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# Determination of radioactivity concentration from sand samples from riverbanks of Goronyo dam, Sokoto Nigeria using high-resolution gamma-ray spectrometry

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***Abstract***
*The activity concentrations of radionuclides level in the soil samples from the riverbank of Goronyo dam have been investigated using the high-resolution gamma-ray spectrometry to evaluate health hazards indices and excess lifetime cancer risk (ELCR). The minimum, maximum and mean activity concentrations of $^{238}U$, $^{232}Th$, and $^{40}K$ in the soil sample was 13.34 Bq/kg -54.37 Bq/kg with a mean value of 34.7 Bq/kg ±12.4 Bq/kg, 21.56 Bq/kg -71.23 Bq/kg with a mean value of 45.5±13.8 Bq/kg, and 198.83 Bq/kg -891.63 Bq/kg with a mean value of 541.2±192 Bq/kg, respectively. The mean Radium equivalent activity concentrations (141.5±30.4 Bq/Kg), outdoor external dose (81.06±17.6 nGy/h), indoor external dose (342.25±70.4 nGy/h), and total average annual effective dose ($405.31 \pm 88\, m.Sv/yr$ was calculated. The total excess lifetime cancer risk was found to be 1.4±0.3 and is above the world's average.*

***Keywords:*** *radionuclides, activity concentration of $^{238}U$, $^{232}Th$, and $^{40}K$. dose rate, riverbank of Goronyo, Excess lifetime cancer risk (ELCR), Radiation indices (I)*

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## I. Introduction:

Naturally occurring radioactive materials (NORMs) are substances that have existed since the beginning of time. The human body, earth, water, and air are among the materials. NORMs are found in our environment primarily from extraterrestrial (cosmic radiation) and terrestrial sources [1]. Radioactive nuclides from the primary decay chains for $^{238}$U, $^{235}$U, $^{232}$Th, and their daughter products, as well as long-lived radioactive nuclides like $^{40}$K, can be found in naturally occurring materials [2-4]. The release of radioactive nuclides into the soil, which is the primary source of natural background radiation, is caused by the weathering of the earth's crust. Furthermore, fertilizer elements like phosphates ($^{238}$U and $^{232}$Th) and potassium, employed in plant nitration processes, are regarded as significant causes of soil contamination [4].

Almost all building materials derived from rock or soil contain radionuclides at varying levels. Long-lived radionuclides with half-lives comparable to Earth's age, such as those originating from the $^{238}$U or $^{232}$Th series, as well as $^{40}$K, can still be found in the Earth's Based on the local geology of the location, underlying rock, and distinct geological formations with differing concentrations [5]. $^{238}$U, $^{40}$K, and $^{232}$Th are among the nuclides that can be determined by gamma-ray spectrometry. Daughter nuclides of the $^{235}$U, $^{238}$U, and $^{232}$Th isotopes are present [6]. Gamma spectrometry of NORMs is complicated for a variety of reasons. First, the activity levels are usually rather low and can require long counting periods. Secondly, is the nature of background spectrometry; a large number of peaks can be present in the background spectra owing to the NORM nuclides in the surroundings of the detector. Depending on the local environment, there may be evidence of contamination from neutron-capture and fission-product nuclides, such as $^{60}$Co and $^{137}$Cs [7]. Some radionuclides emit characteristics of gamma rays, which can be measured by using a gamma spectrometry system.

Goronyo Local Government area is among the rice-producing area in Sokoto State due to the presence of Fadama land and the Goronyo dam. As a result of long-term activities such as farming, fishing, and constant use of sand and water from the dam to build houses. There is likely hold that the region might have a higher dose of radioactive nuclides obtained by plants through their roots or leaves, and by animals through plant intake. These radionuclides enter the human body either directly from plants as food that is ingested in water, or milk [8-11]. Therefore, a need to investigate the effect of radiation and the danger it posed to the environs. The effect of radiation at high, moderate, and low doses is associated with death, cancer, and genetic effects, respectively [12]. Earlier work from the Wurno Local Government area indicates that naturally occurring radionuclides $^{40}$K were found significantly higher in a concentration above the world mean values [13]

In this work, High Purity Germanium detector (HPGe) was used to determine the concentration of radionuclides due to its ability to accurately and reliably identify radionuclides from their passive gamma-ray emission.

