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Assessment of Natural Radionuclides and Their Associated Radiogenic Heat Production in Soils of Ahero Fields, Kisumu County, Kenya

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ABSTRACT

The activity concentrations of the three radionuclides: 238U, 232Th and 40K in the soils of Ahero fields were determined using NaI(Ti) detector employing the gamma ray spectroscopy technique at Kenyatta University physics laboratory. The activity concentrations were then converted into radioelement concentrations in ppm (238U and 232Th) and % (40K) that were used in obtaining Radiogenic Heat Production (RHP).The average activity concentrations for the various fields were: for field 1: 32.63 ± 1.63 Bq/kg for 238U, 104.69 ± 5.20 Bq/kg for 232Th and 75.00 ± 3.2 6 Bq/kg for 40K. The average activity concentrations of 238U and 40K for fields 2, 3 and 4 were within the world average values except for 232Th that was 68.03 ± 3.40 Bq/kg, 91.73 ± 4.58 Bq/kg and 121.11 ± 6.05 Bq/kg for fields 2, 3 and 4 respectively that were above the world average of 45 Bq/kg. The RHP values ranged from a minimum of 2.4 μW/m3 to a maximum of 9.0 μW/m3 with an average of 4.8 μW/m3. The findings on natural radioactivity will inform the various stake holders on setting up of standards and guidelines to safeguard the general public against exposure to high background radiation. The data on RHP will form a baseline information for other studies in other areas and hence may prompt a possible exploitation of geothermal energy.

KEYWORDS

Radiogenic heat production; natural radioactivity

1. INTRODUCTION

Soils contain natural radionuclides that may disintegrate releasing ionizing radiations that are a health risk to the individual exposed especially when they exceed the permissible world limits [1]. The consequence of natural radiations is because of exposure of the individual's body organs from radon and its progenies. Studies on natural radioactivity levels and distribution of the natural radionuclides are essential in providing baseline data for human exposure due to natural and anthropogenic sources. Furthermore, this information is important in setting up of guidelines and regulations relating to radiation protection and safety [2]. The most crucial radionuclides in this study were 238U, 232Th and 40K because of their abundances and long half – lives. The decay of 238U and 232Th and the singly occurring 40K emits particles (alpha and beta) and gamma rays (energy). Most of the energy emanates from 238U and 232Th [3]. The energy by the decay processes consists of kinetic energy of the particles emitted and associated gamma radiation absorbed in the rocks and eventually transformed into heat [4, 5]. This heat produced in the mantle and crust of the Earth during the decay of 238U, 232Th and 40K is referred to as the Radiogenic Heat Production or RHP [9,13]. Radiogenic heat production is vital in determining the heat flow in the rocks from which the soils are formed. This heat has been used in assessing of geothermal energy in various parts of the world which is among the renewable sources of energy [2, 6,7].

This research aimed at assessing the natural radionuclide levels and associated RHP due to 238U, 232Th and 40K in the soils of Ahero fields, Kisumu County, Kenya. The natural radioactivity levels of the radionuclides will form benchmark

information for the relevant authorities in setting up standards and guidelines to safeguard the general public against the harmful effects of radiations while the RHP values will provide baseline data for further research of its impact in the study area.

2. LOCATION AND GEOLOGY OF STUDY AREA

Ahero fields are part of Ahero irrigation scheme situated in the Kano plains between the Nandi escarpment and Nyabondo plateau. The fields are located in Muhoroni Sub County, Kisumu County. Geographically, it is located on latitude 00^° 9^(´´)S and longitude 34^° 56^(´´)E and at an altitude of 1160m above sea level. The Sub County has a population of 151799, [11]. The main crop is rice but Soybeans, sorghum, watermelon, maize, tomatoes and cowpeas are also grown. The source of water for irrigation is river Nyando. The main rock types that surround the Ahero region are the granites and granodiorites on the north and south, while on the eastern and north western are the phonolites [12]. Figure 1 below shows the map of the study area.

