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RADIOLOGICAL RISK ASSESSMENT OF ^{238}U, ^{232}Th AND ^{40}K IN THE TOP SOILS OF AHERO PADDY FIELDS OF KISUMU COUNTY, KENYA

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ABSTRACT

A radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K in the top soils of Ahero paddy fields of Kisumu County has been measured using NaI(TI) gamma ray spectroscopy. A total of 17 samples were collected at a depth of 15 - 20 cm and measured for activity concentrations of three radionuclides which were used to calculate the absorbed dose rates and Annual effective dose rates of the samples. Samples were collected from fields at various stages of farming process i.e., four (4) weeks after transplanting (field 1), during transplanting (field 2), after harvesting and land ploughed (field 3) and a control field (field 4) where rice farming had not been done for 2 years. 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 $75.00 \pm 3.2\,6$ 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. The average Absorbed Dose Rates were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62 nGy/h for field 2; 74.68 ± 3.73 nGy/h for field 3 and 91.79 ± 4.59 nGy/h for field 4. The values were below the permissible limit of 1500 nGy/h, thus the radiological risk associated with the top soils of the Ahero Paddy fields of Kisumu County, Kenya is insignificant.

I. INTRODUCTION

The origin of radionuclides of Uranium ^{238}U, Thorium ^{232}Th and Potassium ^{40}K dates back to the formation of the Earth [1]. The three radionuclides are found in significant concentrations in various environmental media such as water, soil sediments, plants and foodstuffs [2] and their contents in the soil are directly related to the weathered bedrock. The radionuclides of ^{238}U, ^{232}Th and ^{40}K forms a major source of radiation exposure to the largest group of human population [3]. The radionuclides along with essential nutrients may be absorbed from the soil via the plant roots and transported to other parts of the plant. When they get in edible parts of the crop; they can cause internal exposure to human beings [4]. It is worth noting that ^{238}U and ^{232}Th are radiotoxic elements if they exceed permissible levels whereas ^{40}K is both radiotoxic and nutritionally important [5]. Humans and their foodstuffs are exposed to various types of radiations that originate from primordial, cosmogenic, terrestrial and natural decay series radionuclides [6]. Human beings ingest and inhale radionuclides via consumption of food, water and air respectively. ^{238}U, ^{232}Th and ^{40}K and their numerous progeny are the common radionuclides available in food [7]. An amount of eighty three percent annual effective dose is experienced by individuals due to natural decay series radionuclides, whereas sixteen percent is contributed by primordial ^{40}K and the remaining one percent is due to

anthropogenic radionuclide. Soil to plant and plant to human beings is one of the foremost corridors for transmission of radionuclides [8]. It should be noted that rice is one of the main food consumed by the Kenyan population both in the rural and urban areas. Consequently, human exposure owing to the ingestion of radionuclides via consumption is global concern [9]. Whichever is the mode of exposure, it's a fact that ionizing radiation is detrimental to human health [10].

Human activities such as Agricultural practices have continued to make significant additions to the radioactivity levels of the soil. The use of inorganic fertilizers to replenish both micro and macro elements lost and other agrochemical inputs are associated with the release and subsequent accumulation of natural and artificial radionuclides in the agricultural soils and nearby water sources [11]. The discharge from machines used in production of rice also adds to the overall radionuclide concentration of the soils. The large scale rice farming in Ahero paddy fields is not void of use inorganic fertilizres, agrochemicals, untreated water and mechanical implements. These operations have consequential effects on radioactivity levels of the soil and the whole farming environment [11]. Notwithstanding the economic benefits to the community and government; the knowledge of natural radioactivity due to ^{238}U, ^{232}Th and ^{40}K was important in order to qualify the radiological safeness of the soils as well as categorizing the radiological hazards to the farmers and the general public.

II. MATERIALS AND METHODS

II. 1 STUDY AREA

The study was done in Ahero paddy fields of Muhoroni SubCounty of Kisumu County, Kenya whose population is 151799 (2019 census). It is located on latitude $00^{\circ}9^{\prime\prime}S$ and longitude $34^{\circ}56^{\prime\prime}E$ and at an altitude of 1160 m above sea level. The other crops grown here includes soy beans, maize and tomatoes but on a small scale. The source of water for irrigation in this paddy fields is from River Nyando [12]. The soils in the paddy fields are suitable for irrigation of rice due to their low percolation rates. The main rock types that surround the Ahero paddy fields are granites and granodiorites on the north and south while on the eastern and north western are phonolites.

Figure 1: Route Map of Ahero irrigation scheme.
Source: Authors, (2022).

II.2 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 the control site field.