## II. Materials And Method

**Study area**

This study was carried out in the Goronyo local government Area of Sokoto State Nigeria. The soil samples were collected from river banks of the Goronyo dam. Goronyo LGA has a total land mass of 1,704 $km^2$ with an approximate population of 220,000 and lies between the coordinates of longitude $5^0$10’00’’ E and $5^0$40’02’’E and latitude $12^0$39’00’’ N and $13^0$0’00’’N [14].

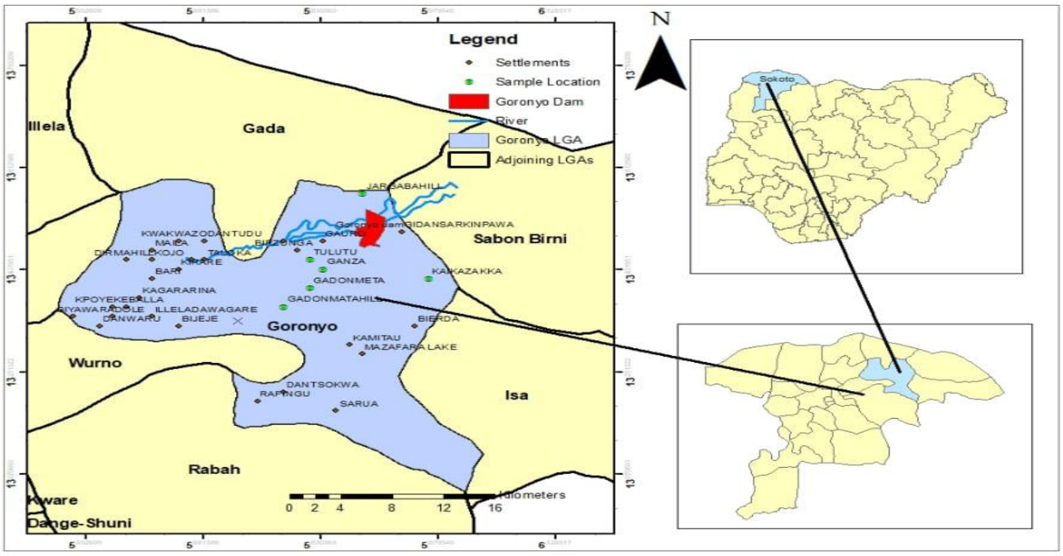


**Figure 1.** Map of Goronyo L.G.A of Sokoto, Nigeria depicting the area under study [33]

**Sample collection**

Twenty samplings (20) points were collected, and each point is 4 km away from the next close to the river bank area where farming activities take place. A zig-zag pattern was followed by the 20 sampling points in agreement with the International Atomic Energy Agency [15]. For some places, four (4) different samples were homogenized within 60 cm portions to produce a 94-98% representation of the soil.

**Sampling processing**

A total of 20 sand samples were collected from the river banks of the Goronyo dam. - at different locations along a 40-km stretch of the dam. and then filled into labeled polyethylene bags. Each sample bag was marked with a sample code GR1-GR20 indicating the various sand samples. To assure the removal of moisture from the samples, they were placed in a drying oven at 80 $^oC$ for 24-hours before being pulverized and passed through a 1-mm sieve. The samples were weighed 300gm into a plastic container capped, sealed, and kept for about 1-month to achieve a radioactive equilibrium of $^{222}Rn$ with its parent $^{226}Ra$ in the $^{238}U$ chain. The soil samples were subjected to a thorough gamma spectrometry examination. Finally, the samples were measured for 24-hours to achieve good count statistics.

**Activity determination**

The samples were analyzed using A P-type coaxial HPGE detector (with 25% efficiency and a 3 keV resolution) having a low background. The setup was used to determine the activity concentrations of $^{238}U$, $^{232}Th$, and $^{40}K$ in the collected samples as shown in Table 1 below.

