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Ground Radiometric Survey and Geothermal Energy Investigation In Ikogosi Warm Spring, Ekiti, Southwestern Nigeria

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Abstract

Gamma-Ray Spectrometer was used to measure radiations from natural radionuclides in Ikogosi warm spring in order to determine the pattern of natural radioactivity, elemental concentration and radiogenic heat production emanating from surface rock units. The pattern of Radiogenic heat production rates of surface rock units at Ikogosi warm spring was determined through quantitative determination of concentrations of Uranium, Thorium and Potassium isotopes in the rock units. The radiogenic heat production rates ranged from Below Detectable Limit (BDL) to 0.0098 pW/kg for ^{40}K, BDL to 622.08 pW/kg for ^{232}Th and BDL to 723.52 pW/kg for ^{238}U. The Total heat generated or production from the radionuclide (THP) varied from 65.59 pW/kg to 1154.65 pW/kg and a mean value of 454.59 pW/kg for the study area. The measurement of radioactive contents (2.46 ppm U, 8.61 ppm Th and 1.18 % K) of surface rocks obtained for the area appears to be comparatively high enough to be a geothermal resource potential in comparison with other know geothermal sites in the world. The average total heat production in the study area is a manifestation of the geological rock types. Uranium has the highest heat production; followed by 232Th and 40K has the lowest. The ratio of 238U contribution to radiogenic heat production with respect to 232Th and 40K is 1.0:0.57:0.000018.

Keywords: Gamma-ray spectrometer, radiogenic heat, concentration, geothermal, Ikogosi

Introduction

Radiometric survey is one of the geophysical techniques in use in exploration for geothermal energy, which is generated mainly from the decay of long-lived radioactive isotopes.

The use of radiation (alpha-α, beta-β and gamma-ɣ) emanating from the decay of radioactive element contained in the rock unit around the study area is of particular interest. The most useful of these radiations in radiometric survey are gamma radiations. They are usually among the decay products of radioactive elements such as Uranium, Thorium and Potassium (K-40). Of all known radioactive elements, only those of Uranium, Thorium and Isotopes of Potassium (K-40) are of importance. The rest are either so rare or so weakly radioactive or both as to be of no significance in applied geology. It is therefore important to investigate the pattern of contribution of radionuclide to the geothermal system of the area as this will help to understand its potential for exploration of geothermal energy [11, 12].

The radiogenic heat sources present in continental earth crust contributes significantly to the total surface heat flow and temperature distribution in the crust [12]. One of the ways to achieve greater accuracy in subsurface interpretation is by the use of radiation (alpha-α, beta-β and gamma-ɣ) emanating from the decay of radioactive element contained in the rock unit. The most useful of these radiations in radiometric survey are gamma radiations [11].

Radiogenic heat production decreases with depth. The concentrations of Uranium and Thorium in rocks are generally in trace amounts measured in parts per million, while Potassium is much more abundant in the range of few percent of which a small but well-known fraction is the radioactive K-40. The global mean value of heat production in the continental crust is 65±1.6 mW/m2 of which about 30mW/m2 is attributed to radiogenic heat production within the crust; the rest is due to heat supplied to the lithosphere by convective processes in the deeper mantle [8, 10]. The origin of radioactive elements in rocks is linked directly with the crystallization of magma. The Ikogosi warm spring is absolutely a geothermal system because it is made up of four main elements: a heat source, a reservoir, a fluid, which is the carrier that transfers the heat, and a recharge area. The heat source is generally a shallow magmatic body, usually cooling and often still partially molten [9]. For this geothermal energy to be explored, a series of geophysical techniques is needed to be applied. The geophysical surveys are directed at obtaining indirectly, from the surface or from shallow depth, the physical parameters of the geothermal systems [4, 6]. Considering the limitations of the various methods, it is probably necessary to use an integrated geophysical approach. As a part of the ongoing research work, one of the geophysical methods (Radiometric survey) was used in order to determine the pattern of radiation emanating from radioactive elements contained in rock formations so as to validate the existence of geothermal activities of Ikogosi warm spring and to generate heat production data to support existing data in Nigeria.

Material and Methods

Study Area Description

The study area is situated in the southwestern part of Nigeria and located between geographic latitudes 7°35′30″ N and 7°35′45″ N and geographic longitude 4°58′45″E and 4°58′54″ E (Figure 1). It is situated between lofty steep-sided and heavily wooded, north-south trending hills about 27.4 km east of Ilesha, and about 10.4 km southeast of Effon Alaye [3]. The spring is a low enthalpy system, with temperature being around 38.6°C as at last average measurement taken for six months (morning and night). The geothermal system discharges a virtually constant volume of water all year round. It is a popular national tourist attraction. The Ikogosi area is underlain by Basement Complex rocks of southwestern Nigeria.

