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Assessment of Radiogenic Heat Production Due To ^{238}U, ^{232}Th and ^{40}K In Surface Soils of Ortum Region, West Pokot County, Kenya

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ABSTRACT

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg were determined using a HPGe detector at the Institute of Nuclear Science and Technology at the University of Nairobi (Kenya). The activity concentrations were then converted into ppm (^{238}U and ^{232}Th) and % for ^{40}K that were used for computing Radiogenic Heat Production (RHP) for individual radionuclides and the overall RHP contributed by the three radionuclides. The average activity concentrations were 3.198753ppm, 13.42265ppm and 1.372154% for ^{238}U, ^{232}Th and ^{40}K respectively. The average RHP for the individual radionuclides was found to be 0.239883μW/m^3, 0.2658μW/m^3 and 0.036378μW/m^3 for ^{238}U, ^{232}Th and ^{40}K respectively. the overall RHP contribution by the three radionuclides was found as 0.540764 μW/m^3. All the RHP values for the individual radionuclides including their overall contribution was below the world RHP value of 1μW/m^3. The findings of this study will provide benchmark information on RHP status of the study area that can be extended to other areas to enable possible geothermal energy exploitation.

KEYWORDS

radiogenic heat production; natural radioactivity; elemental concentration

INTRODUCTION

Radiogenic heat production refers to the thermal energy resulting from radioactive decay. The radioactive disintegration is due to gravitational contraction and decay of unstable radioisotopes [1]. RHP is associated with the radioisotopes: ^{238}U, ^{232}Th and singly occurring ^{40}K due to their enrichment relative to other radionuclides [2]. Besides the heat of the earth, the RHP due to ^{238}U, ^{232}Th and ^{40}K constitutes the biggest internal source of heat. According to [3], the annual radiogenic heat production in the earth is 6.3×10^{20}J which is greatly more than twice the world primary energy. Most mass of the radionuclide is converted into heat during radioactive decay [4]. The radionuclides of ^{238}U, ^{232}Th and ^{40}K are associated with long half- lives: ^{40}K (half-life = 1.277x 10^9 years, ^{238}U (half-life =4.468x10^9 years and ^{232}Th (half -life = 1.405X10^{10} years). Most of the significant emissions from the radionuclides are converted into heat especially within the rocks [4,5]. The energy emitted by all the decay consisting of kinetic energy of the emitted particles and gamma radiation is absorbed and eventually transformed into heat [7]. The large energy source from the earth alone is greater than the global requirement predicted by [6] for the year 2030. Thus, if this energy is tapped to a large extent then it may take care of the demands of the primary energy for the rest of the years. According to the study by [8], RHP is an important parameter in geothermal exploitation studies. It is also essential in explaining continental thermal flux density for providing information on the temperature and structure of the lithosphere [9]. Several studies have been done globally on radiogenic heat production due to natural radioactivity. According to a study by [10] on RHP and excess life time cancer risk of the sand in India some samples registered higher RHP values compared with the world average value of 1μW/m^3 although the average for all the samples was below1μW/m^3.

From the study done by [11] on migmatites, biotite gneisses using gamma ray spectroscopy, some of the rocks revealed high levels of natural radioactivity and hence some of the RHP values for the samples were high. In addition, [12] did a study on RHP in crustal quarry rocks where the mean RHP ranged from 0.549 to 3.122μW/m^3 with Uranium contributing the highest RHP with a correlation coefficient of 83.09%. In the East Africa, there are scanty researches on RHP. In Uganda, [13] did study on RHP in river sediments from Gulu and Amum districts. The RHP values ranged from 2.5 ± 0.6μW|m^3 to 10.2 ± 2.6μW|m^3 μW/m^3 with an average of 4.5μW/m^3. The RHP value was higher than the usual average value of 1μW/m^3.