The rice fields were demarcated as field 1, field 2, field 3 and field 4. The field 4 (control site) was 1 km away from the fields 1, 2 and 3. Five soil samples were collected from each of the fields 1, 2 and 3 while two samples were collected from field four (control site). The samples were collected using the 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 1, 2 and 3. 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). Soil samples from uncultivated land (for 2 years) at about 1 km from the fields which served as a control site was also collected and prepared in the same way. 170 g of each sample from the fields was weighed in to cylindrical plastic containers of uniform geometry which were soaked in dilute Sulphuric acid and then rinsed with distilled water to avoid external contamination of samples. 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.

II.3 GAMMA RAY SPECTROSCOPY

Each sample was placed in a NaI(Ti) γ ray spectrometer that was shielded to prevent stray radiations. The system included an oxford PCA-P multichannel analyzer (MCA) card and its software for spectral acquisition and analysis. The gamma ray spectrometer was calibrated using certified samples of ^{238}U, ^{232}Th and ^{40}K. The peaks of corresponding to ^{232}Th (2615 KeV), 1460 KeV (^{40}K) and 1765 KeV (^{238}U) were considered for the respective activity concentrations. Each sample was put in the NaI(Ti) detector for

measurement for a period of 30000 seconds. Distilled water was also put in the detector to provide background measurement.

II.4 DETERMINATION OF ACTIVITY CONCENTRATIONS OF THE RADIONUCLIDES

The spectra for ^{238}U, ^{232}Th and ^{40}K were obtained using the peaks as follows: 1765 KeV (^{214}Bi), 2615KeV (Ti) and 1460 KeV ((^{40}K). The activity concentration was computed using equation 1 in Bq/kg [13].

$$A_i(Bqkg^{-1}) = \frac{NC_i}{\mathcal{E}\times Y_i\times m\times t} \quad (1)$$

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

II.5 ESTIMATION OF ABSORBED DOSE RATE (ADR)

The radiation absorbed dose rate, ADR was estimated for radiation risk assessment to quantify the amount of radiation energy that may be deposited per unit time on a potentially exposed person [11]. The absorbed dose rate was calculated using the activity concentration and the conversion factors [14]. The conversion factors for ^{238}U, ^{232}Th and ^{40}K were 0.462, 0.604 and 0.0417 respectively. Equation 2 shows the equation used in computing ADR [15].

$$ADR = 0.462A_u + 0.604_{Th} + 0.0417_{Ak} \quad (2)$$

Where A_u, A_{Th} and A_k are activity concentrations of ^{238}U, ^{232}Th and ^{40}K in $Bqkg^{-1}$ respectively [16].

III RESULTS AND DISCUSSION

III.1 ACTIVITY CONCENTRATIONS

It can be noted that the mean activity concentrations of 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 field 1 is the one in which rice had already been transplanted and the rice seedlings were a month old and some fertilizer had been applied. The activity concentration of ^{238}U was higher than the world permissible level of 45 Bq/kg and although that of ^{238}U was below the world permissible limit of 33 Bq/kg; it was still high. Their high concentrations can be attributed to the phosphatic fertilizers that had been applied apart from the geology of the place characterized by underlying granitic rocks. The activity concentrations of ^{40}K were below the world permissible limit of 420 Bq/kg [17]. 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's 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 that contains this radionuclide.

The average concentrations of the radionuclides from field 3 (post harvesting) where harvesting had be 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 activity concentrations of ^{238}U and ^{232}Th had higher values than the world permissible limits. At this stage, top dressing had been done twice and this may also have added to increased activity concentrations.

The field 4 that had not been ploughed for two years and was a control field unfortunately 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 phosphatic fertilizers whose origin is from rocks that contains high concentrations of Uranium and Thorium accumulates in the soils increasing their activity concentrations.

Although some of the activity concentrations for ^{238}U and all for ^{232}Th were higher; they were below the 1000 Bq/Kg for both radionuclides [18], thus the soils are not hazardous to the human population interacting with them.

Graphical representation of the activity concentrations for all the samples in this work are as shown in Figure 2.

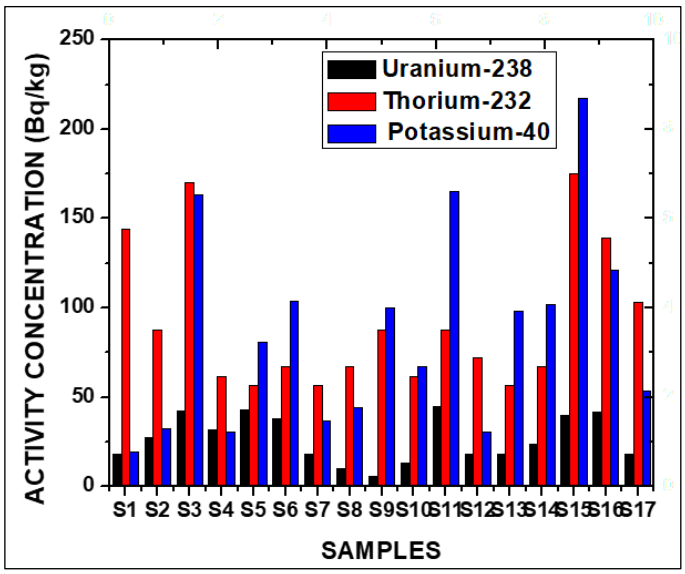

Figure 2: Graphical representations of activity concentrations of the radionuclides in this study.
Source: Authors, (2022).