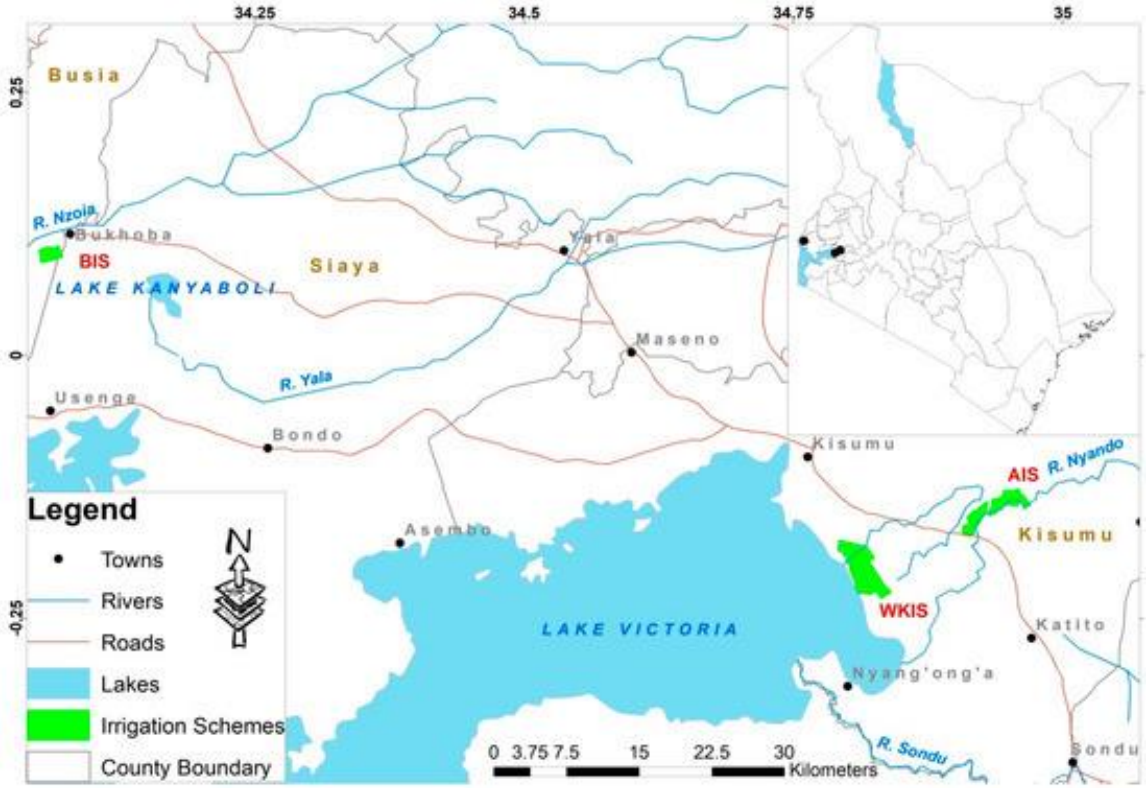


FIGURE 1: Map of Ahero irrigation scheme (google map).

3. MATERIALS AND METHODS

3.1 Sample collection and preparation

The top soil samples within the depths of 15 - 20 cm were collected from three paddy fields where rice had been cultivated and from a field where farming had not been done for two years. The rice fields were demarcated as field 1, field 2, field 3 and field 4. Five soil samples were collected from each of the fields 1, 2 and 3 while two samples were collected from field four. The samples were collected using a manually constructed hand auger and trowel. The top most layers of soil were cleared first to get rid of pebbles and roots from the soil. In each field, five [5] soil samples were collected from the three fields following the X-shape approach [13]. The samples were then put in containers properly labeled to avoid mix up.

The samples were transported to the laboratory and spread on prewashed and labeled polythene mats in an open floor for two weeks for the samples to dry. In order to achieve a constant weight, the samples were manually pulverized using a mortar and pestle and then allowed to pass through a 2.00 mm sieve (< 2.00 mm particles were used). In addition, soil samples from an uncultivated field for 2 years were also collected. 170 g of each sample from the fields was weighed in to cylindrical plastic containers of uniform geometry. The containers were properly labeled and hermetically sealed for a minimum of 30 days to allow for the radioactive secular equilibrium to be reached between parent and daughter radionuclide before embarking on gamma counting.