MATERIALS AND METHODS

Study area& Sample Preparation

The study was done in Ortum region, Kapenguria constituency, West Pokot County. The area studied was 5km^2, the study area lies between longitude 35°15′E and 35°20'E and latitude 1°10′N and 1°30′N and an altitude of about 1550m above sea level as shown in Figure 1. Ortum region is surrounded by Chereng'anyi and Ortum hills with high presence of granitic and silicon rocks that are associated with high levels of background radiations [14]. Most of the population in Ortum depends on Agriculture, quarrying, gold mining and building and construction materials.

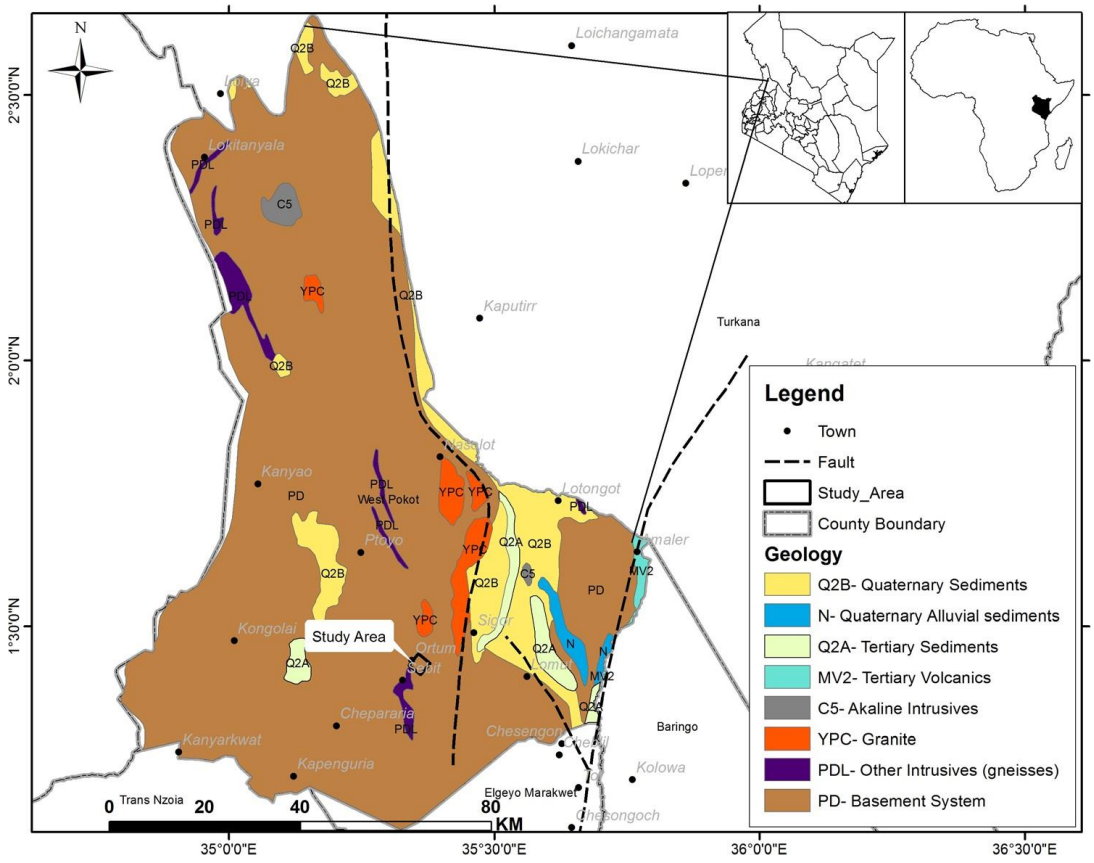

FIGURE 1: Map showing the study area.

A total of 35 soil samples each of about 1kg from the surface at different points (Figure 2) were collected for assessment of ^{238}U, ^{232}Th and ^{40}K levels and their radioelement concentrations. The samples were enclosed in containers properly labeled to avoid mix up. The soil sample were collected using a soil auger, trowel and a panga. The foreign materials: pebbles, roots and grass were removed. The samples were then dried in the oven for 24 hours at 110 0C and then crushed into fine powder and sieved through 100μm sieve. About 350g of each of the soil samples were put and sealed in air tight plastic containers and kept for a minimum of 30 days to allow for secular equilibrium between ^{226}Ra, ^{232}Th and their progenies [15]. The HPGe detector was then used to determine the activity concentrations of the radionuclides of individual samples. Figure 2 below shows the sampling points where the samples were obtained.