Radiometric Measurements

The study area was divided into nine profiles of warm, cold and mixed sections (P1-9). Across these 9 profiles, eighty two (82) measurements were taken with the use of a Gamma-ray spectrometer (model DISA-300) placed 5cm above the rock surfaces and a measurement interval of 5 m was adopted for each profile points with their respective coordinates taken by a GPS. Total profile distances of about 410 m were occupied across the study area. The measurements were taken in parts per million (ppm) and count per second (cps). The concentrations in ppm was then converted to Bq/kg as using the conversion template in Table 1. The obtained values were used to calculate the Radiogenic Heat Production rate Qr (pW/kg) presented in Table 2 which is related to the decay of radioactive isotopes of 232_{TH}, 238_U and 40_K and can be estimated based on the concentration (C) of the respective elements [5] through equation below:

$$Qr = 95.2CU+25.6CTh+0.00348CK \quad (1)$$

where CU, CTh and CK are the concentrations in ppm of U-238, Th-232 and K-40 in each surface radiations respectively.

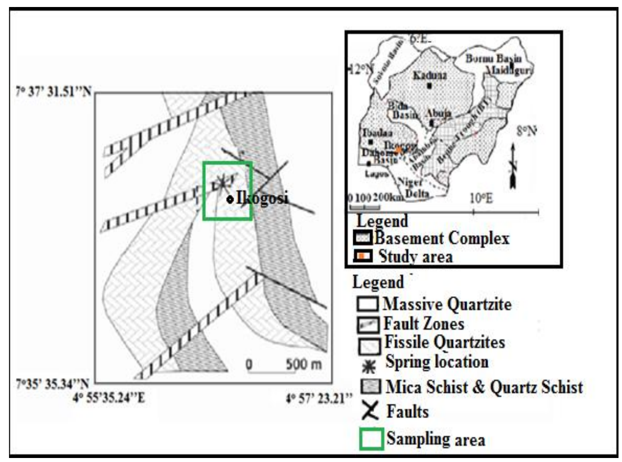

Figure 1. Location and geological map of the study area [1]

Table 1. Conversion factors from Becquerel to Parts per Million [2]

Radionclides	K-40	U-238	Th-232
Bq/kg	0.030259	12.222222	4.074074
PPM	1	1	1

Results and Discussion

The results of the profiles along the warm, cold and mixed sections with their corresponding radioactivity graphs are presented in Figures 2-17 and Tables 2 and 3 respectively.

The Radioactive Heat Production (RHP) rate presented confirmed U-238 as having the highest heat production rate ranging from BDL to 723.52 pW/kg with a mean value of 234.12 pW/kg followed by Th-232 values ranging from 0 (BDL) to 622.08 pW/kg, with a mean of 132. 67 pW/kg and least heat production rate by K-40 with values ranging from BDL to 0.0098 pW/kg. The total heat production rates for the study area ranged from 65.59 to 1154.65 pW/kg and have a mean total heat production rate of 454.60 pW/kg. The surface distribution of the total heat production rate across the study area in form of contour and 3D maps presented in Figures 11-12. Figures 15-17 indicates that areas with close contour lines have high concentrations of radiations and vice-versa. The radiation readings were generally higher for the mixed section (Figures 8-10) than those of warm and cold sections (Figures 2-7). This high rate of concentration recorded in the mixed section (P7-9) may be as a result of nature of the water around the mixed section since the water is a mixture originating from both the warm and cold spring sources associated with igneous rocks such as granite. It was observed that the concentrations of radionuclide in ppm and Bq/kg of Th-232 (2877.11 Bq/kg) had the highest values followed by U-238 (2464.73 Bq/kg) and K-40 2.92 (Bq/kg) as least. This is contrary to the radiogenic heat production (RHP) index. However, Potassium has the highest value of activity concentration in cps followed by (those which dominate in any rock investigation) Uranium and Thorium as trace elements. It was observed that the concentration value of Uranium was moderate in all the profiles. Besides the presence of unconformity surface, fault zone were also observed during the course of taking measurements and their existence in the area further are reflected in the radiometric plots. The major peaks and trough observed in the radioactivity graphs have consistently reflected radioactive element content in different rock units from the area (Figures 2-10).

Generally, radioactive elements (U-238, Th-232 and K-40) are enriched in the residual phases of magmatic differentiation which is associated with the formation of alkaline rocks. There is therefore the likelihood of a Uranium/Thorium bearing unit at a depth in the rock unit of the Ikogosi Warm Spring area. The majority of the continental heat flow originates from the decay of radioactive isotopes in the crust, hence finding areas with high isotope concentration can be equal to finding areas with high heat flow which can be a good prospect for geothermal exploitation [1, 5, 7].

