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Modeling Heat flow from Radiogenic Heat properties of some common rock samples and its significance to geothermal modeling

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ABSTRACT

A radiometric survey was carried out on rocks in Ikogosi warm spring vicinity using a Gamma ray spectrometer. The survey covered three different rock series of granites, quartzite and gneisses with a total of 79 data points acquired due to inhibition. The Radiogenic Heat Production values varied from 0.21 to 3.31 $\mu Wm^{-3}$with mean value of 1.39 μWm^{-3}. The granites series have the highest heat production followed by gneisses and quartzite series. In the same way, Thorium have the highest values of concentration followed by Uranium and Potassium as least with values of 24.3, 7.6 and 3.55 ppm respectively. The heat production data were also used to compute heat flow for the area and the results indicated a wide range in heat flow values with granites rocks ranging between 4.01 and 23.92 $mWm^{-2}$with an average of 10.99 ± 5.82 mWm^{-2}while the gneis is series ranged between 1.64 and 13.95 $mWm^{-2}$with an average of 7.18 ± 4.07 mWm^{-2}. Also the quartzites series ranged between 8.24 and 27.73 $mWm^{-2}$with an average of 15.95± 4.10 mWm^{-2}. The heat flow for Ikogosi warm spring rocks ranged from 1.64 to 27.73 $mWm^{-2}$with an average of 11.50 ± 5.91 mWm^{-2}.The heat flow estimation may suggest the existence of anomalous heat source body in crust and may be the combined thermal effect of high regional background heat flow level due to radiogenic heat of the crust. Hence the result of the study could be reliable model for estimating heat flow.

Keywords: Heat flow, Radiogenic heat production, Geothermal energy, Thermal structure, Ikogosi area

1. INTRODUCTION

Heat flow and heat production play a very critical role in the study of thermal structure of a region. The Ikogosi warm spring (IKGWS) area have been identified as one of the three known areas in Nigeria with geothermal prospect and It is characterized by distinctly different thermal state and surface thermal manifestations. Several geophysical explorations have been undertaken, but studies on fundamental geothermal system remain scarce, including a lack of high-quality heat flow determinations and thermal structure studies. In this work a heat production and heat flow studies of IKGWS rocks were measured in order to characterize and evaluate the thermal structure and radiogenic heat production for possible geothermal exploration in the region.

Heat is a form of energy and in a sense geothermal energy is the heat contained within the Earth that causes geological occurrences on a global scale as tectonic and volcanic action within the Earth crust. Geothermal energy is the amount of the Earth's heat which can be recuperated and explored by man (Dickson and Fanelli 2004). The heat flow from earth's surface can be divided into three components namely heat from radiogenic decay of radionuclides like Potassium, Uranium and Thorium in the Earth's crust, heat conducted through the lithosphere from the convective mantle feature and orogenic heat convectively transported from magmas and fluids that enter the lithosphere from below during orogenic events (Vitorello and Pollack 1980).

Heat flow and heat production within the subsurface are important factors in the search for geothermal energy investigation. In a bid to ascertain the thermal potential of the Ikogosi warm spring for potential energy generation, heat production data were acquired from the area and were utilized in calculating heat flow of the area. The heat flow distribution of Ikogosi warm spring could give a clearer view of the site to be a potential source of geothermal energy. So we can characterize the subsurface structure from the radiogenic heat production and geothermal flow distribution of the area. The result is expected to make a conviction for harnessing the geothermal energy of Ikogosi warm spring as it is being done in other African countries and the world in entire.

Not much have been done as regards the exploration and utilization of geothermal energy in Nigeria, though limited data are available due to the cost effect of acquiring well logging data. Though geothermal data are not restricted to heat flow measurements alone, other kinds of data are often sought. Earlier studies have been undertaken in southwestern Nigeria and the warm spring in particular has been limited to selected geophysical, geological and geochemical studies (Rogers et al. 1969; Ajayi et al. 1996; Adegbuyi and Abimbola 1997; Oladipo et al. 2005; Adegbuyi et al. 1996; Ojo et al. 2011; Joshua and Alabi 2012; Abraham et al. 2014; Loehnert 1985).

However, in Ikogosi warm spring area and the entire Southwest region, information about thermal studies of the different rock formations of the region is practically non-existent primarily due to a lack of access to equipment for investigations. The doubts in the determination of heat flow initiated by movement of underground water, landscape, and active tectonics in the area, have prevented regular heat flow research. In recent years, however, interest in geothermal studies in the area have been propelled primarily because of the growing realization of the role of thermal evolution in understanding tectonics of the area and assessment of geothermal potential of the hot springs. Thermal conductivity of rock formations of a region constitutes an integral component of any geothermal study. Thermal models so far proposed for the area and other terrains in Nigeria are dependent on assumed values of thermal conductivity of the various rock types (Abraham et al. 2014; Guillot and Allemand 2002; Beaumont et al. 2004; Olorunfemi et al. 2013). These investigations and studies on fundamental geothermal theory remain scarce, including a lack of high-quality heat flow determinations and thermal structure studies. In Nigeria for example some researchers have published related works in the search for geothermal resources most especially in the sedimentary basin but not much have been done in the basement terrain in the southwestern part of Nigeria. It is therefore important to investigate the subsurface of Southwestern region including Ikogosi warm spring using some appropriate geophysical, geochemical and other techniques in order to confirm its potential for exploration of geothermal energy. All rocks contain natural radionuclides such as Potassium, Thorium and Uranium and the radioactivity levels depend strongly on the type of rock. The amount of heat generated is relative to the rate of decay and the amount of radioactive material present at the time. This includes the fact that surface heat flow correlates positively with heat production in particular heat flow provinces (Susumu 1995; 1996).