3.2 Experimental Procedures used in Analysis of the Data

The energy calibration of the gamma ray spectrometer was done using the energy peaks of 662 KeV of ^{137}Cs, 1170 KeV and 1330 KeV of ^{60}Co. The efficiency of a detector was calculated by comparing a spectrum from a source of known activity to the count rates in each peak to the count rates expected from the known intensities of each gamma ray. In this work, certified samples of ^{40}K, ^{232}Th and ^{238}U were used. The peaks corresponding to ^{232}Th (2615 KeV), 1460 KeV (^{40}K) and 1765 KeV (^{238}U) were considered for the respective activity concentrations.

The efficiency was calculated using equation 4.1

$$\varepsilon = \frac{An}{XP_Z M} \qquad (1)$$

Ɛ is the efficiency of the detector An is the peak count P_z is the emission probability of a given radionuclide in the sample in question; X is the activity concentration of the radionuclide m is the mass of the standard sample.

3.3 Acquisition of Spectral Data

The time taken for the acquisition of data for each sample and distilled water was set at 30000seconds (time used for the certified samples used during calibration). The spectra for ^{40}K, ^{232}Th and ^{238}U were determined using the peaks as follows: the peak corresponding to 1765 KeV (^{214}Bi) for ^{238}U, 2615 KeV (^{208}TI) for ^{232}Th and 1460 KeV (^{40}K) for ^{40}K. The selected peaks weakly interfere with the other peaks and thus they form pure peaks of the spectrum. A region of interest was selected at the peak in order to obtain the total peaks. The net area was subtracted from the gross area to obtain the region of interest (ROI)

3.4 ^{238}U, ^{232}Th and ^{40}K Activity Concentrations

The activity concentrations of the samples in Bq/kg were computed using the equation 2 [14].

$$A_i(Bqkg^{-1}) = \frac{NC_i}{\varepsilon \times Y_i \times m \times t} \qquad (2)$$

Where A_i is the activity concentrations of the ith radio nuclide in Bq/kg^{-}, Ɛ is the efficiency of the detector at the energy of the ith radionuclide, N_{ci} is the net counts of the ith radionuclide in the corresponding photo peak after background subtraction, Y_i is the emission probability of the ith radionuclide, m is the mass of the sample in kg and t is the counting time.

3.5 Elemental Concentrations of the radioelements

The activity concentrations in Bq/kg were converted into elemental concentration in ppm (^{238}U, ^{232}Th) and % (^{40}K) of the radionuclides using the conversions in equations 3[15].

$$\left.\begin{aligned} 1ppm\ of 238_U &\equiv 12.35 \tfrac{\text{Bq}}{\text{kg}} \\ 1ppm\ of 232_{Th} &\equiv 4.06 \tfrac{\text{Bq}}{\text{kg}} \\ 1\%\ of 40_K &\equiv 313 \tfrac{\text{Bq}}{\text{kg}} \end{aligned}\right\} \qquad (3)$$

The sum of the individual contributions by A_u, A_{Th}, and A_k in rock segments will be overall heat production [16].

3.6 Radiogenic Heat Production (RHP)

The radiogenic heat generated was calculated using equation 4 [17] since ρ and activity concentrations are known.

$$RHP(\mu w/m^3) = 10^{-5}\rho[9.52C_U(ppm) + 2.56C_{Th}(ppm) + 3.48C_K(\%)] \qquad (4)$$

Where ρ is the density of the soil sample, C is the activity concentration of the respective radionuclides

4. RESULTS AND DISCUSSIONS

The activity concentrations of ^{238}U, ^{232}Th and ^{40}K of all the samples was calculated using equation 2 and their results summarized as shown in Table1.

TABLE 1: Activity concentrations of ^{238}U, ^{232}Th and ^{40}K of the samples in this work.