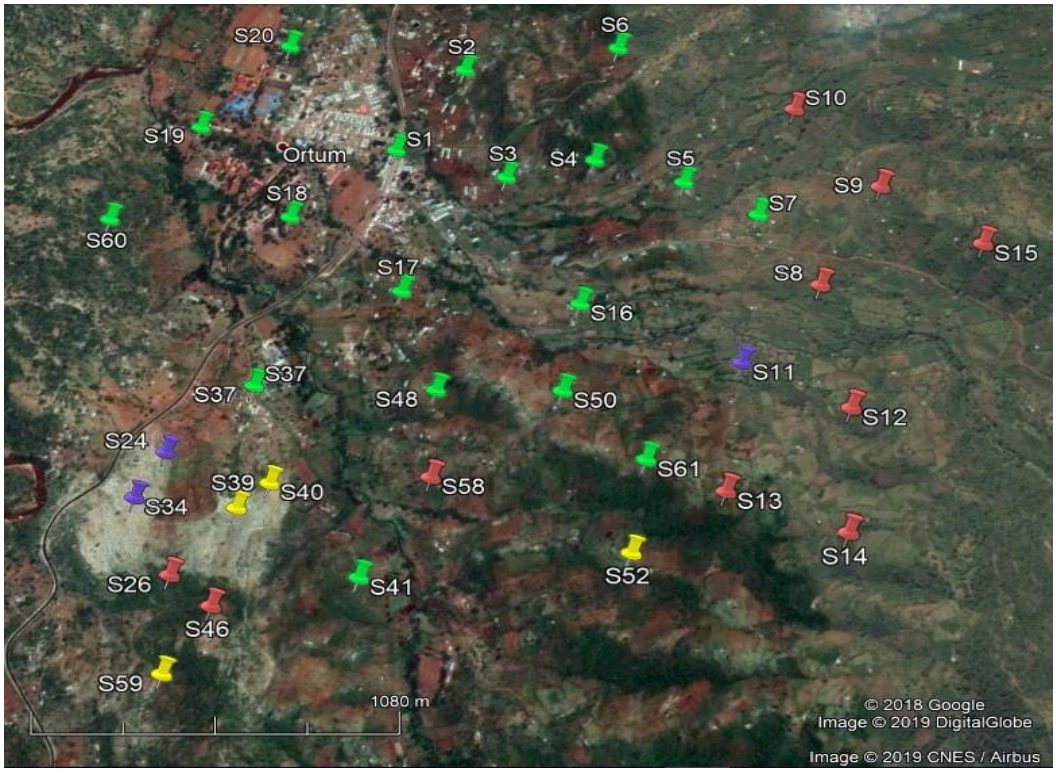

FIGURE 2: Surface soil sampling points.

Experimental Techniques

The HPGe detector at the institute of Nuclear Science and Technology (University of Nairobi) was used to determine the activity concentrations of ^{238}U,^{232}Th and ^{40}K in the soil and rock samples. The efficiency calibration was done using standard reference materials: RGU – 1, RGTh – 1 and RGK – 1 provided by the IAEA with known activity concentrations using equation 1[16].

$$\square = \frac{N}{A \times P \times M \times T} \quad (1)$$

where $\square$ is the efficiency, A is the activity concentration, N is the net area under the photo peak, T is the counting time, P is the emission probability and m is the mass of the sample.

The energy calibration was done by relating the channel number with the photo energy using gamma lines of ^{214}Pb, ^{214}Bi, ^{228}Ac and ^{40}K with energies 351Kev, 609Kev, 911Kev and 1460Kev. The energy was evaluated using equation 2 [16].

$$E = a\,(ch) + b \quad (2)$$

where E is the energy, a and b are constants and ch is the channel number.