In this work, we reported the measurements of radioelemental concentrations from different rocks (gneisses, quartzites and granites) that comprise the study area, and dwell upon their implications for geothermal studies in the region and further model the heat flow of the area.

1.1. Geology and Location of Study Area

Generally, the Southwestern region of Nigeria is of basement complex and the Ikogosi Warm Spring (IKGWS) is the only known geothermal spring in the southwestern Nigeria and it is located within latitude 7°35'35.51" to 7°37'36.34" N and longitude 4°55'35.21" to 4°57'23.21" E. Largely, metamorphic rocks of the Precambrian basement complex lie beneath Ekiti State and which the majority are very primordial in age. Ekiti State belongs to geological area of post-cretaceous basement complex (undifferentiated) region, which comprises of shale and sandstone (Adebuyi and Abimbola 1997; Oyinloye 2011). The Ikogosi warm spring area is particularly made of Quartzite and Psalmites. The Ikogosi warm spring area is surrounded and lie beneath massive quartzite and fissile quartzite bedrocks that made up fragment of the Okemesi quartzite, member of the Effon psammite formation in the Ilesha schist belt of Nigerian Basement Complex (Fig.1). The Okemesi quartzite featured a North-South trending ridge underneath by quartz mica schist and quartz sillimanite schist. As a result the Ikogosi warm spring area is surrounded by land forms with quartzite making the highland and river channels signifying valleys. The quartzite constitutes the residual hills covered with gently sloping sediment that post erosion threat to the environment (Oladipo et al. 2005; Ojo et al. 2011).

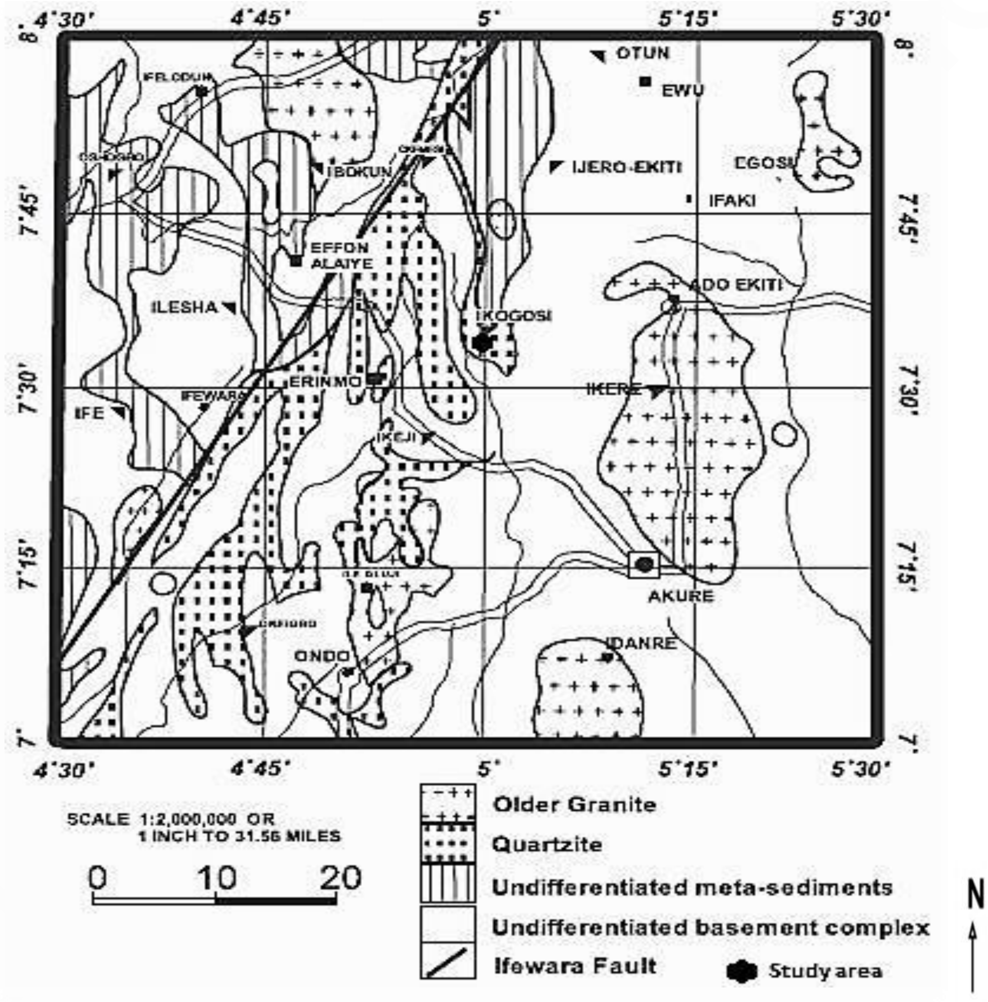


Fig1. Geological Map of Ikogosi warm spring (after Abraham et al. 2014)

2. METHODOLOGY

2.1. Acquisition of Radiometric Data and Estimation of Radiogenic Heat Production (RHP)

The Radiometric data were acquired using an *in-situ* Gamma ray spectrometer with a 3 in × 3 in NaI detector. Radiations from the decay of radioelements (Uranium: ^{238}U, Thorium: ^{232}Th and Potassium: ^{40}K) contained in the outcrop of rock units. This provides the most direct method for measuring the abundance of uranium, potassium and thorium in rock. The gamma-ray energy spectrum emitted from a rock is the sum of the individual characteristic spectra of the radiogenic components. The total signal was analyzed to determine the proportion of each element and measurements can be completed under field or laboratory conditions but the laboratory measurements are considered to be of greater feature and quality.