III.2 ABSORBED DOSE RATE (ADR)

The average Absorbed Dose Rates were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62 nGy/h for field 2, 74.68 ± 3.73 nGy/h, for field 3, and 91.79 ± 4.59 nGy/h for field 4 (Figure 3). The values obtained from the samples were represented in Figure 3 below.

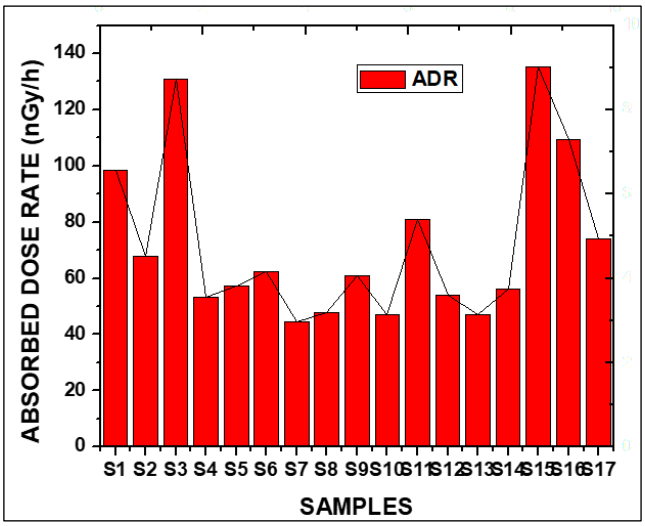

Figure 3: Representation of Absorbed Dose Rate in this work.
Source: Authors, (2022).

It can be noted that apart from field 2 where transplanting was being done; all the other fields had Absorbed Dose Rate values above the world value; 60 nGy/h Figure 3). The values are higher because the activity concentrations were also higher and since Absorbed Dose Rates are calculated from these values; they contributed to the higher values. Despite their higher values, they were below the world acceptable limit of 1500 nGy/h [19].

IV. CONCLUSION

Radiological risk assessment of ^{238}U, ^{232}Th and ^{40}K have been measured in the top soil samples collected from Ahero Paddy fields of Kisumu County, Kenya using gamma ray spectroscopy. The average activity concentrations for the three radionuclides in all the four were within the permissible levels. The average Absorbed Dose Rates (ADR) were 81.50 ± 4.07 nGy/h for field 1, 52.59 ± 2.62nGy/h f for field 2; 74.68 ± 3.73 nGy/h for field 3 and 91.79 ± 4.59 nGy/h for field 4. All the ADR average values were below the permissible limit of 1500 nGy/h. The average annual effective dose rate AED (in) and an average AED (out) for field 1 were 0.30 ± 0.01 mSv/y and an average AED (out) of 0.20 ± 0.01 mSv/y, an average AED (in) of 0.19 ± 0.01 mSv/y, an average AED (out) of 0.20 ± 0.01 mSv/y, for field 2, an average AED (in) of 0.28 ± 0.01 mSv/y and an average AED (out) of 0.18 ± 0.01 mSv/y for field 3 and an average AED (in) of 0.34 ± 0.01 mSv/yand an average AED (out) of 0.23 ± 0.01 mSv/y, for field 4. All the annual effective dose rates of the samples from all the fields were below the world acceptable limit of 1 mSv/y, hence there is minimal exposure risk to the general population at study area. There is need for radiological survey to be done on the rice components that includes rice grains, rice stalks and rice roots to provide a single analytical and information data base of radiation hazard safety.

V. AUTHOR'S CONTRIBUTION

Conceptualization: Wanyama Mukanda Kere, Michael Nakitare Waswa, Linda Ouma.
Methodology: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Investigation: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Discussion of results: Wanyama Mukanda Kere, Michael Nakitare Waswa and Linda Ouma.
Writing – Original Draft: Wanyama Mukanda Kere.
Writing – Review and Editing: Wanyama Mukanda Kere and Michael Nakitare Waswa.
Resources: Wanyama Mukanda Kere.
Supervision: Michael Nakitare Waswa and Linda Ouma.
Approval of the final text: Wanyama Mukanda Kere, Michael Nakitare Waswa and Linda Ouma.

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VII. COMPETING INTEREST STATEMENT

The authors declare no conflict of interest.

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