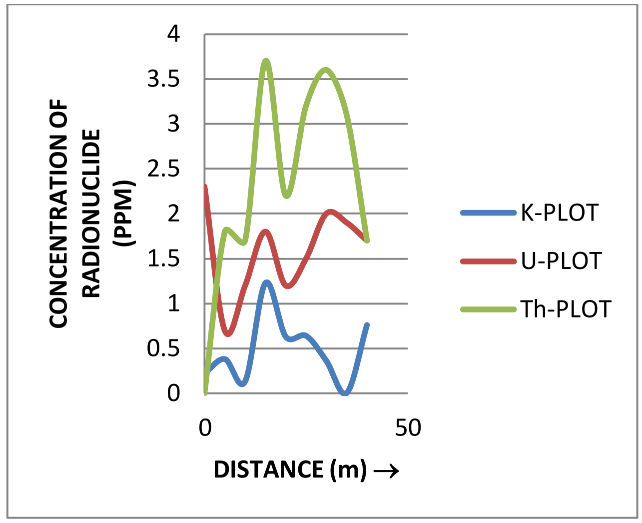

Figure 2. Radionuclide concentration for Profile 1 (Warm section)

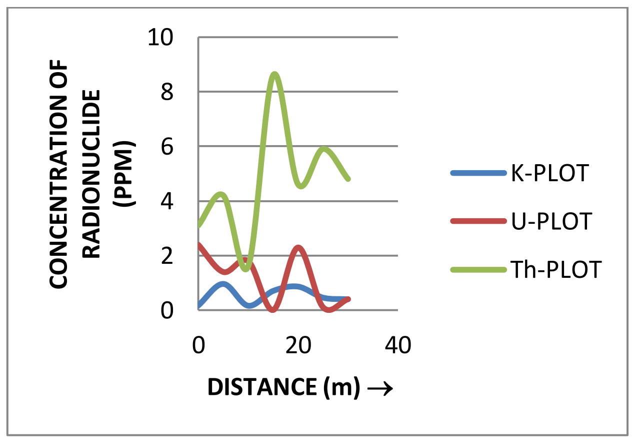

Figure 3. Radionuclide concentration for Profile 2 (Warm section)

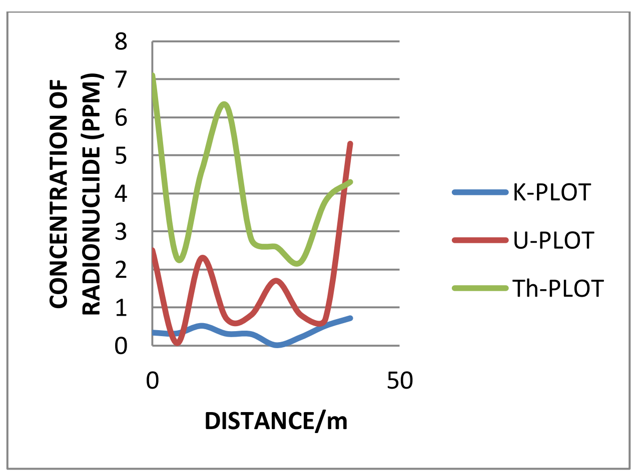

Figure 4. Radionuclide concentration for Profile 3 (Warm section)

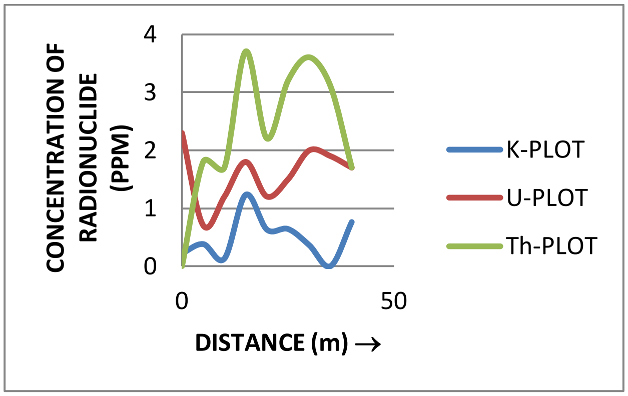

Figure 5. Radionuclide concentration for Profile 4 (Cold section)

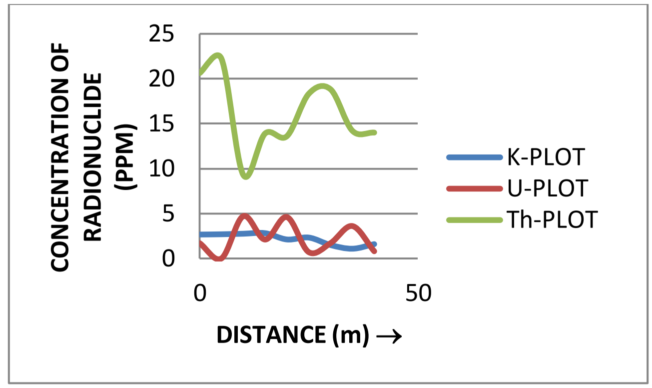

Figure 8. Radionuclide concentration for Profile 7(Mixed section)