The study area consists of three main rock types (quartzite, gneisses and granite) and a total of 77 data points was acquired. The measurements were taken in parts per million (ppm) and count per second (cps) and were used to estimate the Radiogenic Heat Production Q_r (•Wm^{-3}) associated with the decay of ^{232}Th, ^{238}U and ^{40}K. This was estimated based on the concentrations of respective radioelements through equation (1) given by Rybach (1986), Emsley (1989) and Jessop (1990) below:

$$H_{RT}(Wm^{-3}) = \rho(96.7*10^{-12}C_U + 26.3*10^{-12}C_{Th}+ 3.5*10^{-11}C_K) \qquad (1)$$

Where ρ is the density of the rock types, C_U, C_{Th} and C_K are the concentrations in ppm of ^{238}U, ^{232}Thand ^{40}K, respectively. The results are presented in Table 1 and summarized in Table 2.

2.2. Heat flow computation

The heat flow was determined in this study by employing an unconventional method of heat flow computations. Heat flow was calculated using the Turcotte and Schubert relationship (Turcotte and Schubert 2002) given in equation (2) as:

$$H_f = \frac{H_{RT}(Mm+Cr)}{S} \qquad (2)$$

Where H_f is the heat flow in (mWm^{-2}), H_{RT} is the total heat production from radioactive decay in the rock; $Mm + Cr$ is the mass of mantle plus crust given as 4 × 10^{24} kg and S is the total surface area of the earth given as 5.1 × 10^{14} m^2. The heat flow computed is presented in Table 1.

3. RESULTS AND DATA DISCUSSION

The measurement of radioelement concentration of 238U, 232Th and 40K radio-nuclides in rocks in the study area showed discrepancy. This is expected and is most likely due to the irregular distribution of the rock types in the area. The average values of the concentration from the radio-nuclides in each rock series and their mean are presented in table 1 and the plots of the link between Radiogenic Heat Production (RHP) and the respective concentration in the different rock series are presented in Figs. 2 and 3. Also the variation of RHP and heat flow distribution maps within the area is presented in Figs.4 and 5 which indicated that the RHP distribution is more concentrated along the NW and SW of the area compared to NE and SE trend. The relatively high rate of concentration, heat flow and heat production values recorded in the quartzite series may be as a result of closeness to the warm spring source associated with metamorphic rocks so the quartzite series has the highest heat production value of 3.54 µWm^{-3} followed by granite with 3.05 µWm^{-3} and gneisis with least value of 1.78 µWm^{-3}.

Rock wise, the granite series had concentration of Thorium as highest followed by Uranium and Potassium respectively and the gneiss series had Potassium as having the highest value of concentration followed by Uranium and Thorium while for the quartzite series Potassium has the highest concentration followed by Uranium and Thorium (table 1).

Generally, in the whole survey area, Thorium has the highest value of concentration (24.3 ppm) followed by Uranium (7.6ppm) and Potassium (2.81 %). It can be observed that the concentration value of Uranium is reasonable in all the series.

Table 1. Heat production (HP) and Heat flow data from major rocks in IKGWS

n	K%	U (ppm)	Th (ppm)	Heat Production (per elemental concentration)			Total Heat Production (µWm^{-3})	Heat Flow (mWm^{-2})	Lithology	Long.	Lat.
				K	U	Th					
1	1.71	4.4	5.9	0.16	1.15	0.42	1.73	13.56	Gneisis	4.98171	7.595528
2	0.57	3.7	3.4	0.05	0.97	0.24	1.26	9.89	Gneisis	4.98128	7.594592
3	1.78	3.8	8.6	0.17	0.99	0.61	1.77	13.89	Gneisis	4.98051	7.59423
5	0.02	1.1	1.2	0	0.29	0.09	0.37	2.94	Gneisis	4.980324	7.593465
6	1.19	2.9	7.1	0.11	0.76	0.5	1.37	10.77	Gneisis	4.980427	7.592103

