

## Research

# Investigation into radioactivity levels in soil samples from wheat cultivation sites in Kapchorwa district Uganda

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## Abstract

Using a NaI(Tl) gamma ray spectrometer, the activity concentrations of three natural radionuclides,  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$ , were assessed for soil samples taken from various locations within the Kapchorwa district wheat plantation region. The average values found for  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  are  $47.8 \pm 4.1 \text{ Bqkg}^{-1}$ ,  $61.0 \pm 3.8 \text{ Bqkg}^{-1}$ , and  $1339.05 \pm 65.3 \text{ Bqkg}^{-1}$ , respectively, all of which were above world average values. Radiological health hazard indices were calculated, including radium equivalent activity, absorbed dose rate, annual effective dose equivalent, external and internal health hazard indices, as well as gamma and alpha indices. The findings revealed that the annual effective dose equivalent (HR) and absorbed dose rate (DR) are respectively  $0.58 \pm 0.03 \text{ mSv}^{-1}$  and  $118.1 \pm 7.7 \text{ nGy}^{-1}$ , and the mean value of radium equivalent activity is  $246.9 \pm 10.4 \text{ Bqkg}^{-1}$ . The gamma and alpha health hazard indices have values of  $0.93 \pm 0.05$  and  $0.25 \pm 0.02$ , respectively, whereas the external and internal health hazard indices have values of  $0.66 \pm 0.04$  and  $0.79 \pm 0.04$ , respectively. The findings showed that although the soil's radioactivity levels were higher than acceptable limits established by international standards, the computed hazard indices were lower than acceptable limits established by international standards, indicating a low risk of radiation contamination in the region. Important information about the natural radioactivity levels in agricultural soils and their effects on the environment and public health in Kapchorwa District and surrounding areas is provided by this study.

**Keywords** Radioactive concentration · Uganda · Uranium · Fertilizer · Environment

## 1 Introduction

Since the Earth's origin, naturally occurring radioactivity has been a part of our environment [1–3]. Commonly found in rocks and soils are radioactive elements like uranium ( $^{238}\text{U}$ ), thorium ( $^{232}\text{Th}$ ), and potassium ( $^{40}\text{K}$ ) [4–6], which all contribute to background radiation levels [7–9]. However, some human activities particularly poor farming methods like overusing fertilizer, might make it worse for these radionuclides to build up in the soil [10–12], which raises questions about possible health risk from radiation exposure.

The study of natural radioactivity in soil samples holds significant importance due to its implications on human health and environmental sustainability [13, 14]. Understanding the distribution and concentration of radionuclides in soil is crucial for assessing potential radiation exposure risks [8, 15, 16], particularly in agricultural areas where crops are cultivated for human consumption [17–19]. This study focuses on determining the radioactivity concentrations and dose assessment in soil samples from wheat plantation areas of Kapchorwa District, Uganda.

The specific objectives were:

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- I. To determine the activity concentration of the natural radionuclides  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  and their daughter radionuclides in soil samples from wheat plantation areas of Kapchorwa District.
- II. To calculate the radiation absorbed dose rates and annual effective dose rates from gamma rays emitted by soil samples.
- III. To determine the radium equivalent activity, external and internal hazards indices and gamma and alpha indices of the soil.

Numerous investigations have been conducted worldwide to evaluate the levels of natural radioactivity in soil samples. Studies in regions such as the Brazilian state of Rio Grande do Norte [20] and phosphate-rich areas of El-Sabaea Aswan in Egypt [21] have reported varying activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ . These investigations have highlighted the significance of understanding the distribution of naturally occurring radionuclides in soil and their potential impact on human health and the environment.

In Uganda, several studies have been undertaken to assess the levels of natural radioactivity in various environmental settings [22–27]. However, there remains a gap in research focusing specifically on agricultural fields, particularly in Kapchorwa District. Therefore, this study aims to contribute to the existing body of knowledge by providing valuable insights into the radioactivity concentrations and radiological hazards in soil samples from wheat plantation areas, thus addressing the need for comprehensive assessments of radiation exposure in agricultural settings.

The novelty of this study lies in its specific focus on wheat plantation areas in Kapchorwa District, Uganda, which has not been extensively studied for natural radioactivity levels previously. By conducting a detailed analysis of radionuclide activity concentrations and dose assessment, this study seeks to fill the existing research gap and provide essential data for assessing radiation exposure risks in agricultural environments. Furthermore, the evaluation of radiological hazards will contribute to enhancing our understanding of the potential health risks associated with soil radioactivity in this region.

