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Assessment of radiogenic heat generation in a flood plain of crystalline Basement rocks

Assessment of radiogenic heat generation in a flood plain of crystalline Basement rocks

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Abstract. Concentrations of radioelements in a flood plain of Crystalline Basement Complex are determined, with the aim of assessing the radiogenic heat produced in the study area. Ten soil samples are collected for analysis using Inductively Coupled Plasma Mass Spectrometry technique from ACME Laboratories. The radiogenic heat contributions by each radioelement in the flood plain varied from 95.70 to 393.37 ρw/kg; 71.68 to 642.56 ρw/kg; and 0.0088 to 0.0188 ρw/kg for uranium, thorium and potassium respectively. However, the total radiogenic heat production varied from 167.39 to 1034.9 ρw/kg, with thorium being the major contributor to the total heat generated in the study area. Nine locations in the study area are characterized by Low Heat Potential (LHP), while the remaining one is characterized by Moderate Heat Potential. On average, the study area could be classified as LHP, which is in agreement with some of the studies in crystalline terrain of Nigeria.

Keywords: Radiogenic heat generation, flood plain, Crystalline Basement rocks, Geothermal energy, Radioisotopes

1. Introduction

Geothermal Energy is the heat produced by the Earth. Its source of power generation is reliable and dependable, because it contains no emission of greenhouse gasses, and therefore categorized as renewable [1]. Out of the three (3) sources of geogenic heat production (heat generated during accretion and formation of the planet, frictional heating of the outer core and the radioactive heat production), the heat produced as a result of decayed long-lived radioelement (that is, radioactive heat production) is the major geogenic heat source of the Earth, which governs all the geodynamic activities [2]. Various geophysical techniques are available for geothermal exploration, which vary from potential field applications (magnetic [3-4] and gravity methods [5]), magnetotellurics [6-7], seismic [8-9], geochemical thermometrics [10-12], shallow temperature measurements [13-15] to radiometrics [16-17]. In the quest for choosing the most suitable technique for ones study, it depends

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on the advantages and disadvantages of each method. For example, some methods become inactive for deep exploration due to sensitivity issue, while some lack maturity under rugged conditions [18].

Gamma radiometric survey entails investigation of nuclear emission from rock which contains radioactive minerals. The major elements that are of interest in this kind of survey are uranium (^{238}U), thorium (^{232}Th) and potassium (^{40}K) [19]. Its survey can either be airborne or ground (in-situ or laboratory). Applications of radiometric survey have been noticed of recent in mapping of geological structures [20-21], mineral exploration [22-24], geothermal exploration [25], and variations of radioelements in different rock formations [26-34]. In addition, demand for nuclear fuels in the last few decades has made radiometric survey important in geothermal exploration [18].

In Nigeria, geothermal exploration is vital because it reduces necessity for importation of fuels for power generation. Contributions from radioelements in the subsurface to geothermal heat production would assist in the assessment of potential zones for geothermal resources and its possible exploitation. In this study, ground radiometric survey was used to determine the concentrations of radioelements in the soil of Odo-Oba, a flood plain zone in southwestern Nigeria. This study will help to understand the thermal history of the study area.

2. Geological Settings and the Study area

The flood plain is situated some kilometers away from the southwest of Ogbomoso, Oyo State, Nigeria. It is bounded by longitude 4.00222 – 4.25250° east and latitude 8.77889 – 8.97556° north, with the mean height above the sea level of 267 m. Due to the flooding activities in the study area, deposition of the Quarternary sediments has been so enhanced. The dwellers around the zone are majorly into farming and fishing [35]. The drainage pattern and the climatic conditions of the study area have been discussed by [29], [32] and [35].

The flood plain zone of Odo-Oba is concealed within the Precambrian Basement rocks of southwestern Nigeria (Figure 1a), which are majorly composed of crystalline and metamorphic rocks of over 550 million years old [32, 36-38]. This geological domain is made up of meta-sedimentary, gneiss and older granites [29, 37, 39-52]. The notable rocks in the study area include banded gneiss, granite gneiss, and quartzite (Figure 1b).