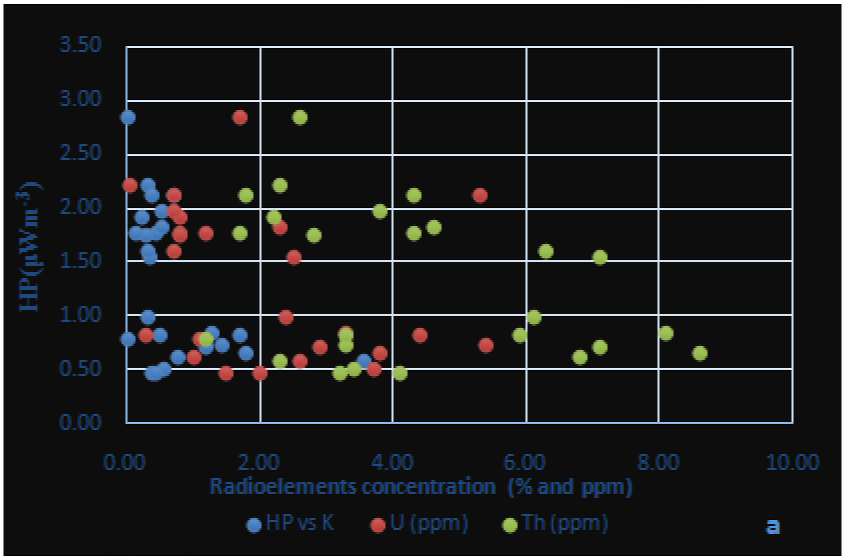
7	0.78	1	6.8	0.07	0.26	0.48	0.82	6.41	Gneisis	4.98321	7.591104
8	1.28	3.3	8.1	0.12	0.86	0.58	1.56	12.22	Gneisis	4.980169	7.590636
9	1.42	5.4	3.3	0.13	1.41	0.23	1.78	13.95	Gneisis	4.979976	7.599806
10	3.55	2.6	2.3	0.34	0.68	0.16	1.18	9.24	Gneisis	4.979997	7.591104
11	0.31	2.4	6.1	0.03	0.63	0.43	1.09	8.54	Gneisis	4.981564	7.590997
12	0.37	2	4.1	0.03	0.52	0.29	0.85	6.65	Gneisis	4.982358	7.591189
13	0.45	1.5	3.2	0.04	0.39	0.23	0.66	5.19	Gneisis	4.983087	7.590317
15	0.51	0.3	3.3	0.05	0.08	0.23	0.36	2.83	Gneisis	4.982959	7.590295
16	0.44	0.8	4.3	0.04	0.21	0.31	0.56	4.36	Gneisis	4.983624	7.590955
17	0.34	2.5	7.1	0.03	0.65	0.5	1.19	9.33	Gneisis	4.984332	7.59038
18	0.32	0.06	2.3	0.03	0.02	0.16	0.21	1.64	Gneisis	4.984396	7.591742
19	0.52	2.3	4.6	0.05	0.6	0.33	0.98	7.66	Gneisis	4.985297	7.596605
20	0.31	0.7	6.3	0.03	0.18	0.45	0.66	5.17	Gneisis	4.985383	7.596693
21	0.3	0.8	2.8	0.03	0.21	0.2	0.44	3.42	Gneisis	4.985083	7.59662
22	0.01	1.7	2.6	0	0.44	0.18	0.63	4.94	Gneisis	4.984997	7.59664
23	0.22	0.8	2.2	0.02	0.21	0.16	0.39	3.03	Gneisis	4.986091	7.59666
24	0.52	0.7	3.8	0.05	0.18	0.27	0.5	3.94	Gneisis	4.986134	7.59668
25	0.72	5.3	4.3	0.07	1.38	0.31	1.76	13.78	Gneisis	4.986993	7.59661
27	0.38	0.7	1.8	0.04	0.18	0.13	0.35	2.72	Gneisis	4.987465	7.59662
28	0.13	1.2	1.7	0.01	0.31	0.12	0.45	3.50	Gneisis	4.98798	7.59651
min	0.01	0.06	1.2	0	0.02	0.09	0.21	1.64			
max	3.55	5.4	8.6	0.34	1.41	0.61	1.78	13.95			
av	0.73	2.08	4.29	0.07	0.54	0.3	0.92	7.18			
sd	0.77	1.53	2.13	0.07	0.4	0.15	0.52	4.07			
29	1.23	1.8	3.7	0.12	0.5	0.28	0.9	7.05	Granite	4.987679	7.59691
30	0.63	1.2	2.2	0.06	0.33	0.17	0.56	4.40	Granite	4.987872	7.59692
31	0.64	1.5	3.2	0.06	0.41	0.24	0.72	5.64	Granite	4.987937	7.59721
32	0.36	2	3.6	0.04	0.55	0.27	0.86	6.74	Granite	4.988945	7.59741
33	0.1	1.9	3.1	0.01	0.53	0.23	0.77	6.03	Granite	4.987143	7.59762
34	0.76	1.7	1.7	0.08	0.47	0.13	0.67	5.29	Granite	4.987765	7.59712
35	0.16	2.4	3.1	0.02	0.66	0.23	0.91	7.16	Granite	4.987659	7.599211
36	0.96	1.4	4.2	0.1	0.39	0.32	0.8	6.27	Granite	4.98211	7.599764
37	0.15	1.8	1.6	0.02	0.5	0.12	0.63	4.97	Granite	4.982122	7.598551
39	0.86	2.3	4.6	0.09	0.64	0.35	1.07	8.38	Granite	4.98221	7.591338
40	0.45	0.1	5.9	0.05	0.03	0.44	0.52	4.05	Granite	4.982112	7.59121
41	0.39	0.4	4.8	0.04	0.11	0.36	0.51	4.01	Granite	4.98221	7.591848
42	0.97	1.3	5.8	0.1	0.36	0.44	0.89	7.00	Granite	4.98171	7.591891
43	1.75	2.5	13.8	0.18	0.69	1.04	1.9	14.94	Granite	4.98162	7.59221
44	1.93	1.7	13.3	0.19	0.47	1	1.66	13.05	Granite	4.98164	7.591933
45	2.24	5.8	7.3	0.22	1.6	0.55	2.38	18.65	Granite	4.98165	7.591614
46	2.02	3.0	12.5	0.2	0.83	0.94	1.97	15.47	Granite	4.98166	7.590423
47	2.66	2.5	10.2	0.27	0.69	0.77	1.72	13.53	Granite	4.98338	7.591104
48	2.12	2.3	13.8	0.21	0.64	1.04	1.89	14.79	Granite	4.98322	7.589359
49	2.26	7.6	9.6	0.23	2.1	0.72	3.05	23.92	Granite	4.98311	7.590104