## 2 Geographical location of Kapchorwa district

This research was conducted in the district of Kapchorwa, which is located in Uganda's Eastern Region. Bulambuli District to the west and northeast, Sironko District to the south, and Kween District to the east and northeast. The closest big city, Mbale, is roughly 65 km (40 miles) northeast of Kapchorwa, the district seat, which translates to "home of friends". Uganda's capital and largest city, Kampala, is located roughly 295 km (183 miles) northeast of the area. The district's coordinates are 01 24N, 34 27E. Figure 1 shows a Map of the area of the investigation.

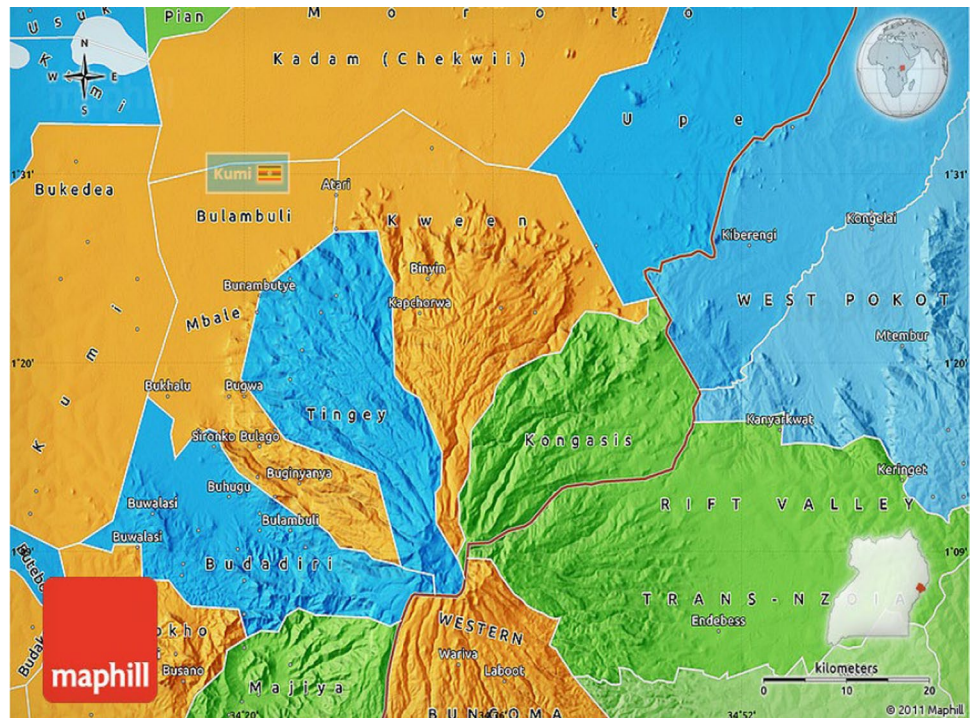
### 2.1 Methodology

A total of twenty-four 500 g surface soil samples were gathered from the wheat plantation area in Uganda's Kapchorwa District. The locations where the samples were taken were Chemonges Square, Barawa, Kawowo, Kapkwomurya, Kapsinda, and Chepsukuroi. To ensure statistical sensitivity of sampling, a simple random sample technique was used [28, 29]. Within the plantation area, random selection was used to choose the sampling locations. At each test location, the soil was first made visible by clearing away any vegetation and debris. After that, soil samples were taken with a trowel at a depth of 10 to 15 cm, and they were put in a polythene bag with a clear label. After that, each polythene bag was sealed to prevent sample contamination on the way to the lab.

