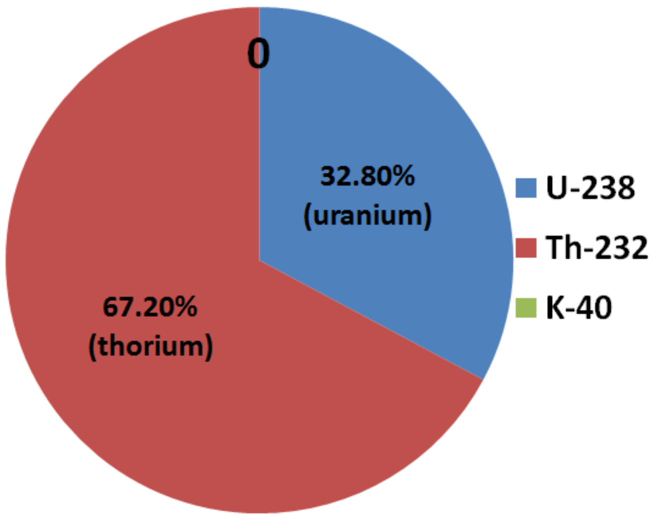

Figure 3: Heat produced per radioelement (%)

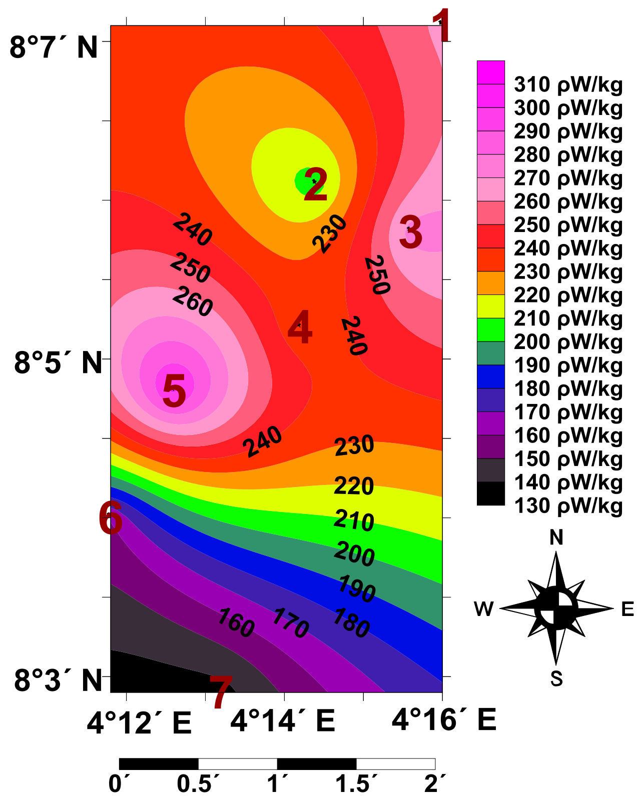

Figure 4: Total radiogenic heat model in southern part of Ogbomoso

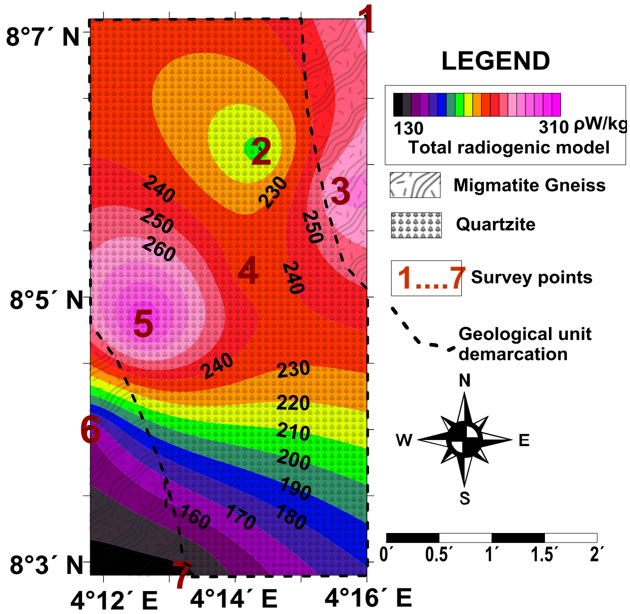

Figure 5: Composite map of the total radiogenic model in the study area

5. Conclusion

The estimated heat produced per radionuclide showed that thorium is the major contributor to the total radiogenic heat in the study area. The computed radiogenic model showed that the lower half of the study area is characterized by extremely LHPP, while there is increase in the radiogenic heat towards the upper half. Generally, the study area is characterized by LHPP, which is a representation of homogenized crystalline rocks. Comprehensive radiometric survey to cover the entire city is recommended. This will help in characterization of the radiogenic heat produced per geological unit.

Acknowledgment

We appreciate the partial conference support received from the Centre for Research, Innovation, and Discovery, Covenant University, Nigeria.

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