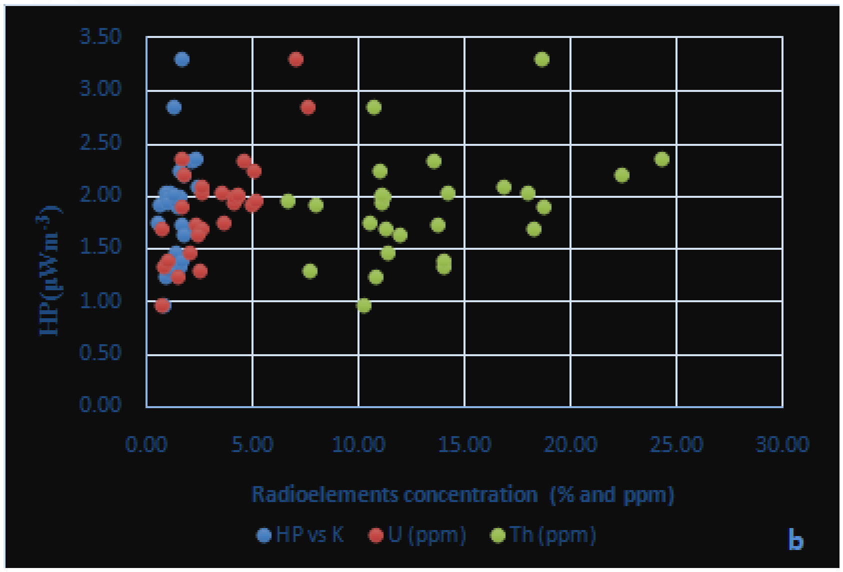
50	1.78	1.7	18.8	0.18	0.47	1.41	2.06	16.18	Granite	4.98301	7.590593
51	2.19	3.3	13.1	0.22	0.91	0.99	2.12	16.61	Granite	4.98322	7.591742
52	2.66	1.7	20.6	0.27	0.47	1.55	2.29	17.93	Granite	4.98281	7.59038
54	2.75	4.7	9.3	0.28	1.3	0.7	2.27	17.84	Granite	4.98271	7.590955
55	2.81	2.1	13.9	0.28	0.58	1.05	1.91	14.96	Granite	4.98271	7.590295
min	0.1	0.1	1.6	0.01	0.03	0.12	0.51	4.01			
max	2.81	7.6	20.6	0.28	2.1	1.55	3.05	23.92			
av	1.39	2.35	8.15	0.14	0.65	0.61	1.4	10.99			
sd	0.93	1.61	5.51	0.09	0.44	0.41	0.74	5.82			
56	2.12	4.6	13.6	0.21	1.27	1.02	2.51	19.67	Quartzites	4.98261	7.590317
57	2.33	0.7	18.3	0.23	0.19	1.38	1.8	14.14	Quartzites	4.98262	7.59641
58	1.51	1.7	18.8	0.15	0.47	1.41	2.04	15.96	Quartzites	4.98261	7.59652
59	1.11	3.6	14.2	0.11	1	1.07	2.17	17.06	Quartzites	4.98251	7.59653
60	1.61	0.8	14	0.16	0.22	1.05	1.44	11.26	Quartzites	4.98254	7.59661
61	0.95	2.6	18	0.1	0.72	1.35	2.17	17.00	Quartzites	4.98252	7.59661
62	1.71	2.3	13.8	0.17	0.64	1.04	1.85	14.47	Quartzites	4.98241	7.59672
63	0.66	5	8	0.07	1.38	0.6	2.05	16.08	Quartzites	4.98242	7.59673
64	1.39	2.1	11.4	0.14	0.58	0.86	1.58	12.37	Quartzites	4.98243	7.59681
65	1.05	4.3	11.1	0.11	1.19	0.83	2.13	16.70	Quartzites	4.98245	7.59682
66	0.95	1.5	10.8	0.1	0.41	0.81	1.32	10.37	Quartzites	4.98231	7.59683
67	0.59	3.7	10.5	0.06	1.02	0.79	1.87	14.68	Quartzites	4.98232	7.59691
68	1.04	2.5	7.7	0.1	0.69	0.58	1.37	10.78	Quartzites	4.98233	7.59692
69	0.82	0.7	10.3	0.08	0.19	0.77	1.05	8.24	Quartzites	4.98221	7.59693
70	1.03	4.1	11.1	0.1	1.13	0.83	2.07	16.25	Quartzites	4.98222	7.59694
71	1.75	1.8	22.4	0.18	0.5	1.68	2.36	18.49	Quartzites	4.98223	7.59714
72	1.65	7.1	18.7	0.17	1.96	1.41	3.54	27.73	Quartzites	4.98224	7.59716
73	2.32	2.6	11.3	0.23	0.72	0.85	1.8	14.13	Quartzites	4.98225	7.59718
74	2.32	1.7	24.3	0.23	0.47	1.83	2.53	19.84	Quartzites	4.98212	7.59712
75	1.27	7.6	10.7	0.13	2.1	0.8	3.03	23.79	Quartzites	4.98214	7.59713
76	2.39	2.6	16.9	0.24	0.72	1.27	2.23	17.49	Quartzites	4.98216	7.59714
77	1.77	2.4	12	0.18	0.66	0.9	1.74	13.67	Quartzites	4.98218	7.59721
78	1.67	1	14	0.17	0.28	1.05	1.5	11.74	Quartzites	4.98222	7.59731
79	1.42	5.2	6.7	0.14	1.44	0.5	2.08	16.35	Quartzites	4.98223	7.59721
80	1.59	4.1	11.2	0.16	1.13	0.84	2.14	16.75	Quartzites	4.98112	7.59731
81	1.6	5.1	11	0.16	1.41	0.83	2.4	18.81	Quartzites	4.980222	7.59522
82	1.3	4.3	11.1	0.13	1.19	0.83	2.15	16.90	Quartzites	4.98333	7.59541
min	0.59	0.7	6.7	0.06	0.19	0.5	1.05	8.24			
max	2.39	7.6	24.3	0.24	2.1	1.83	3.54	27.73			
av	1.48	3.17	13.4	0.15	0.88	1.01	2.03	15.95			
sd	0.52	1.84	4.35	0.05	0.51	0.33	0.52	4.10			