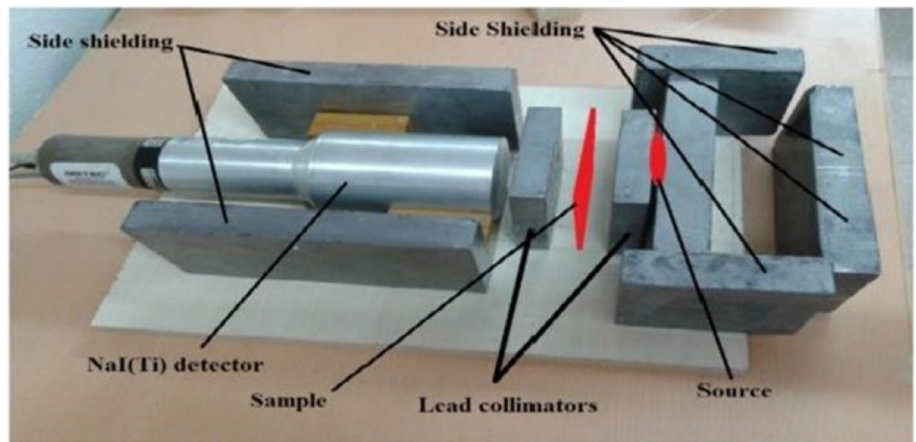
Samples were initially allowed to dry fully outside in the laboratory before being ground into a fine powder, homogenized, and oven dried at a temperature of around 110 °C to eliminate any remaining moisture. In order to achieve secular equilibrium between  $^{226}\text{Ra}$  and  $^{232}\text{Th}$  and their daughter radionuclides, the processed samples were moved to uniform plastic containers, weighed, and sealed for a period of thirty days [30–32]. Using a NaI(Tl) detector (Fig. 2), the natural radioactivity levels in the wheat plantation region in Kapchorwa District were determined.

The gamma ray spectrometer used for radiation detection and measurements is a  $3'' \times 3''$  NaI(Tl) crystal detector coupled with a high voltage operated photomultiplier tube (PMT). The system has an Oxford PCAP Multichannel Analyzer (MCA) card and its software for spectral data acquisition and analysis. The PMT consist of photocathode where electrons are released via the photoelectric effect by the scintillation photons and a series of dynodes. Each dynode is biased to a higher voltage with respect to the preceding dynode to multiply the number of electrons in the pulse of charge. For the selected bias voltage, energy deposited by the gamma-ray in the scintillator is proportional to the charge arriving

**Fig. 1** Map of area of the investigation



**Fig. 2** Picture Showing Na(Tl) Gamma Ray Spectrometer [33]



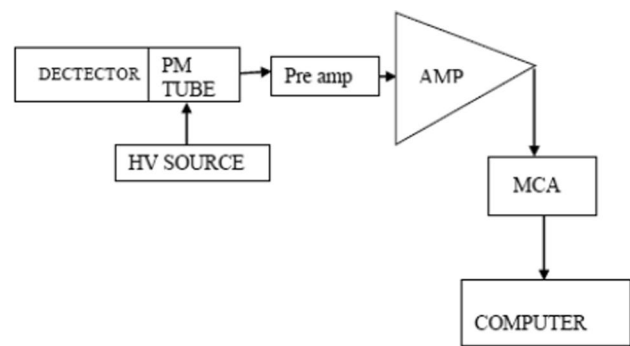
at the anode. From the anode, the preamplifier collects the charge on a capacitor and turns it into a voltage pulse. The voltage pulse is transmitted to the supporting amplifier. At the output of the preamplifier and at the output of the linear amplifier, the energy deposited in the scintillator by the detected gamma ray is proportional to the pulse height. The pulse heights delivered by the amplifier are measured by the Multichannel Analyzer (MCA) and sorted into a histogram to record the energy spectrum produced by the NaI(Tl) detector. Figure 3 shows an electronic diagram of the NaI(Tl) gamma-ray spectrometer used in this work.

**2.2 Radioactivity concentration**

The activity concentration of the radionuclides in the samples was calculated using the comparison method, given by the Eq. (1) [34, 35];

$$\frac{C_r M_r}{I_r} = \frac{C_s M_s}{I_s} \tag{1}$$

**Fig. 3** Schematic diagram for gamma ray spectroscopy used in this work



where  $C_r$  is the radionuclide activity concentration in the standard reference sample,  $M_r$  is the mass of standard reference sample,  $I_r$  is the peak intensity of the radionuclide in the standard sample,  $C_s$  is the activity of radionuclide in the sample,  $M_s$  is the mass of the sample and  $I_s$  is the peak intensity of the radionuclide in the sample.