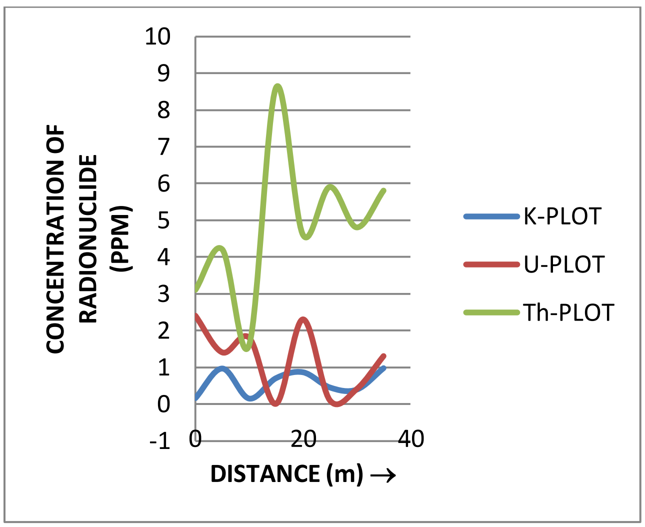

Figure 6. Radionuclide concentration for Profile 5 (Cold section)

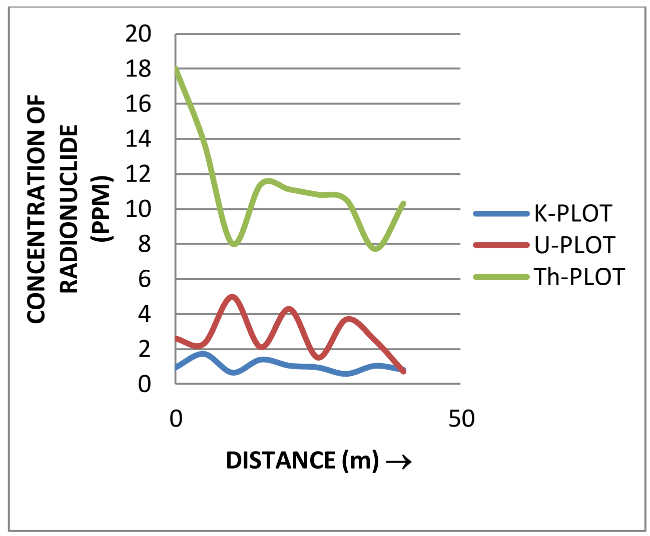

Figure 9. Radionuclide concentration for Profile 8 (Mixed section)

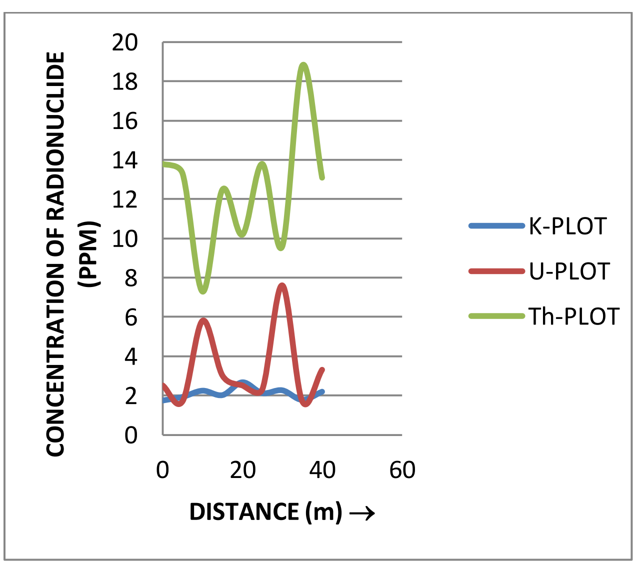

Figure 7. Radionuclide concentration for Profile 6 (Cold section)

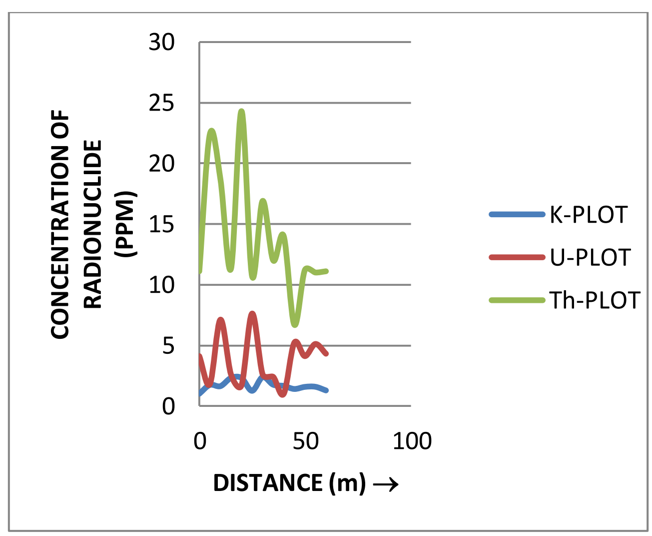

Figure 10. Radionuclide concentration for Profile 9 (Mixed section)