Determination of Activity Concentrations

The activity concentrations of the individual radionuclides were determined using equation 3 [16].

$$\frac{M_S\, A_S}{I_S} = \frac{M_r\, A_r}{I_r} \quad (3)$$

where M_s is the mass of the sample, A_s is the activity concentration of the sample, I_s is the intensity of the sample, M_r is the mass of the standard sample, A_r is the activity concentration of standard reference material and I_r is the intensity of the reference material.

Radiogenic Heat Production (RHP)

The Radiogenic Heat Production was computed by converting the activity concentrations of the individual samples into ppm using equations 4 [17]

$$\left.\begin{aligned} 1ppm\ of\ 238_U &\equiv 12.35\frac{Bq}{Kg} \\ 1ppm\ of\ 232_{Th} &\equiv 4.06\frac{Bq}{Kg} \\ 1\%\ of\ 40_K &\equiv 313\frac{Bq}{Kg} \end{aligned}\right\} \quad (4)$$

The sum total of the individual contributions of C_U, C_{Th} and C_k in the soil and rock samples gives the overall heat production given by equation 5 [18].

$$RHP\left(\frac{\mu w}{m^3}\right) = 10^{-5}\ \rho[9.52C_U(ppm) + 2.56C_{Th}(ppm) + 3.48C_k(\%)] \quad (5)$$

where ρ is the density of the individual samples.

RESULTS AND DISCUSSIONS

Activity concentrations of the radionuclides and associated RHP in the surface soil samples

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the 35 soil samples were determined using the HPGe detector following equation 3. Thereafter the activity concentrations were converted into individual radioelement concentrations in ppm using the relations 4 for use in computing the RHP using equation 5. The table 1 below shows the activity concentrations of the three radionuclides: ^{238}U, ^{232}Th and ^{40}K in ppm (for ^{238}U and ^{232}Th) and % for ^{40}K and the associated radiogenic heat produced due to the three radionuclides.

TABLE 1: Activity concentration of the samples and associated RHP.

Samples	U-238 (ppm)	Th-232 (ppm)	K-40 (%)	U-238 RHP(μW/m³)	Th-232 RHP(μW/m³)	K-40 RHP(μW/m³)	Total RHP(μW/m³)
S1	2.069636	11.46305	0.543035	0.153249	0.228249	0.014699	**0.396197**
S2	3.523887	13.76601	1.08901	0.260932	0.274104	0.029477	**0.564513**
S3	2.808907	11.23892	0.985719	0.20799	0.223786	0.026681	**0.458456**
S4	2.071255	9.263547	0.473674	0.153369	0.184453	0.012821	**0.350643**
S5	1.653441	8.273399	0.866358	0.122416	0.164737	0.02345	**0.310603**
S6	2.11498	9.288177	0.807284	0.156607	0.184943	0.021851	**0.363401**
S7	2.006478	8.800493	0.788243	0.148573	0.175233	0.021336	**0.345141**
S8	2.877733	12.78818	1.0123	0.213086	0.254634	0.0274	**0.495121**
S9	4.263158	17.54433	3.257412	0.315672	0.349337	0.08817	**0.753179**
S10	4.451012	17.68227	3.200607	0.329582	0.352084	0.086632	**0.768298**
S11	3.145749	15.45074	1.820511	0.232932	0.30765	0.049277	**0.589859**
S12	2.553036	11.42365	0.995272	0.189044	0.227464	0.026939	**0.443447**
S13	2.823482	11.97537	0.884824	0.209069	0.23845	0.02395	**0.471469**
S14	3.215385	13.00739	1.311406	0.238088	0.258999	0.035496	**0.532584**
S15	2.039676	8.997537	0.730639	0.151031	0.179156	0.019777	**0.349964**
S16	5.417814	17.94828	2.795719	0.40117	0.35738	0.075673	**0.834224**
S17	2.235628	9.837438	0.920032	0.165541	0.19588	0.024903	**0.386323**
S18	3.866397	15.37438	1.448658	0.286293	0.30613	0.039211	**0.631635**
S19	2.259109	8.980296	0.904377	0.167279	0.178813	0.024479	**0.370571**
S20	2.484211	11.04926	0.922204	0.183947	0.220009	0.024962	**0.428918**
S24	3.783806	15.85961	1.588466	0.280178	0.315791	0.042996	**0.638965**
S26	4.77247	18.30542	2.138403	0.353385	0.364492	0.057881	**0.775758**