### 2.3 Radium equivalent activity

This activity index represents a weighted sum of activity concentrations of the natural radionuclides  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  and is based on the estimation that  $1 \text{ Bqkg}^{-1}$  of  $^{226}\text{Ra}$ ,  $0.7 \text{ Bqkg}^{-1}$  of  $^{232}\text{Th}$ , and  $13 \text{ Bqkg}^{-1}$  of  $^{40}\text{K}$  produce the same gamma radiation dose rates [36]. The index is given as:

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077C_K \quad (2)$$

where  $C_{Ra}$ ,  $C_{Th}$  and  $C_K$  are the concentrations in  $\text{Bq/kg}$  of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  respectively. The maximum dose  $Ra_{eq}$  in soil samples must be less than  $370 \text{ Bq/kg}$  [37, 38], in order to keep the external dose below  $1 \text{ mSv}^{-1}$ .

### 2.4 Gamma radiation absorbed dose rate

The activity concentrations of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  are converted into dose rates by applying the conversion factors 0.462, 0.604, and 0.0417 for  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ , respectively [39]. These factors are used to calculate the total dose rate ( $D_R$ ) ( $\text{nGy h}^{-1}$ ) using the following equation:

$$D_R (\text{nGy h}^{-1}) = 0.462 C_{Ra} + 0.604 C_{Th} + 0.0417 C_K \quad (3)$$

where  $C_{Ra}$ ,  $C_{Th}$  and  $C_K$  are activities of  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$ , respectively in  $\text{Bq/kg}$ .

### 2.5 Annual effective dose

The annual effective dose received by an individual was determined using Eq. (4) [40];

$$H_R = D_R T f_c \quad (4)$$

where  $D_R$  is the absorbed dose rate,  $T$  is the outdoor occupancy time of 20% and  $f_c$  is conversion factor of  $0.7 \text{ SvGy}^{-1}$  respectively.

### 2.6 External ( $H_{ex}$ ) and internal ( $H_{in}$ ) hazard indices

Beretka and Mathew [41] defined two indices that represent external and internal radiation hazards. The external hazard index ( $H_{ex}$ ) is calculated using the given equation [39]:

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (5)$$

The internal hazard index ( $H_{in}$ ) gives the internal exposure to carcinogenic radon and its short-lived progeny [42]. To account for this threat the maximum permissible concentration for  $^{226}\text{Ra}$  must be reduced to half of the normal limit (185 Bq/kg) and it is given by the following equation [43, 44];

$$H_{in} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (6)$$

To have negligible hazardous effects of radon and its short-lived progeny to the respiratory organs, the values of  $H_{ex}$  and  $H_{in}$  must be less than unity [39].

## 2.7 Gamma index ( $I_\gamma$ )

Gamma index was calculated using Eq. (7). This is used to estimate the  $I_\gamma$ - radiation hazard associated with the natural radionuclide in specific investigated samples. Values of  $I_\gamma \leq 1$  corresponds to an annual effective dose of less than or equal to 1 mSv, while  $I_\gamma \leq 0.5$  corresponds to annual effective dose less or equal to 0.3 mSv [40];

$$I = \frac{C_{Ra}}{300} + \frac{C_{Th}}{200} + \frac{C_K}{3000} \quad (7)$$

where  $C_{Ra}$ ,  $C_{Th}$ , and  $C_K$  are the  $^{226}\text{Ra}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  activity concentrations (Bq/kg) in the soil samples respectively.

## 2.8 Alpha index ( $I_\alpha$ )

This index was used to assess the excess alpha radiation due to radon inhalation from soils, defined as follows [45]:

$$I_\alpha = \frac{C_{Ra}}{200} \quad (8)$$

# 3 Results and discussion

The radiation absorbed dose rate, annual effective dose rate, radium equivalent activity, external and internal hazard indices, gamma and alpha indices, and radioactivity concentrations in soil samples were all determined. These amounts have been calculated, and the outcomes are shown in Tables 1 and 2.

## 3.1 Measured activity concentrations

In 24 soil samples from the wheat plantation region of Kapchorwa, the activity concentration of the radionuclides  $^{238}\text{U}$ ,  $^{232}\text{Th}$ , and  $^{40}\text{K}$  has been measured. Samples 1 through Sample 24 are designated as S1 through S24, accordingly.  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  were found to have lowest activity concentrations of  $09.8 \pm 2.6 \text{ Bqkg}^{-1}$ ,  $20.0 \pm 0.2 \text{ Bqkg}^{-1}$  and  $820.6 \pm 53.6 \text{ Bqkg}^{-1}$ , respectively, and maximum values of  $100.1 \pm 2.5 \text{ Bqkg}^{-1}$ ,  $79.8 \pm 6.4 \text{ Bqkg}^{-1}$  and  $1724.3 \pm 12.1 \text{ Bqkg}^{-1}$ . In the wheat plantation area, the mean activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  are  $47.8 \pm 4.1 \text{ Bqkg}^{-1}$ ,  $61.0 \pm 3.8 \text{ Bqkg}^{-1}$  and  $1339.05 \pm 65.3 \text{ Bqkg}^{-1}$  respectively.