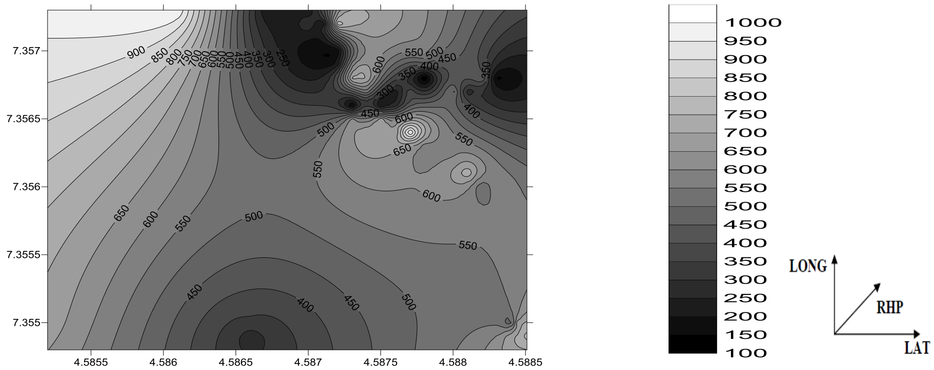

Figure 11. Contour map of total RHP rate of the study area

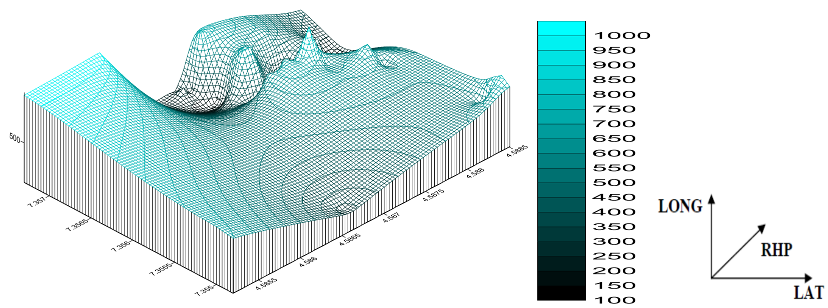

Figure 12. 3D map of total RHP of study area

Table 2. Radiogenic Heat Production Rate of the rocks around study area

S/N	40-K (pW/kg)	238-U (pW/kg)	232-Th (pW/kg)	Total(pW/kg)	Coordinates Long.	Lat.
1	0.005951	418.88	151.04	569.926	4.5878	7.357
2	0.001984	352.24	87.04	439.282	4.5878	7.3569
3	0.006194	361.76	220.16	581.9262	4.5878	7.3569
4	0	85.68	0	85.68	4.5878	7.3568
5	6.96E-05	104.72	30.72	135.4401	4.5883	7.3568
6	0.004141	276.08	181.76	457.8441	4.5882	7.3568
7	0.002714	95.2	174.08	269.2827	4.5881	7.3567
8	0.004454	314.16	207.36	521.5245	4.588	7.3567
9	0.004942	514.08	84.48	598.5649	4.588	7.3567
10	0.012354	247.52	58.88	306.4124	4.5878	7.3567
11	0.001079	228.48	156.16	384.6411	4.5877	7.3567
12	0.001288	190.4	104.96	295.3613	4.5877	7.3567
13	0.001566	142.8	81.92	224.7216	4.5876	7.3567
14	0.000348	199.92	66.56	266.4803	4.5876	7.3566
15	0.001775	28.56	84.48	113.0418	4.5876	7.3566
17	0.001183	238	181.76	419.7612	4.5875	7.3566
18	0.001114	5.712	58.88	64.59311	4.5875	7.3566
19	0.00181	218.96	117.76	336.7218	4.5874	7.3566
20	0.001079	66.64	161.28	227.9211	4.5874	7.3566
21	0.001044	76.16	71.68	147.841	4.5874	7.3566
22	3.48E-05	161.84	66.56	228.4	4.5874	7.3566