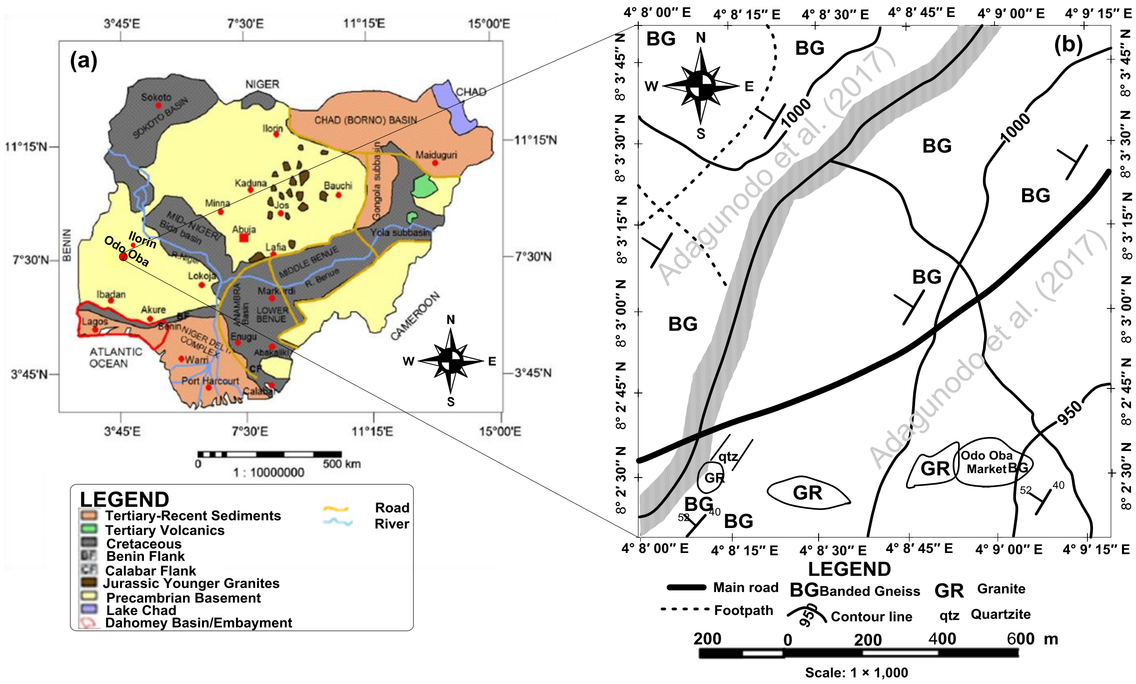

Figure 1: (a) Geology of Nigeria (b) Geology of Odo-Oba (Adapted from [32] and [35]).

3. Materials and Methods

Ground survey was carried out over a flood plain zone in Odo-Oba, where soil samples were randomly taken at ten (10) locations, and packaged individually into polythene bag. The samples were keenly labeled on the field for proper identification. The labeled samples were air-dried and sieved, such that the specs and unwanted materials could be removed from the samples. Each of the sieved samples was packaged in a plastic container and transported to ACME Laboratories for analysis. The Inductively Coupled Plasma Mass Spectrometry analysis was used to determine the concentrations of uranium, thorium and potassium in each soil sample. The units of three radioelements analyzed in this study were recorded in parts per million (ppm) for uranium and thorium, while potassium was recorded in percentage concentration (%). The sample's collection and laboratory analysis procedure used in this study have been reported by [29] and [32]. In order to determine the radiogenic heat produced in the study area, the Rybach's et al. model [53] was adopted. The radiogenic heat produced (Q) due to radioactivity of ^{238}U, ^{232}Th and ^{40}K in rocks, soil or sediments can be obtained using Eq. (1). This model has recently been used by [1] and [18] to determine the radiogenic heat produced over granitic domains in Nigeria.

$$Q = 95.70C_U + 25.60C_{Th} + 0.00348C_K \quad (1)$$

where, C_U, C_{Th} and C_K are the concentrations of ^{238}U, ^{232}Th and ^{40}K in the analyzed samples.

4. Results and Discussion

The concentrations of ^{238}U, ^{232}Th and ^{40}K in the flood plain zone are presented in Figures 2 (a-c). The uranium concentrations varied from 1.00 to 4.10 ppm, with the mean value of 2.38 ppm; thorium concentrations varied from 2.80 to 25.10 ppm, with the mean value of 10.90 ppm; and potassium concentrations varied from 2.52 to 5.41%, with the mean value of 3.52% respectively. By applying the radiogenic model as presented in Eq. (1), individual radioelement contribution to the total radiogenic heat production are presented in Table 1. The radiogenic heat contributions by each radioelement in the flood plain varied from 95.70 to 393.37 ρw/kg; 71.68 to 642.56 ρw/kg; and 0.0088 to 0.0188 ρw/kg for uranium, thorium and potassium respectively. The mean values of 227.77, 279.04 and 0.0123 ρw/kg were recorded for ^{238}U, ^{232}Th and ^{40}K respectively.