	Activity concentrations (Bq/kg)			
	sample	**^{238}U**	**^{232}Th**	**^{40}K**
Field 1	S_1	18.09 ± 0.90	144.30 ± 7.21	19.21 ± 7.21
	S_2	27.70 ± 1.38	86.71 ± 4.38	32.66 ± 1.63
	S_3	42.25 ± 2.11	170.07 ± 8.5	163.30 ± 8.16
	S_4	31.89 ± 1.59	61.84 ± 3.09	30.74 ± 8.16
	S_5	43.21 ± 2.16	56.69 ± 2.83	80.69 ± 4.03
	Average concentration	$\mathbf{32.63 \pm 1.63}$	$\mathbf{104.69 \pm 5.20}$	$\mathbf{75.00 \pm 3.26}$
Field 2	S_6	38.27 ± 1.91	67.00 ± 3.34	103.74 ± 5.18
	S_7	18.09 ± 0.90	56.69 ± 2.83	36.50 ± 1.82
	S_8	9.93 ± 1.38	66.99 ± 3.34	44.18 ± 2.20
	S_9	5.42 ± 0.27	87.61 ± 4.38	99.90 ± 4.99
	S_{10}	13.15 ± 0.65	61.84 ± 3.09	67.24 ± 3.36
	Average concentration	$\mathbf{16.97 \pm 0.84}$	$\mathbf{68.03 \pm 3.40}$	$\mathbf{70.31 \pm 3.51}$
Field 3	S_{11}	44.93 ± 2.24	87.61 ± 4.38	165.21 ± 8.26
	S_{12}	18.20 ± 0.90	72.15 ± 3.60	30.74 ± 1.53
	S_{13}	17.93 ± 0.89	56.69 ± 2.83	98.17 ± 4.90
	S_{14}	23.83 ± 1.19	67.00 ± 3.34	101.82 ± 5.09
	S_{15}	39.72 ± 1.98	175.22 ± 8.76	217.08 ± 10.85
	Average concentration	$\mathbf{28.92 \pm 1.44}$	$\mathbf{91.73 \pm 4.58}$	$\mathbf{122.60 \pm 6.13}$
Field 4	S_{16}	41.49 ± 2.07	139.15 ± 6.95	121.03 ± 6.05
	S_{17}	17.98 ± 0.89	103.07 ± 5.15	53.79 ± 2.68
	Average concentration	$\mathbf{29.74 \pm 1.48}$	$\mathbf{121.11 \pm 6.05}$	$\mathbf{87.51 \pm 4.37}$

From Table 1 it can be noted that the average activity concentrations of the three radionuclides for Field 1 were 32.63 ± 1.63 Bq/kgfor ^{238}U, 104.69 ± 5.20 Bq/kg for ^{232}Th and 75.00 ± 3.26 Bq/kg for ^{40}K. The field 1 is the one in which rice had already been transplanted and the rice seedlings were a month old and some topdressing fertilizer had been applied. The activity concentration of ^{232}Th was higher than the world average level of 45 Bq/kg and although that of ^{238}U was below the world average limit of 33 Bq/kg; it was still high. The high concentrations of ^{232}Th and ^{238}U can be attributed to the phosphatic fertilizers that had been applied apart from the geology of the place characterized by underlying granitic rocks that contain high concentrations of ^{238}U and ^{232}Th. The average activity concentrations of ^{40}K were below the world average value of 420 Bq/kg. The average concentrations of the radionuclides from field 2 where transplanting was being done were 16.97 ± 0.84 Bq/kg, 68.03 ± 3.40 Bq/kg and 70.31 ± 3.51 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. It can be noted from these values that it is only ^{232}Th that had higher activity concentrations above the world acceptable limit of 45 Bq/kg; this can be attributed to either underlying rocks of the field or River Nyando where water for irrigation originates from that contains this radionuclide. The underlying rocks are granitic in nature and thus contains ^{232}Th. The activity concentrations of ^{40}K increased for all the samples of field 2 and hence the average activity concentration as compared to field 1. This can be attributed to the fact that in field 1, top dressing had been done and the inorganic fertilizer therefore added to activity concentrations of ^{40}K. However, in field 2 the values were higher owing from the fact that the water used to flood the field might have originated from another field where fertilizers had been applied and completely dissolved as opposed to field 1 where the fertilizers had just been applied and had not completely dissolved.

The average concentrations of the radionuclides from field 3 (post harvesting) where harvesting had been done and ploughed were 28.92 ± 1.44 Bq/kg, 91.73 ± 4.58 Bq/kg and 122.60 ± 6.13 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average activity concentrations of ^{232}Th had higher values than the world value limits of 45 Bq/kg. At this stage, top dressing using CAN had been done twice and this may also have contributed to increased activity concentrations.