23	0.000766	76.16	56.32	132.4808	4.5873	7.3566
24	0.00181	66.64	97.28	163.9218	4.5873	7.3566
25	0.002506	504.56	110.08	614.6425	4.5873	7.3565
26	0.000766	218.96	0	218.9608	4.5872	7.3569
27	0.001322	66.64	46.08	112.7213	4.5872	7.3569
28	0.000452	114.24	43.52	157.7605	4.5872	7.357
29	0.00428	171.36	94.72	266.0843	4.5872	7.357
30	0.002192	114.24	56.32	170.5622	4.5872	7.357
31	0.002227	142.8	81.92	224.7222	4.5871	7.3571
32	0.001253	190.4	92.16	282.5613	4.5871	7.3571
33	0	180.88	79.36	260.24	4.5871	7.3571
34	0.002645	161.84	43.52	205.3626	4.5871	7.3572
35	0.000557	228.48	79.36	307.8406	4.587	7.3572
36	0.003341	133.28	107.52	240.8033	4.587	7.3572
37	0.000522	171.36	40.96	212.3205	4.587	7.3573
38	0.002436	0	220.16	220.1624	4.5867	7.3573
39	0.002993	218.96	117.76	336.723	4.5866	7.355
40	0.001566	9.52	151.04	160.5616	4.5866	7.355
41	0.001357	38.08	122.88	160.9614	4.5866	7.355
42	0.003376	123.76	148.48	272.2434	4.5866	7.3549
43	0.00609	238	353.28	591.2861	4.5883	7.356
44	0.006716	161.84	340.48	502.3267	4.5882	7.356
45	0.007795	552.16	186.88	739.0478	4.5881	7.3561
46	0.00703	285.6	320	605.607	4.588	7.3562
47	0.009257	238	261.12	499.1293	4.588	7.3562
48	0.007378	218.96	353.28	572.2474	4.5878	7.3563
49	0.007865	723.52	245.76	969.2879	4.5877	7.3564
50	0.006194	161.84	481.28	643.1262	4.5877	7.3563
51	0.007621	314.16	335.36	649.5276	4.5876	7.3564
52	0.009257	161.84	527.36	689.2093	4.5876	7.3564
53	0.009361	0	568.32	568.3294	4.5876	7.3565
54	0.00957	447.44	238.08	685.5296	4.5875	7.3565
55	0.009779	199.92	355.84	555.7698	4.5875	7.3566
56	0.007378	437.92	348.16	786.0874	4.5875	7.3566
57	0.008108	66.64	468.48	535.1281	4.5874	7.3567
58	0.005255	161.84	481.28	643.1253	4.5874	7.3567
59	0.003863	342.72	363.52	706.2439	4.5874	7.3568
60	0.005603	76.16	358.4	434.5656	4.5874	7.3568
61	0.003306	247.52	460.8	708.3233	4.5873	7.3568
62	0.005951	218.96	353.28	572.246	4.5873	7.3569
63	0.002297	476	204.8	680.8023	4.5873	7.3569
64	0.004837	199.92	291.84	491.7648	4.5872	7.3569
65	0.003654	409.36	284.16	693.5237	4.5872	7.3569
66	0.003306	142.8	276.48	419.2833	4.5872	7.357
67	0.002053	352.24	268.8	621.0421	4.5872	7.357
68	0.003619	238	197.12	435.1236	4.5872	7.357
69	0.002854	66.64	263.68	330.3229	4.5871	7.3571
70	0.003584	390.32	284.16	674.4836	4.5871	7.3571
71	0.00609	171.36	573.44	744.8061	4.5871	7.3571
72	0.005742	675.92	478.72	1154.646	4.5871	7.3572
73	0.008074	247.52	289.28	536.8081	4.587	7.3572
74	0.008074	161.84	622.08	783.9281	4.5872	7.3572
75	0.00442	723.52	273.92	997.4444	4.5861	7.3573
76	0.008317	247.52	432.64	680.1683	4.5852	7.355
77	0.00616	228.48	307.2	535.6862	4.58833	7.355
78	0.005812	95.2	358.4	453.6058	4.58840	7.355
79	0.004942	495.04	171.52	666.5649	4.58844	7.355
80	0.005533	390.32	286.72	677.0455	4.58839	7.3549
81	0.005568	485.52	281.6	767.1256	4.58851	7.3549
82	0.004524	409.36	284.16	693.5245	4.58850	7.3548
Total	0.335855	19198.03	18078.72	37277.09		
Mean	0.004096	234.122	132.667	454.599		

NB: 0= Below Detection level

Table 3. Gamma radiation readings of radionuclides in Ikogosi warm spring

Radionuclids	Warm Section		Cold section		Mixed/Surrounding section	
	Average concentration					
	Ppm	Cps	Ppm	Cps	Ppm	Cps
Potassium (K)	0.71	1.1	0.53	0.79	1.74	2.31
Uranium (U)	2.1	0.3	1.41	0.29	3.12	0.6
Thorium (Th)	4.25	0.17	3.51	0.14	13.51	0.49