In order to determine the variability strength of the contributions by the radioelements, the Standard Deviation (SD) value for each isotope is obtained. The SD for ^{238}U, ^{232}Th and ^{40}K are 98.71, 164.86 and 0.0032 ρw/kg respectively. The coefficient of variation (CV) obtained for: uranium is 43.34%, thorium is 59.08%; and potassium is 26.06% respectively. Estimation of CV is to determine the heterogeneity and/or homogeneity of dataset. The CV $\leq$ 50% is said to be homogeneous (low variability), while CV $\geq$ 50% is said to be heterogeneous (high variability) [54-56]. The estimated CV in the study area revealed that uranium and potassium are homogeneous, while thorium is heterogeneous. The major contributor to the total heat produced in the study area is thorium. As reported by [32], the study area is greatly enriched by thorium. The anomalously high contributions from thorium might be due to the transportation of thorium-rich materials from far distance to the plain during the deposition of the Quaternary sediments in Odo-Oba. The results obtained in this study corroborate with the assessments of [57] and [58]. This might be due to the deposition of sediments in the study area over years.

As presented in Figure 3, the total radiogenic heat production (Q) in the study area varied from 167.39 to 1034.94 ρw/kg, with the mean value of 506.82 ρw/kg. The study area can be categorized as Low Heat Potential (LHP) zone, which is in agreement with the studies of [1] and [18], which were carried out over a Basement Complex rocks.