The field 4 that had not been cultivated for two years and but surprisingly also recorded higher concentrations of ^{232}Th. The average concentrations of the radionuclides were 29.74 ± 1.48 Bq/kg, 121.11 ± 6.05 Bq/kg and 87.51 ± 4.37 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. This field had been cultivated continuously previously. The continuous use of inorganic fertilizers during the farming stages for example phosphatic ones (DAP) whose origin is from rocks that contain high concentrations of Uranium and Thorium accumulates in the soils increasing their activity concentrations. It can also be noted that the activity concentration of S_3, S_{11} and S_{15} from field 1 and field 3 for ^{232}Th and ^{40}K were extremely higher. The two fields 1 and 3 were not level; they sloped towards their centers and hence most of the water together with the applied fertilizers accumulated at their centers increasing the concentrations of ^{232}Th and ^{40}K. This phenomenon can be minimized by alternating the finishing of ploughing of the fields both on the side and at the center. These research findings are similar to those of (18) done in the paddy fields of Ebonyi state in Nigeria where sampling was done in two different fields. All the values at harvesting were higher than those before planting and after planting; ^{238}U, ^{232}Th and ^{40}K activity concentrations were 52.36 Bq/kg, 9.89 Bq/kg and 259.54 Bq/kg respectively. These values are also in agreement from Tongaren constituency (19) where the average concentrations for ^{238}U and ^{232}Th were 260.3 ± 13.0 Bq/kg and 85.0 ± 4.3 Bq/kg respectively.

The RHP in each of the samples was computed using equation 4 and tabulated in Table 2.

TABLE 2: Showing activity concentrations in Bq/kg, in ppm and RHP (μW/M^3) .

Sample	^{238}U (Bq|kg)	^{232}Th (Bq|Kg)	^{40}K (Bq|Kg)	^{238}U (ppm)	^{232}Th (ppm)	^{40}K(%)	RHP(μW/m^3)
S1	18.1970	144.30	19.21	1.4734	35.5418	0.0613	3.5 (0.17)
S2	27.6983	87.6117	32.6583	2.2428	21.5792	0.1043	3.4(0.17)
S3	42.2450	170.0698	163.292	3.4206	41.8891	0.5216	7.9(0.39)
S4	31.8850	61.8435	30.7373	2.5818	15.2324	0.0982	3.2(0.16)
S5	43.2112	56.68993	80.6854	3.4989	13.9640	0.2577	4.7(0.23)
S6	38.2728	66.99719	103.7384	3.0990	16.5011	0.3314	5.1(0.25)
S7	18.0896	56.68993	36.5005	1.4648	13.9630	0.1166	2.5(0.12)
S8	9.93053	66.99719	44.1848	0.80409	1.6501	0.1411	2.4(0.11)
S9	5.42153	87.6117	99.8962	0.4389	21.5792	0.3191	3.5(0.17)
S10	13.1512	61.84356	67.2378	1.0649	15.224	0.2148	2.9(0.14)
S11	44.9289	9487.61117	165.213	3.6279	21.5792	0.5278	6.9(0.34)
S12	18.1970	72.15082	30.7373	1.4734	17.7711	0.0982	2.6(0.13)
S13	17.9286	56.68993	98.1672	1.3924	13.9630	0.3136	3.7(0.18)
S14	23.8332	66.9917	101.8173	1.9298	16.3017	0.3252	4.3(0.21)
S15	39.7221	175.2234	217.0823	3.2163	43.1584	0.6935	9.0(0.33)
S16	41.4935	139.148	121.0282	3.3598	34.2729	0.3866	3.6(0.17)
S17	17.9823	103.0726	53.79029	1.4560	25.3873	0.1718	4.5(0.22)

The amount of heat generated by the decay of the radioactive elements of interest depends on the quantities present, their rates of decay as well as the energies of the emissions. The RHP ranged from a minimum of 2.4 μW/m^3 to a maximum of 9.0 μW/m^3 (Table 2, Figure1) with an average of 4.8 μW/m^3. It is evident from the table 2 that ^{232}Th was the highest contributor the RHP followed by ^{238}U while ^{40}K was the least contributor. The high ^{232}Th can be attributed to phosphatic fertilizers previously applied apart from the granitic nature of the underlying rocks. These results are similar to those of [20] in which their values ranged from 1.1 μW/m^3 to 15.5 μW/m^3. They attributed the high RHP to the high activity concentrations of^{238}U and ^{232}Th from the phosphate rocks.