Table 2. Summary of Heat production and Heat flow data from major rocks in IKGWS

Lithology	**N**		**K (%)**	**U (ppm)**	**Th (ppm)**	**A (μWm^{-3})**	**Heat Flow (mWm^{-2})**
Quartzite (IKGL1)	22	min	0.01	0.06	1.20	0.21	8.24
		max	3.55	5.40	8.60	1.77	27.73
		av	0.73	2.08	4.29	0.91	15.95
		sd	0.77	1.53	2.13	0.51	4.10
Gneiss (IKGL2)	28	min	0.10	0.10	1.60	0.48	1.64
		max	2.81	7.60	20.60	2.86	13.95
		av	1.39	2.35	8.15	1.31	7.18
		sd	0.93	1.61	5.51	0.69	4.07
Granite (IKGL3)	27	min	0.59	0.70	6.70	0.98	4.01
		max	2.39	7.60	24.30	3.31	23.92
		av	1.48	3.17	13.40	1.90	10.99
		sd	0.52	1.84	4.35	0.49	5.82

A= Heat Production; IKGL1= Quartzite series; IKGL2= Gneiss series; IKGL3= Granite series





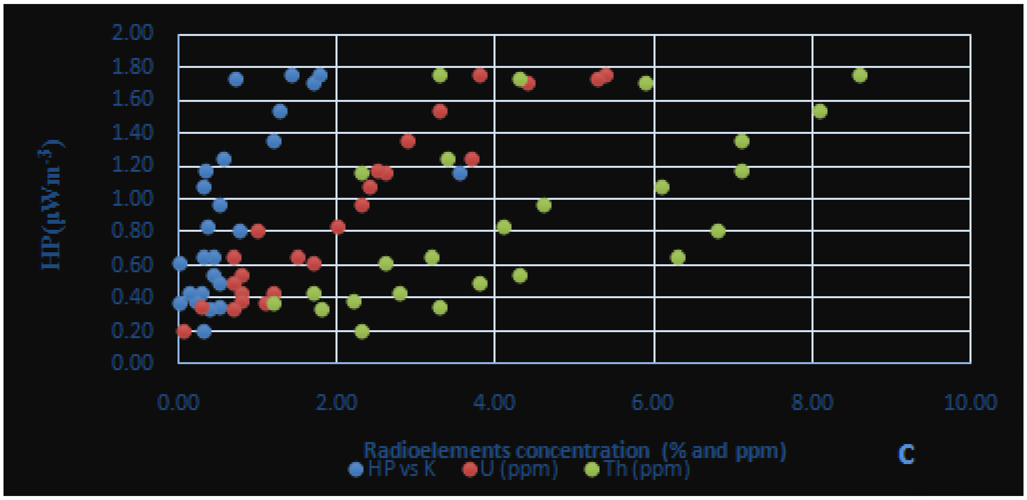
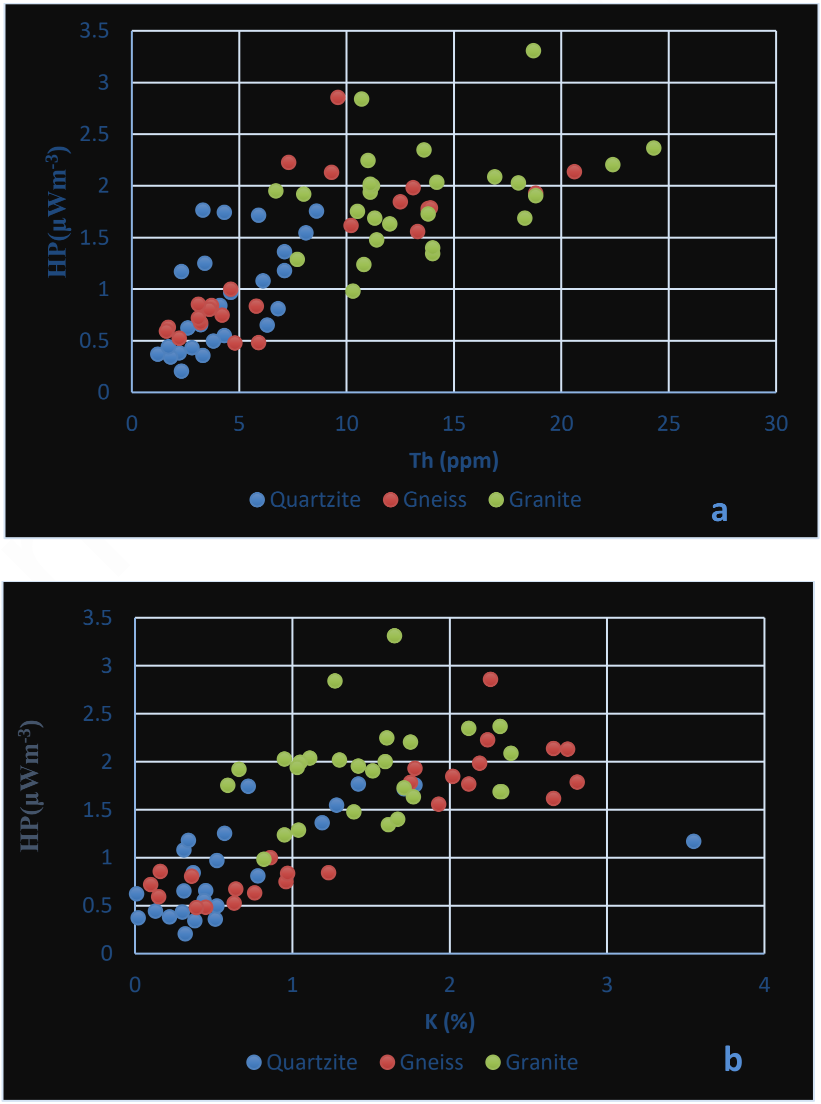