In comparison to the global weighted average of  $33 \text{ Bqkg}^{-1}$  for  $^{238}\text{U}$ ,  $45 \text{ Bqkg}^{-1}$  for  $^{232}\text{Th}$  and  $420 \text{ Bqkg}^{-1}$  for  $^{40}\text{K}$  [39], the values of radionuclide activity concentration is considerably greater.

The high concentrations of  $^{40}\text{K}$  are explained by the fact that the soil samples came from farms that continuously apply inorganic fertilizers high in potassium and other chemicals to increase crop yields.  $^{232}\text{Th}$  and  $^{238}\text{U}$  are also higher than the world average values. The reason for high  $^{238}\text{U}$  levels is the ongoing use of phosphate fertilizers, which are required to replenish depleted soils from the natural nutrients lost to farming and erosion. The phosphate rock used to make this fertilizer has a high uranium percentage. Rocks known to be rich in these radionuclides, such as carbonatite and monazite, are associated with elevated  $^{238}\text{U}$  values.

**Table 1**  $^{40}\text{K}$ ,  $^{238}\text{U}$  and  $^{232}\text{Th}$  and  $\text{Ra}_{\text{eq}}$  activity concentrations

Sampling Sites	$^{40}\text{K}$ (Bqkg <sup>-1</sup> )	$^{238}\text{U}$ (Bqkg <sup>-1</sup> )	$^{232}\text{Th}$ (Bqkg <sup>-1</sup> )	$\text{Ra}_{\text{eq}}$ (Bqkg <sup>-1</sup> )
S1	1724.3 ± 12.1	28.2 ± 9.1	20.0 ± 0.2	190.1 ± 0.3
S2	1642.8 ± 76.3	49.4 ± 8.5	71.0 ± 0.3	278.2 ± 2.7
S3	820.6 ± 53.6	50.1 ± 1.2	50.7 ± 2.6	180.3 ± 7.8
S4	1119.8 ± 42.1	48.6 ± 1.3	60.2 ± 1.6	217.3 ± 6.8
S5	1436.2 ± 46.8	33.2 ± 1.3	59.8 ± 6.3	232.2 ± 1.3
S6	1359.57 ± 87.1	53.6 ± 2.6	76.1 ± 1.0	266.5 ± 1.4
S7	1035.4 ± 73.2	40.1 ± 0.1	49.8 ± 8.3	200.4 ± 7.3
S8	1329.8 ± 89.7	46.1 ± 0.1	88.2 ± 0.1	270.9 ± 8.3
S9	1202.2 ± 59.2	40.1 ± 1.2	35.1 ± 0.2	200.2 ± 1.3
S10	1445.3 ± 53.1	57.9 ± 5.8	24.7 ± 4.5	198.9 ± 3.4
S11	888.1 ± 21.1	46.1 ± 3.4	66.1 ± 2.1	210.3 ± 4.2
S12	1687.2 ± 12.1	19.8 ± 3.2	75.1 ± 6.2	260.7 ± 14.2
S13	1449.9 ± 93.8	75.9 ± 4.2	77.9 ± 8.4	300.4 ± 34.3
S14	1529.8 ± 82.4	100.1 ± 2.5	50.3 ± 4.6	284.3 ± 23.2
S15	1369.8 ± 83.4	09.8 ± 2.6	29.8 ± 3.4	160.2 ± 9.4
S16	1252.6 ± 58.4	29.9 ± 3.2	50.2 ± 4.2	200.1 ± 9.5
S17	1468.7 ± 74.3	69.8 ± 7.2	69.1 ± 7.2	289.4 ± 4.3
S18	1498.8 ± 84.6	66.2 ± 5.3	79.3 ± 6.2	296.3 ± 18.4
S19	1290.1 ± 65.8	50.1 ± 3.6	78.1 ± 2.7	255.1 ± 18.6
S20	1630.8 ± 94.3	75.4 ± 4.3	66.6 ± 2.1	300.2 ± 29.1
S21	1670.4 ± 79.4	39.6 ± 6.2	59.7 ± 4.2	259.1 ± 10.3
S22	1549.7 ± 68.2	79.8 ± 8.4	78.5 ± 2.5	299.8 ± 12.6
S23	1420.5 ± 83.4	58.7 ± 5.2	68.8 ± 6.9	277.3 ± 11.3
S24	1350.3 ± 73.2	69.5 ± 7.4	79.8 ± 6.4	298.3 ± 10.7
Mean	1339.05 ± 65.3	47.8 ± 4.1	61.0 ± 3.8	246.9 ± 10.4