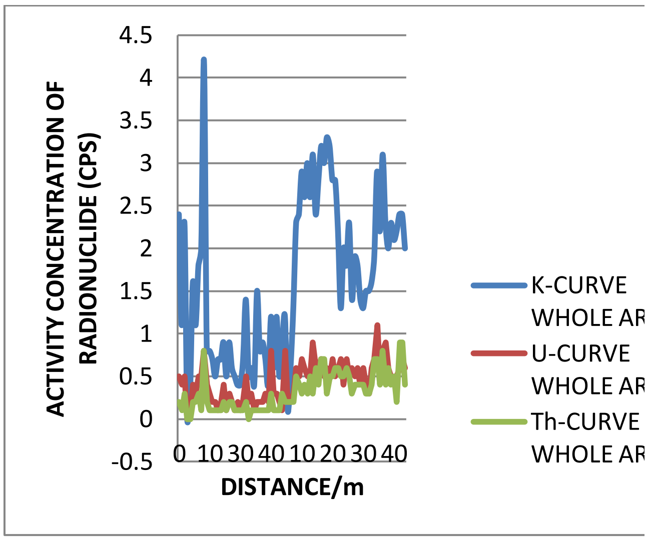

Figure 13. Plot of gamma radiation (cps) against distance (m) for whole study area

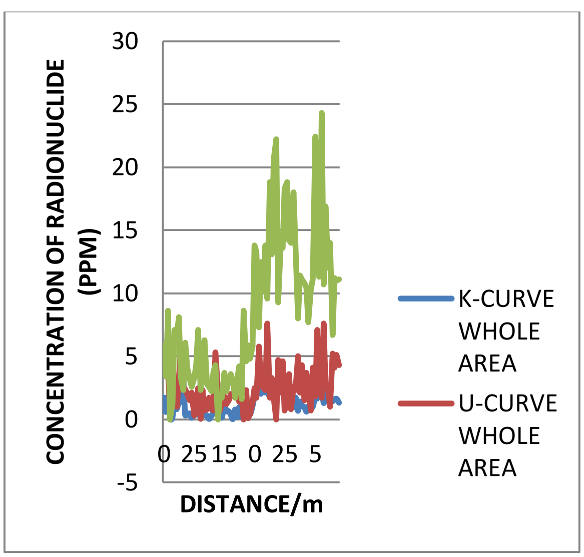

Figure 14. Plot of gamma radiation (ppm) against distance (m) for whole study area

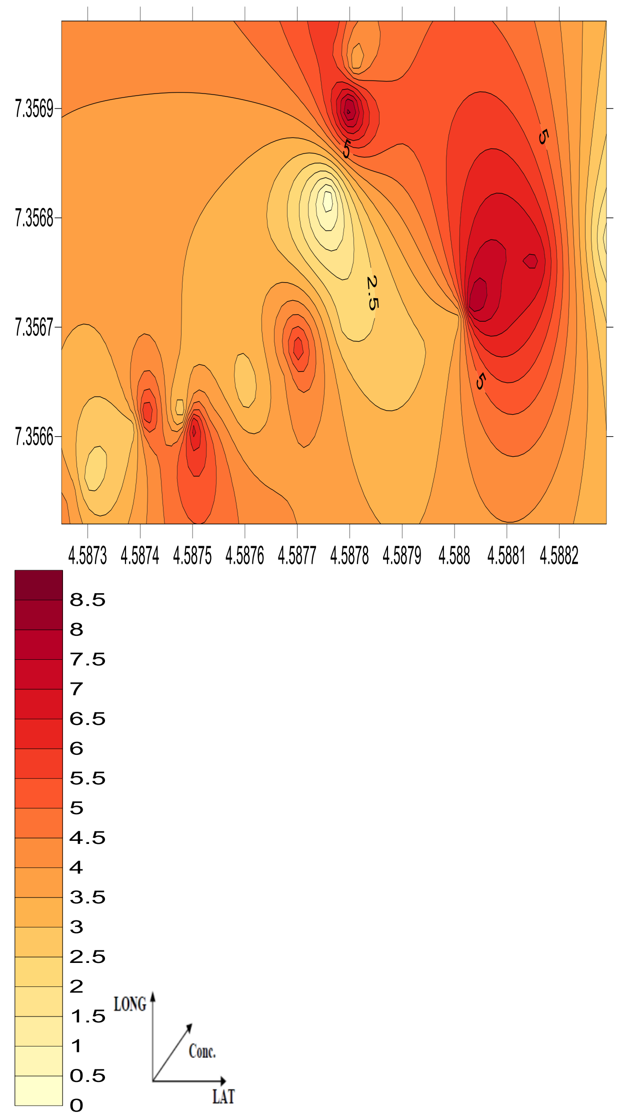

Figure 15. Radiometric map for Thorium Distribution (P1-3)