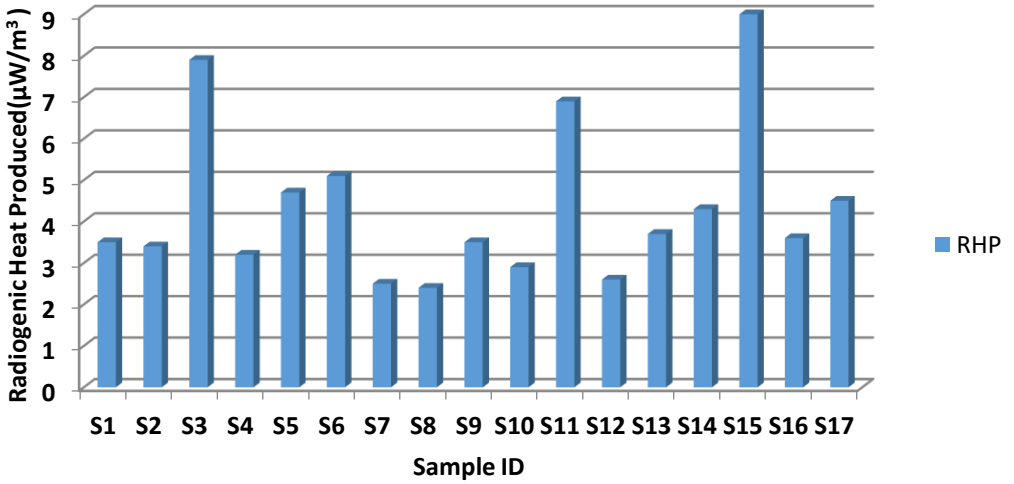
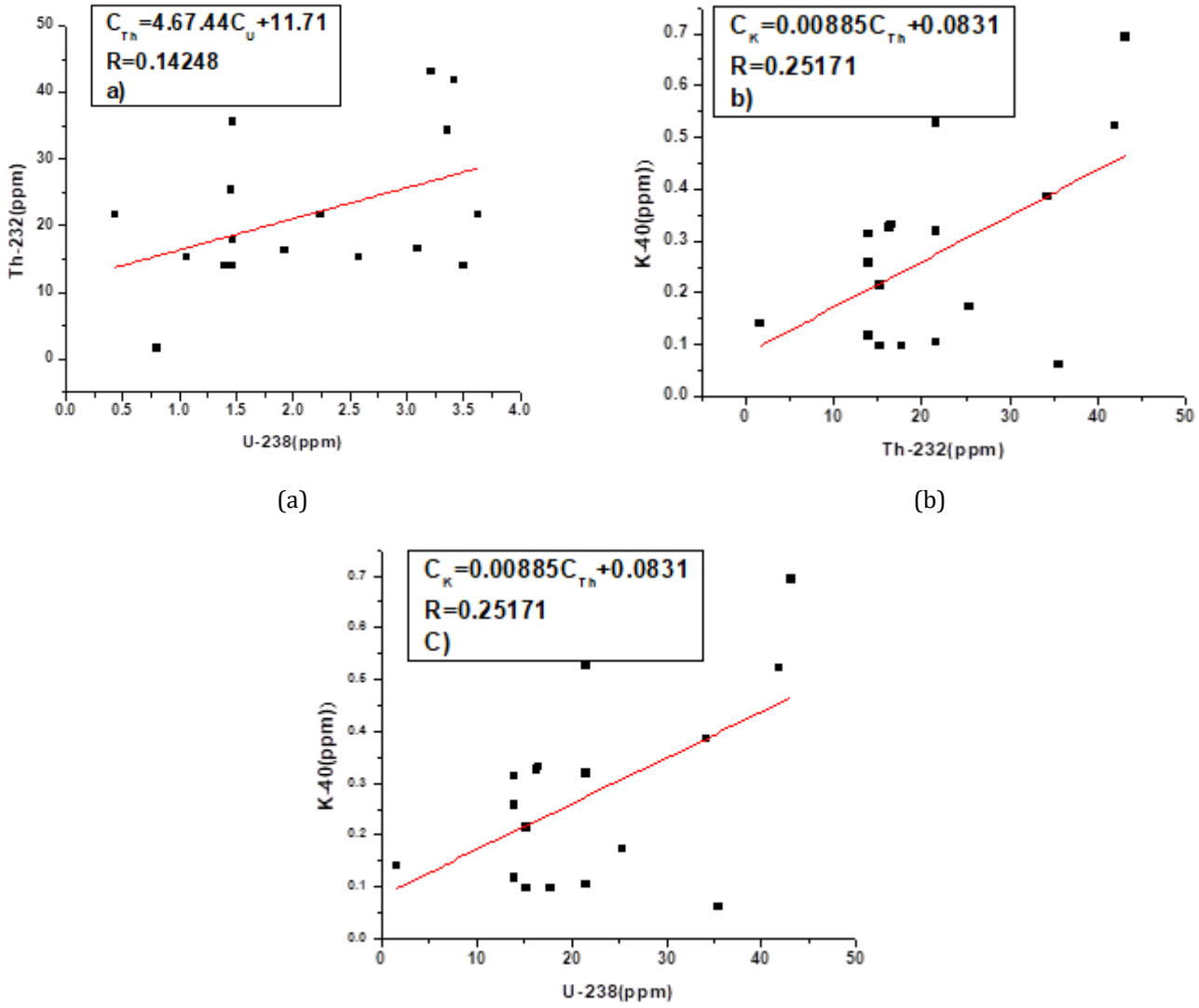