## 3.2 Radiological hazards

### 3.2.1 Radium equivalent activity $\text{Ra}_{\text{eq}}$

Table 1 shows the estimated values of  $\text{Ra}_{\text{eq}}$  for the collected samples.  $\text{Ra}_{\text{eq}}$  varied from  $160.2 \pm 9.4$  Bqkg<sup>-1</sup> to  $300.4 \pm 34.3$  Bqkg<sup>-1</sup>, with an average value of  $246.9 \pm 10.4$  Bqkg<sup>-1</sup> for the samples that were collected.  $\text{Ra}_{\text{eq}}$  values were below the recommended maximum value of 370 Bqkg<sup>-1</sup>, indicating that the soil samples exhibit relatively low levels of radium equivalent activity, which is a positive indication of minimal radiological risk associated with this parameter.

### 3.2.2 Radiation absorbed dose rate

The absorbed dose rate is shown in Table 2. The absorbed dose rate varied from  $79.2 \pm 5.2$  nGyh<sup>-1</sup> to  $150.8 \pm 6.1$  nGyh<sup>-1</sup>, with a mean value of  $118.1 \pm 7.7$  nGyh<sup>-1</sup>. The absorbed dose rate is higher than the world average of 60 nGyh<sup>-1</sup> [39], suggesting a slightly elevated level of radiation exposure in the study area compared to global norms. The high concentrations are explained by the fact that the soil samples came from farms that continuously apply fertilizers to increase crop yields. The use of phosphate-based fertilizers, for example, contribute to elevated levels of uranium and thorium in agricultural soils, thereby influencing absorbed dose rates.

### 3.2.3 The annual effective dose rate

The calculated annual effective dose rate is shown in Table 2. It varies from  $0.39 \pm 0.03$  mSvy<sup>-1</sup> to  $0.72 \pm 0.03$  mSvy<sup>-1</sup>, with an average value of  $0.58 \pm 0.03$  mSvy<sup>-1</sup>. It is below the recommended dose limit of 1 mSvy<sup>-1</sup>, indicating that the potential radiation exposure to individuals from the soil samples is within acceptable levels, thus posing minimal health risks.