Samples	U-238 (ppm)	Th-232 (ppm)	K-40 (%)	U-238 RHP(μW/m³)	Th-232 RHP(μW/m³)	K-40 RHP(μW/m³)	Total RHP(μW/m³)
S34	2.394332	10.31034	0.960863	0.177292	0.205296	0.026008	**0.408596**
S37	2.65668	11.94335	0.919553	0.196718	0.237812	0.02489	**0.45942**
S39	2.487449	10.53695	0.847572	0.184187	0.209808	0.022942	**0.416937**
S40	4.287449	17.88424	1.324952	0.317471	0.356105	0.035863	**0.709439**
S41	2.660729	11.81773	0.981981	0.197018	0.235311	0.02658	**0.458908**
S46	2.655061	11.00246	0.725911	0.196598	0.219078	0.019649	**0.435324**
S48	5.018623	20.50493	2.325815	0.371612	0.408288	0.062954	**0.842853**
S50	4.100405	17.94089	1.759553	0.303621	0.357233	0.047627	**0.708481**
S52	4.321457	17.61823	2.245559	0.319989	0.350808	0.060782	**0.731579**
S58	2.559514	10.78571	0.913514	0.189523	0.214762	0.024726	**0.429011**
S59	2.909312	12.60099	1.260256	0.215425	0.250907	0.034112	**0.500443**
S60	3.22915	15.11576	1.107732	0.239107	0.30098	0.029983	**0.570071**
S61	5.491498	20.99261	2.181214	0.406627	0.417998	0.05904	**0.883665**
Min	**1.653441**	**8.273399**	**0.473674**	**0.122416**	**0.164737**	**0.012821**	**0.310603**
Max	**5.491448**	**20.99261**	**3.257412**	**0.406627**	**0.417998**	**0.08817**	**0.883665**
Av	**3.198753**	**13.42265**	**1.372154**	**0.239883**	**0.2658**	**0.036378**	**0.540764**

The results of the activity concentrations of the three radionuclides: ^{238}U, ^{232}Th and ^{40}K showed a spatial distribution pattern. The radiation levels of ^{238}U, ^{232}Th and ^{40}K ranged from 1.653441ppm to 5.491448 ppm, 8.273399 ppm to 20.99261ppm and 0.473674% to 0.406627% respectively. The average concentrations of the three radionuclides were 3.198753 ppm, 13.42265 ppm and 1.372154% for ^{238}U,^{232}Th and ^{40}K respectively that were higher than the world average (18). ^{232}Th had the highest deviation from world average. The higher activity concentrations could be attributed to the anthropogenic activities especially agricultural like the use of phosphatic fertilizers for increased yields. The results from this study are similar to those of [19], [20] and [21]. The activity concentrations of ^{238}U and ^{232}Th were also higher than those from the study by (23) The individual RHP values for ^{238}U,^{232}Th and ^{40}K ranged from 0.122416 μW/m^3 to 0.406627 μW/m^3, 0.164737 to 0.417998 μW/m^3, 0.012821 μW/m3 to 0.08817 μW/m3 respectively. The average radiogenic heat production was 0.239883 μW/m^3, 0.2658 μW/m^3 and 0.036378 μW/m^3 for ^{238}U, ^{232}Th and ^{40}K respectively. The overall average RHP contributed by all the three radionuclides was 0.540764 μW/m^3. The results from this study agrees with that of [7] where the study obtained an average 0.48±0.1 μW/m^3. The results, however, deviates from those of [13] where they obtained an average RHP of 4.5 ± 1.1 μW/m^3. The difference in the results can be attributed to the different geological set ups of the two study areas considering the type of rocks from which the soils originated. For complete discussions of the results, correlation graphs were drawn to establish some relationships as shown in Figures 3a, 3b and 3c. In Figure 3a of ^{232}Th and ^{238}U the correlation coefficient is R^2 =0.934 showing a very strong correlation. The correlation coefficients of 3b and 3c are R^2 =0.7279 and R^2 =0.6912 respectively both lying between 0.60 and 0.79 showing a strong correlation. The individual radiogenic heat produced for the three radionuclides were further represented in form of a graph as shown in Figure 4. From the figure 4, it can be seen that ^{232}Th and ^{238}U are the major contributors to the RHP. The contribution by ^{40}K is very small.