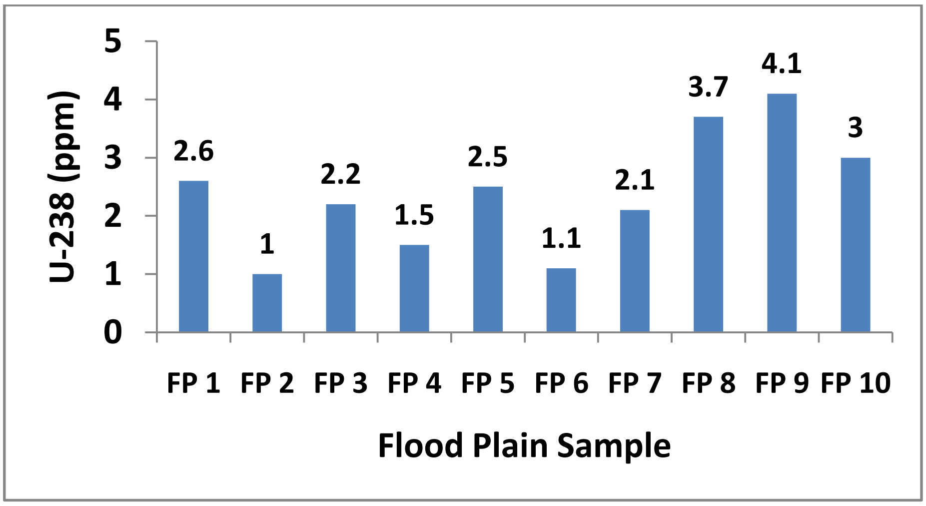

Figure 2a: concentration of uranium in the study area

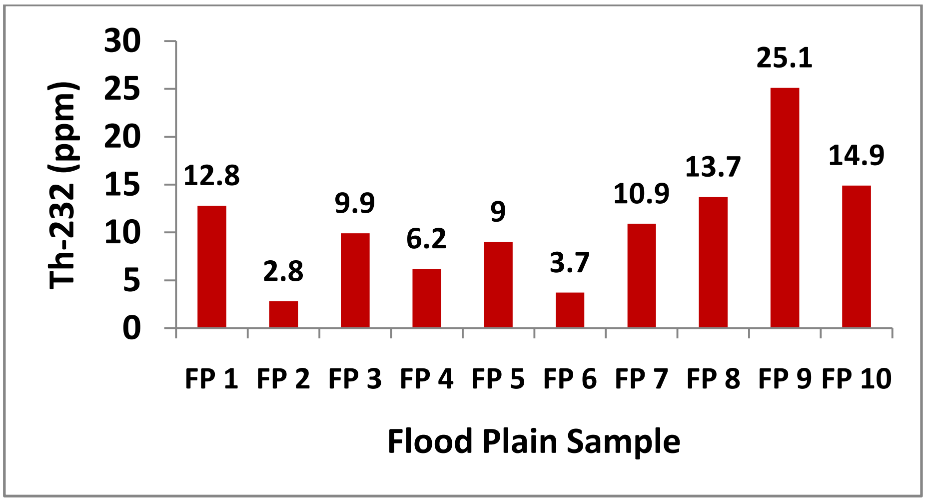

Figure 2b: Concentration of thorium in the study area

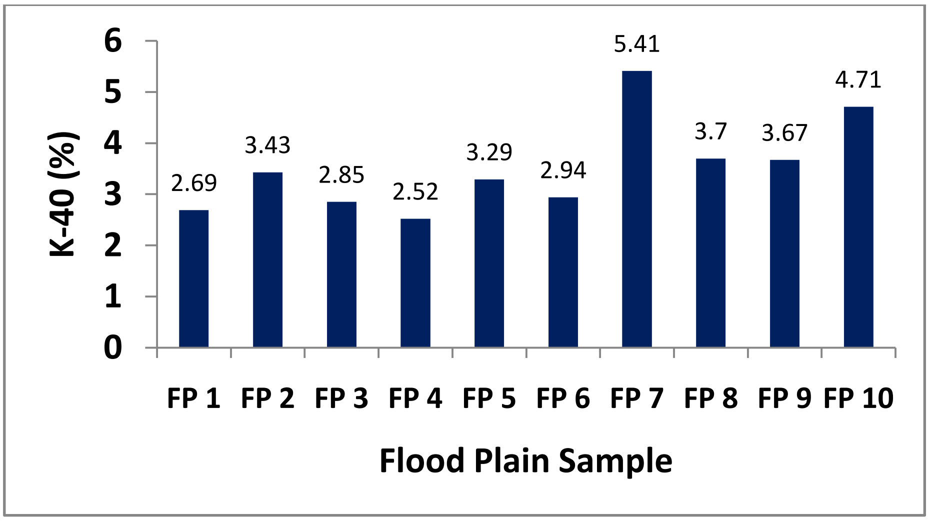

Figure 2c: Concentration of potassium in the study area

Table 1: Radioelement contributions to heat production in the study area

Sample	^{238}U (ρw/kg)	^{232}Th (ρw/kg)	^{40}K (ρw/kg)
FP 1	248.82	327.68	0.0094
FP 2	95.70	71.68	0.0119
FP 3	210.54	253.44	0.0099
FP 4	143.55	158.72	0.0088
FP 5	239.25	230.40	0.0114
FP 6	105.27	94.72	0.0102
FP 7	200.97	279.04	0.0188
FP 8	354.09	350.72	0.0129
FP 9	392.37	642.56	0.0128
FP 10	287.10	381.44	0.0164
Mean	227.77	279.04	0.0123
SD	98.71	164.86	0.0032
Range	95.7 – 392.37	71.68 – 642.56	0.0088 – 0.0188
CV	43.34	59.08	26.0614

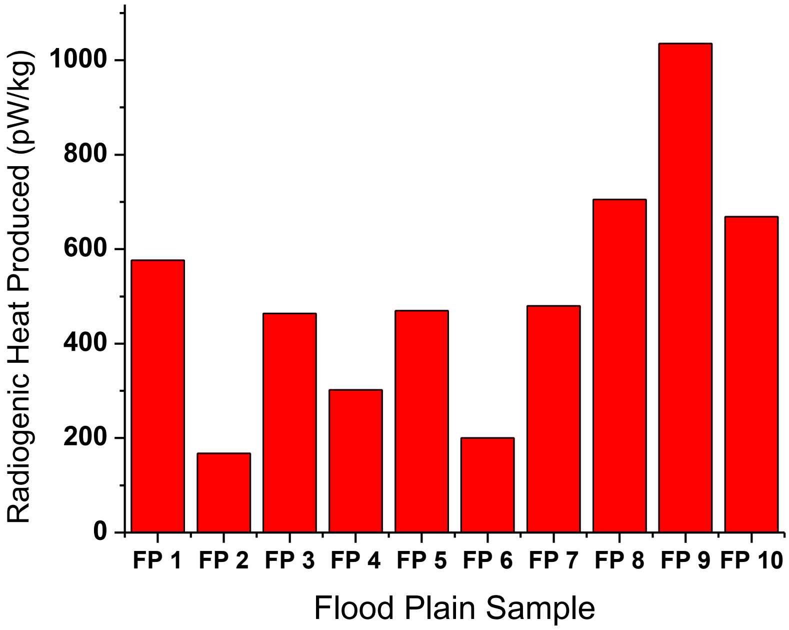

Figure 3: Radiogenic heat production in the study area

5. Conclusion

This study has revealed the radioisotopes present in the ten (10) soil samples collected in a flood plain, over crystalline rocks of SW Nigeria. The contributions by radioisotopes in the samples are in the order $^{232}Th > ^{238}U > ^{40}K$, with thorium being the only heterogeneous radioisotope in the study area. The total radiogenic heat production in the study area varied from 167.39 to 1034.9 ρw/kg, with the mean value of 506.82 ρw/kg. The study area is characterized by LHP.

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