**Table 2** Radiological hazards

Sampling Sites	Absorbed dose rate (nGyh <sup>-1</sup> )	Annual effective dose rate (mSvy <sup>-1</sup> )	H <sub>ex</sub>	H <sub>in</sub>	Gamma Index	Alpha Index
S1	100.3±6.2	0.50±0.04	0.49±0.03	0.60±0.02	0.81±0.04	0.15±0.02
S2	140.2±8.7	0.70±0.04	0.75±0.02	0.91±0.03	1.05±0.05	0.26±0.02
S3	89.3±5.6	0.39±0.03	0.51±0.03	0.59±0.02	0.70±0.04	0.23±0.01
S4	99.7±8.9	0.48±0.02	0.60±0.02	0.68±0.02	0.79±0.04	0.24±0.02
S5	117.7±8.3	0.56±0.02	0.59±0.02	0.69±0.04	0.92±0.03	0.17±0.02
S6	128.4±8.7	0.65±0.03	0.69±0.02	0.87±0.03	0.98±0.03	0.25±0.01
S7	89.7±6.3	0.45±0.04	0.49±0.03	0.59±0.02	0.69±0.04	0.20±0.02
S8	129.8±8.2	0.65±0.02	0.73±0.04	0.59±0.04	0.98±0.04	0.21±0.01
S9	89.4±7.6	0.45±0.03	0.51±0.03	0.88±0.02	0.79±0.02	0.11±0.02
S10	128.7±8.6	0.49±0.03	0.54±0.02	0.59±0.02	0.79±0.03	0.21±0.01
S11	98.7±7.2	0.48±0.02	0.56±0.03	0.69±0.02	0.78±0.02	0.19±0.02
S12	129.9±8.4	0.63±0.02	0.69±0.04	0.70±0.03	0.98±0.04	0.30±0.02
S13	146.2±9.3	0.69±0.02	0.79±0.03	1.02±0.05	1.13±0.05	0.40±0.01
S14	140.3±4.3	0.70±0.03	0.78±0.02	0.89±0.05	1.07±0.05	0.50±0.01
S15	79.2±5.2	0.70±0.02	0.45±0.04	0.46±0.02	0.96±0.02	0.50±0.02
S16	101.8±7.2	0.39±0.03	0.49±0.03	0.58±0.04	0.64±0.05	0.49±0.01
S17	139.8±8.1	0.51±0.03	0.81±0.04	1.04±0.03	0.76±0.05	0.16±0.02
S18	150.8±6.1	0.69±0.02	0.80±0.04	1.00±0.04	1.09±0.04	0.40±0.02
S19	130.2±8.6	0.59±0.02	0.70±0.03	0.79±0.04	1.00±0.05	0.29±0.01
S20	147.3±8.4	0.69±0.02	0.80±0.03	0.99±0.05	1.10±0.04	0.24±0.01
S21	129.4±8.3	0.65±0.03	0.69±0.04	0.84±0.02	0.99±0.04	0.40±0.01
S22	149.3±8.4	0.72±0.03	0.85±0.03	1.08±0.04	1.16±0.05	0.19±0.02
S23	138.2±8.7	0.70±0.03	0.68±0.04	0.89±0.04	0.98±0.04	0.29±0.03
S24	139.8±8.6	0.69±0.02	0.79±0.03	1.00±0.04	1.09±0.04	0.37±0.03
Mean	118.1±7.7	0.58±0.03	0.66±0.04	0.79±0.04	0.93±0.05	0.25±0.02

### 3.3 Internal (H<sub>in</sub>) and external (H<sub>ex</sub>) hazard indices

The internal and external hazard indices is shown in Table 2. The average values for internal and external hazard indices are  $0.79 \pm 0.04$  and  $0.66 \pm 0.04$  respectively. These values are less than 1, which implies that exposure to radiations in the area is negligible. This is reassuring for the safety of individuals residing or working in the vicinity of the wheat plantation areas in Kapchorwa District.

### 3.4 Gamma (I<sub>γ</sub>) and alpha (I<sub>α</sub>) indices

The values of gamma and alpha indices obtained from the activity concentration of radium, thorium and potassium are presented in Table 2 for various soil samples analysed. The values of gamma index varied from  $0.64 \pm 0.05$  to  $1.16 \pm 0.05$  with the average value of  $0.93 \pm 0.05$  while the estimated alpha index values varied from  $0.11 \pm 0.02$  to  $0.50 \pm 0.02$  with the average value of  $0.25 \pm 0.02$ . All values were less than unity, indicating that the soil samples pose minimal radiological risks from both gamma and alpha radiation sources.

## 4 Conclusion

In the studied area, the average radium equivalent activity ( $Ra_{eq}$ ) was  $246.9 \pm 10.4 \text{ Bqkg}^{-1}$ . Since this is less than the  $370 \text{ Bqkg}^{-1}$  safe value that is advised, the radiation risks related to the radionuclides that are found in the soil are within acceptable bounds.

The radiation hazard indices were computed based on the measured activity concentrations of  $^{238}\text{U}$ ,  $^{232}\text{Th}$  and  $^{40}\text{K}$  in the research area. The average values of the radiation hazard indices  $H_{in}$  and  $H_{ex}$  were  $0.79 \pm 0.04$  and  $0.66 \pm 0.04$  respectively. It was discovered that the alpha and gamma indices had average values of  $0.25 \pm 0.02$  and  $0.93 \pm 0.05$ , respectively. These values fall short of the unity's crucial value. This suggests that there are no radiation risks present in the soil in the Kapchorwa wheat planting area.

**Author contributions** S.M.S. contributed to the study conception. S.M.S., A.U., A.O.O. contributed to the study, design, and all aspect of the manuscript. The first draft of the manuscript was written by S.M.S., A.U., and A.O.O. S.M.S., A.U., and A.O.O. read and approved the final manuscript.

**Data availability** Data sets generated during the current study are available from the corresponding author on reasonable request.

## Declarations

**Competing interests** The authors declare no competing interests.

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