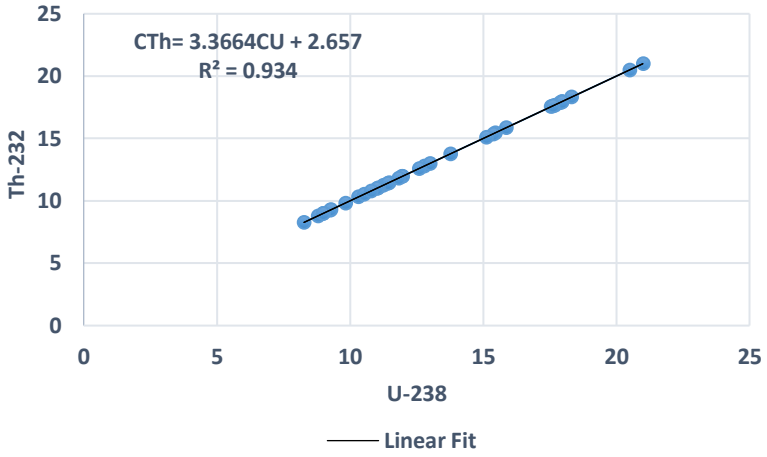

FIGURE 3a: Correlation between232Th and 238U.

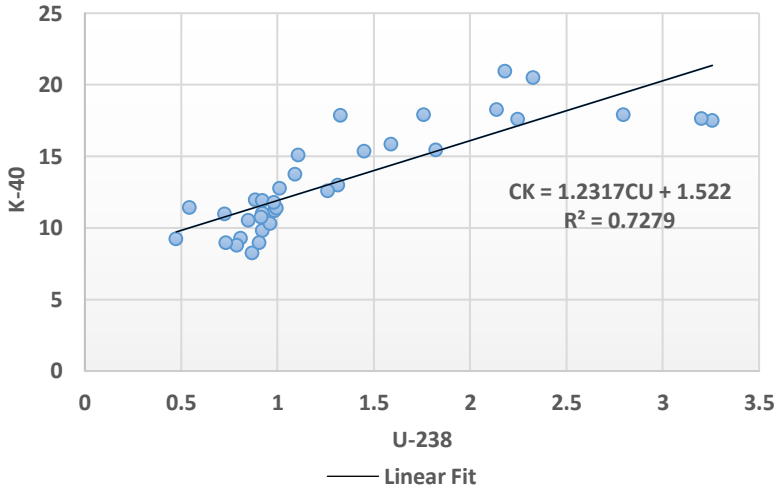

FIGURE 3b: Correlation between ^{40}K and ^{238}U.