FIGURE 1: Distributions of the radiogenic heat production rates for samples in the study area.



(a) (b)

(c)

FIGURE 2: (a) Comparison of 232Th with238U, (b) Comparison of 40K with232Th, and (c) Comparison of 40K with238U.

Correlations in the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the sediment samples were considered in order to determine the existing ratio between them. Figure 2 (a-c) shows the correlations between the activity concentrations of ^{232}Th and ^{238}U, ^{40}K and ^{232}Th, and ^{40}K and ^{238}U, respectively, with a trend line drawn among the data points. In Figure 2 (a–c), linear and positive correlations were found. It can be seen that there is a good correlation between 232Th and ^{238}U with correlation coefficient of (R^2= 0.14248). The relation shows a slope of 4.6744 with intercept 11.71 ppm. Similarly, Figure 3 (b) show a slope of 0.00885, an intercept of 0.0831% with a correlation coefficient of (R^2= 0.25171) while Figure 3 (c) has a 0.0085 and 0.0831% as slope and intercept, respectively with correlation coefficient of (R^2= 0.25171). The results show that a fairly weak correlation exists between the three radionuclides. Similar results have been reported by (Olanya, *et al.,* 2023).

5. CONCLUSION

Assessment of natural radioanuclides and associated Radiogenic Heat Production in the soils of Ahero fields, Kisumu County, Kenya has been done using NaI(Ti) employing gamma ray spectroscopy. The average activity concentrations for the three radionuclides for field 1 were 32.63 ± 1.63 Bq/kg for ^{238}U, 104.69 ± 5.20 Bq/kg for ^{232}Th and 75.00 ± 3.26 Bq/kg for ^{40}K. The average activity concentrations of the radionuclides from field 2 were 16.97 ± 0.84 Bq/kg, 68.03 ± 3.40 Bq/kg and 70.31 ± 3.51 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average activity concentrations of the radionuclides from field 3(post harvesting) were 28.92 ± 1.44 Bq/kg, 91.73 ± 4.58 Bq/kg and 122.60 ± 6.13 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively. The average activity concentrations of the radionuclides were 29.74 ± 1.48 Bq/kg, 121.11 ± 6.05 Bq/kg and 87.51 ± 4.37 Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively for field 4. Thus, activity concentrations from all the fields do not pose any radiological risk to the public since all the values are below the acceptable limit of 1000 Bq/kg for ^{238}U and ^{232}Th and 100000 Bq/kg for ^{40}K (21). However, the RHP was determined from individual samples. The Radiogenic Heat Production ranged from 2.4 μW/m^3 to a maximum of 9.0 μW/m^3 with an average of 4.8 μW/m^3. The findings from this study are important to relevant authorities in setting up standards and guidelines to safeguard the general public against the harmful effects of radiations from the radionuclides. The RHP values will provide baseline data for further research on possible geothermal energy exploitation which may provide global climate change mitigation.

6. RECOMMENDATION

This study recommends further studies to done in other areas on natural radionuclides and their associated RHP and even determine the heat flow that may prompt a possible geothermal energy exploitation.

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