Fig 2.Total Heat Production VsRadioelement conc. of IKGWS for: (a) Gneisis (b) Granites (c) Quartzites



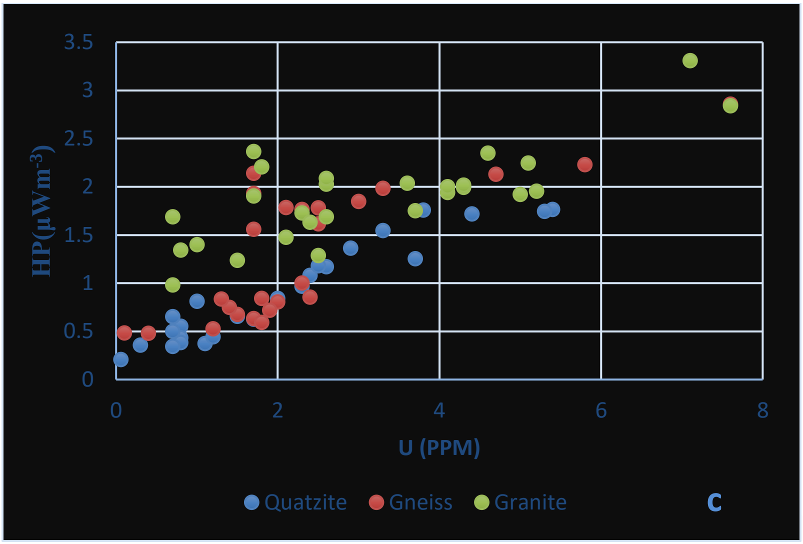


Fig 3.Total Heat Production Vs conc. of eachradioelement in all rock types in IKGWS for (a) Thorium (b) Potassium (c) Uranium