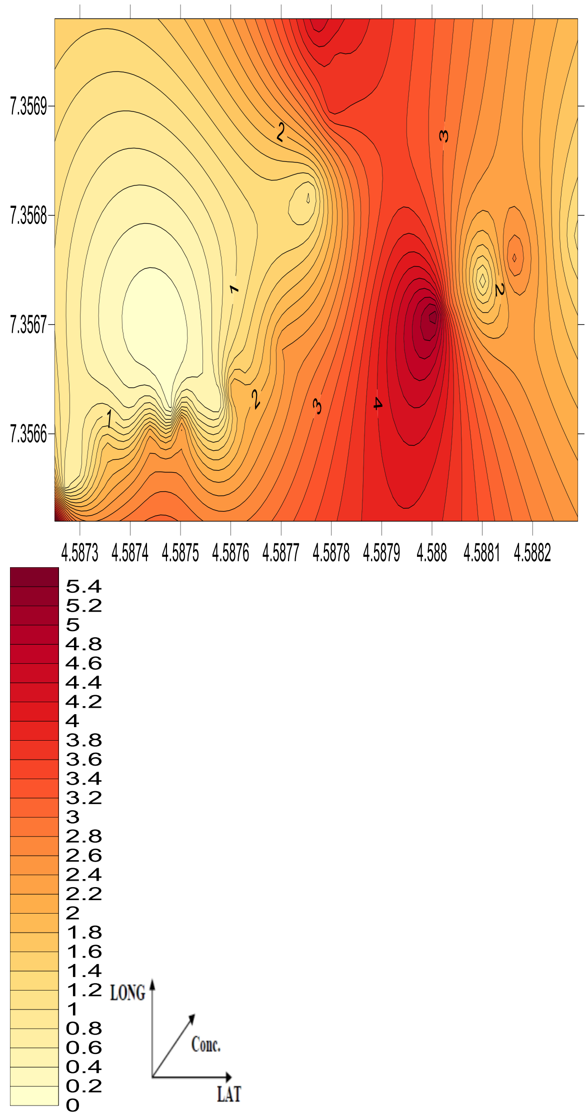

Figure 16. Radiometric map for Uranium Distribution (P1-3)

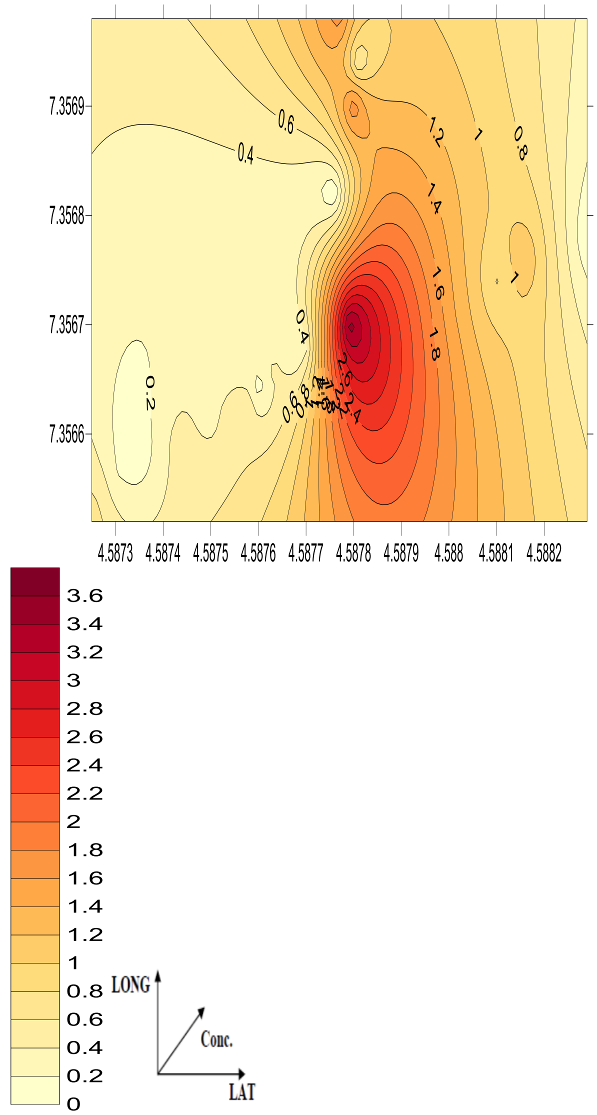

Figure 17. Radiometric map for Potassium Distribution (P1-3)

In conclusion, the concentration of 238U, 232Th and 40K radio-nuclides in Ikogosi warm spring varies, so does the rate of Radiogenic Heat Production (RHP). This is probably due to the uneven distribution of the rock. The pattern of radiogenic heat production of Ikogosi has U-238 as the highest followed by Th and K. The variations in the radiogenic heat production are attributed to the different rock types characterizing the study area. The warm section of the study area has the highest concentration of Uranium. Hence the Lithologic (e.g granite etc) character of each rock surface unit is simply reflected by the amount of gamma radiation recorded. From this study, it can be found that radiometric characterization and mapping may provide an invaluable aid in the further study of mapping of terrains with poor exposures in the study area. It is therefore recommended that core samples should be used for mapping the radiogenic heat flow in the study area.

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