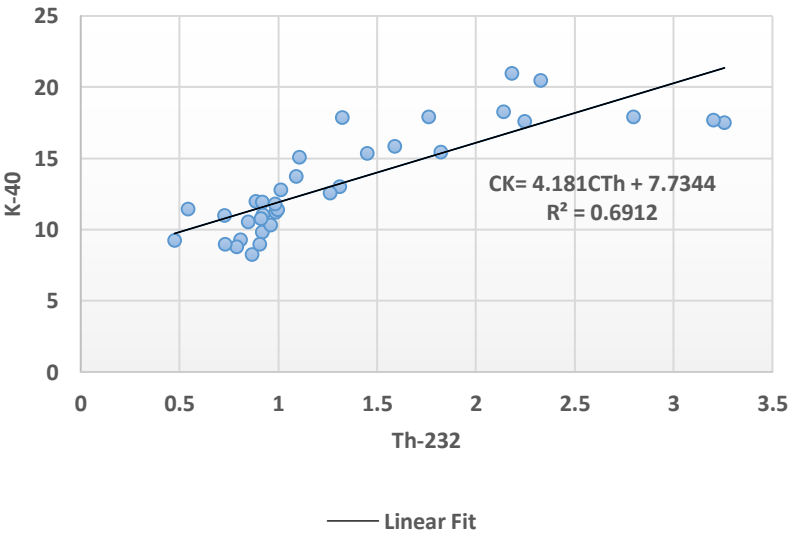

FIGURE 3c: Correlation between ^{40}K and ^{232}Th.

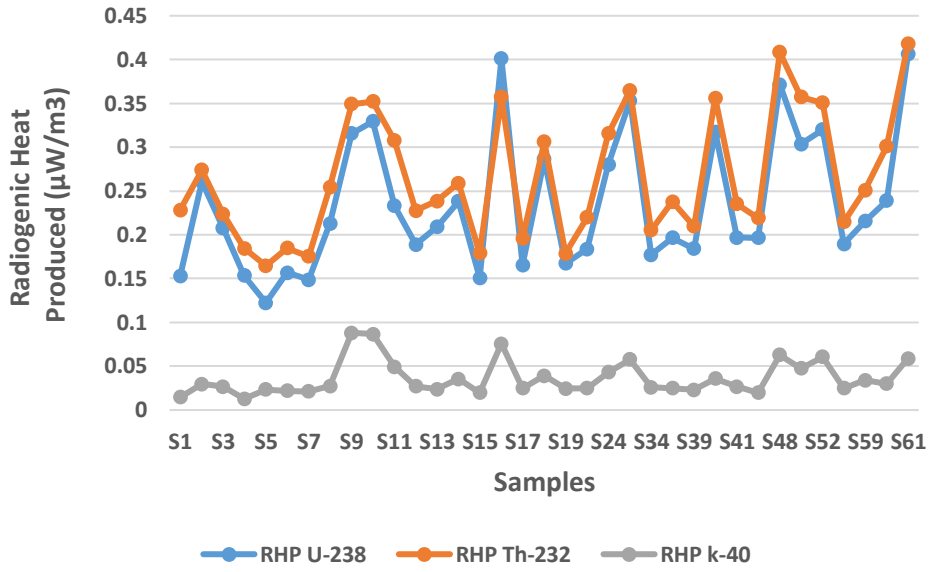

FIGURE 4: RHP comparison for the radionuclides.

CONCLUSIONS

An assessment on RHP due to ^{238}U,^{232}Th and ^{40}K in surface soils of Ortum region has been done in this study. A HPGe detector was used to determine the activity concentrations of the three radionuclides in Bq/kg that were then converted into ppm (^{238}U and ^{232}Th) and % for ^{40}K. The average activity concentrations were 3.198753ppm, 13.42265ppm and 1.372154% for ^{238}U,^{232}Th and ^{40}K respectively. the average RHP for the individual radionuclides was found as 0.239883µW/m^3, 0.2658µW/m^3 and 0.036378µW/m^3 for ^{238}U,^{232}Th and ^{40}K respectively. the overall RHP contribution by the three radionuclides was found as 0.540764 µW/m^3. All the RHP values for the individual radionuclides including their overall contribution was below the world value of 1µW/m^3. This study being the first of the kind at the study area, it will provide benchmark information that can be extended to other areas. Further studies can be done on soils at different depths and on rocks to have comprehensive data base information on RHP values that may prompt possible geothermal energy exploitation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest

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