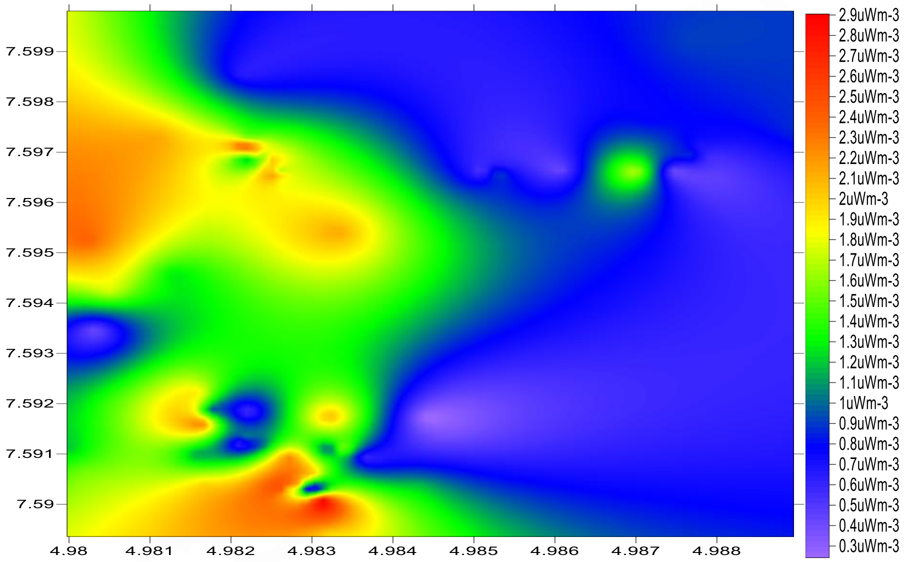


Fig 4. Heat Production distribution map for all rocks in IKGWS

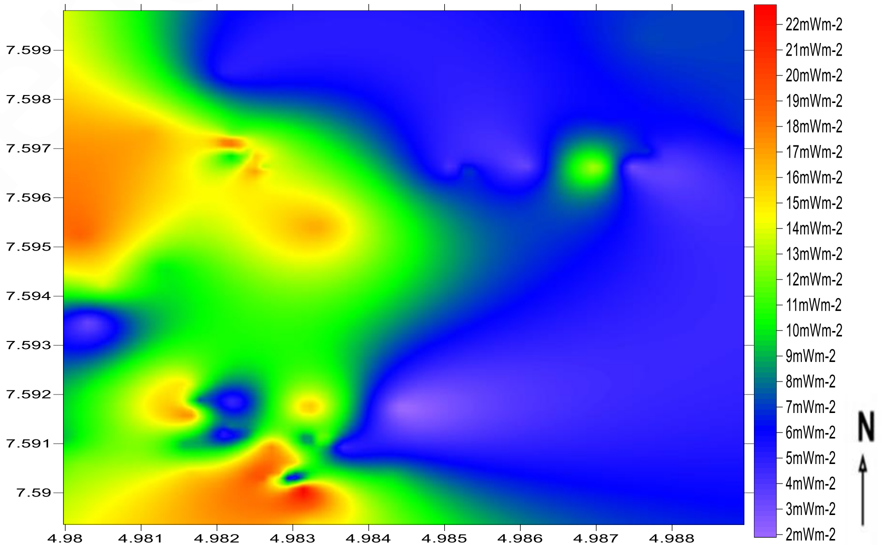


Fig 5. Heat flow distribution map for all rocks in IKGWS

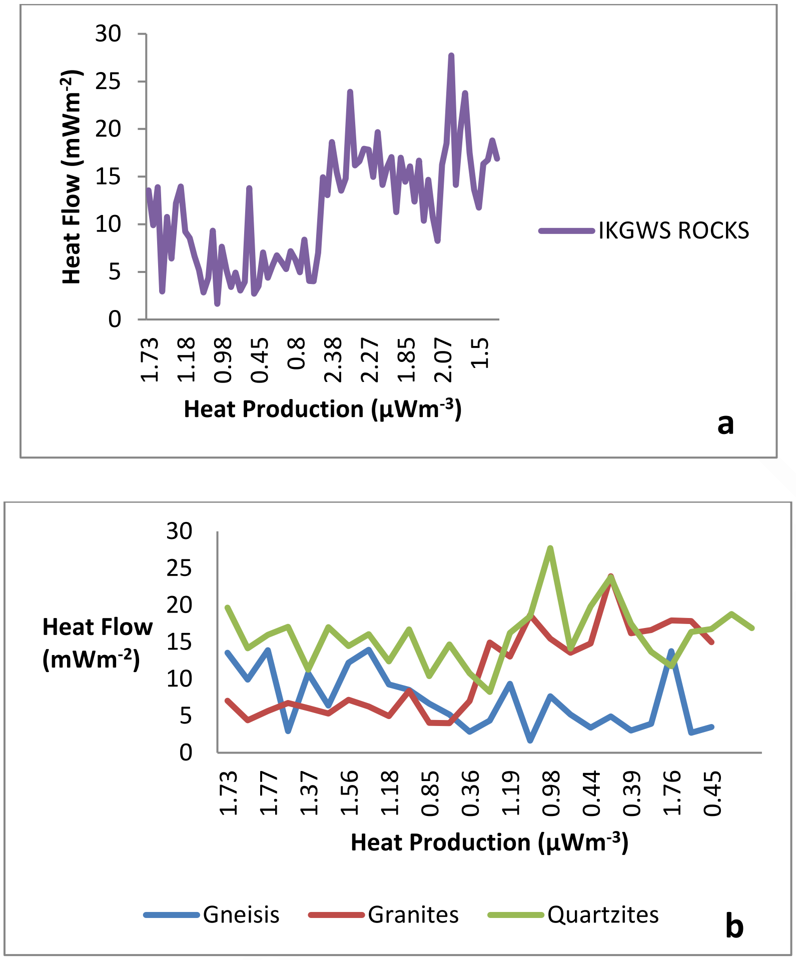


Fig 6. Heat flow, Q (mWm^{-2}) Vs Heat Production, *A* (µWm^{-3}) for, (a) all rocks in IKGWS; (b) each rock samples of IKGWS

Comparing the results with Cermak et al. (1990) whose work published heat generation data for a number of rock types from West Germany, Switzerland and Italy, their findings are regionally biased and clearly indicate greater heat production in acidic, as opposed to basic, rocks. Acid rocks generate significantly more heat than basic rocks. The relative magnitude of heat source depends on geographic location, but, in general, radiogenic sources are dominant.

A firm relationship exists between surface heat production and heat flow, electrical conductivity, seismic velocity and rock history and this empirical linear relationship between surface heat flow and heat generation in local basement rocks have been established for numerous regions around the globe just like in this work (Fig. 6). Mean surface heat flow progressively decreases with the age of basement rocks in both continental and oceanic settings.

4. CONCLUSION

Heat production and heat flow have been reported for Ikogosi warm spring area with a maximum heat flow value of 28 mW/m^{2}and an average value of 12 mW/m^2. Nevertheless the study area is devoid of thermal gradient, thermal conductivity data. In absence of these data, we have tried to model heat flow from diverse varieties of rocks obtainable in Ikogosi warm spring area from the analysis of heat production data (Tables 1-2) with the application of measured or mathematical model. The measured radioelement concentrations (Th, U, K) in rocks (quartzite, gneisses and granites) of IKGWS have an average heat production value of 1.4µWm^{-3}and heat flow values of 12mWm^{-2}. The Heat flow and heat production of these rocks varies in a wide range from 2 to 28 mWm^{-2} and 0.2 to 3.5 µWm^{-3}. Thus, from thermal point of view, the area consists of heterogeneous rocks with large variability in thermal properties.

Conventional heat flow data in Nigeria is very less. Though some heat flow estimation in Southwest Nigeria has been through CPD estimation by assuming a constant Curie temperature and rock Thermal conductivity values like the work of (Abraham et al., 2014) whose value for heat flow was 91.2 mWm^{-2}. This is very wide comparing with this present work.

This model give values within 5-10% of from the measured values from works of Brigaud and Lucazeau (1985) from the West Africa Shield (Nigeria, Ghana and Liberia) with values ranging between 30-40 mWm^{-2} and Verheijen and Ajakaiye (1979) with average value of 38.5 mWm^{-2}.Since there is no precise heat-flow, borehole or well logging data published from the Southwest region so far, this model could be reliable and consistent for the computation of heat flow values for the comparable rocks in the area using radiometric data. Apparently, no far-reaching conclusions can be drawn from a few measurements. There is need to have direct measurements of Bottom hole temperature (temperature-depth data) in Ikogosi area to have a near accurate evaluation and assessment of the geothermal potential of the area. To date, Ikogosi geothermal resource have not been explored in terms of Temperature-Depth profile. This is expected to give a clue to the heat flow mechanism and geothermal potential in the area.

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Conflict of interest

The author declares that they have no conflict of interest.

Data and materials availability

All data associated with this study are present in the paper.

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