The Environmental Monitoring Laboratory of the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, used a High Purity Germanium (HPGe) radiation detector (8023 Model: Gc with Serial Number: 9744 and Pre-Amplifier Model: 2002csl) for gamma spectrometric analysis. The Canberra coaxial HPGe detector has a relative efficiency of 50% and a resolution of 2.4 keV at 1.33 MeV of Co-60 [16]. The internal of the HPGe detector is a 5 cm thick lead shield to aid in the reduction of external radiation interference during measurement. The IAEA calibration Multi-Gamma Ray Standard (MGS6M315) was used to acquire spectrum peaks of radionuclides spanning energy lines. The activity concentration of $^{238}U$ was measured using the 1764 KeV-line of $^{214}Bi$, whereas the activity concentration of $^{232}Th$ was measured using the 2614.5 KeV-line of $^{208}Tl$. The concentration of $^{40}K$ in the samples was determined using a single 1460 KeV-line of $^{40}K$. Following the achievement of secular equilibrium, photo peaks count of progenies with higher intensity were compiled under the respective parents of $^{238}U$ and $^{232}Th$. After then, the samples were counted for 18,000 seconds. The IAEA provided standard reference material for different energies of interest in the prescribed sample geometry, which was used for general quality control of the radiochemical procedures as well as the efficiency calibration of the gamma-counting equipment. After deducting decay correction, the activity concentration ($A_s$) in Bq/kg of the radionuclides in the samples was estimated using the expression

$$A_s = \frac{C_n}{\varepsilon_\gamma M_s I_\gamma} \quad (1)$$

$A_s$ is the specific activity of radionuclide (Bq/kg), $C_n$ is the net count per second of the sample under the corresponding photo peak, $\varepsilon_\gamma$ is the efficiency of the detector at the specific gamma ray energy of interest and $I_\gamma$ is the intensity of gamma ray at a particular energy being counted, $M_s$ is the mass of the sample (kg).

**Calculation of Hazard parameters**

**Dose calculation**

The external Gamma Dose Rate (D) for the sand samples was estimated using the mean activity Concentrations of $^{238}U$, $^{232}Th$, and $^{40}K$ at around 1.0 m above ground using eq.[17, 18];

$$D_\gamma(nGyh^{-1}) = (0.462 \times A_u) + (0.604 \times A_{Th}) + (0.417 \times A_k) \quad (2)$$

Where D is the absorbed dose rate in $(nGyh^{-1})$, the activity concentrations (Bq/kg) for $^{238}U$, $^{232}Th$, and $^{40}K$ are $A_u$, $A_{Th}$, and $A_k$ respectively.

**Radium equivalent activity**

Radium equivalent activity ($Ra_{eq}$) is a mathematically derived index that represents the activity levels of $^{238}U$, $^{232}Th$, and $^{40}K$ and is calculated from the eq. [19];

$$Ra_{eq} = A_U + 1.43\, A_{Th} + 0.077\, A_{Ak} \quad (3)$$

**External hazard indices ($H_{ex}$)**

The external hazard index, or Hex, is a widely used hazard index (representing external exposure) that is calculated using the expression [20];

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (4)$$

The recommendations of eq. (2) were used to estimate the radiological hazard to residents living near the river bank from exposure to ionizing radiation from naturally occurring radionuclides in the environment.

**Internal Hazard Index** ($H_{in}$), is computed by Eq. (4), measures internal exposure to radon and its daughter isotopes [21];

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_k}{4810} \quad (5)$$

**Annual effective dose rate**

The annual effective dose rate is calculated using the

The UNSCEAR report proposed the conversion coefficient from absorbed dose in the air to effective dose (0.7 Sv.Gy1), outdoor occupancy factor (0.2), and indoor occupancy factor (0.8) to estimate annual effective dose rates [22]. are employed. As a result, the yearly effective dose rate (mSv/yr) is calculated using the following eq. (5) and (6) [23];

$$AEDR_{(outdoor)} = 1.2\, D \times 10^{-3}\, m.Sv/yr \quad (6)$$

$$AEDR_{(indoor)} = 4.91\, D \times 10^{-3}\, m.Sv/yr \quad (7)$$

**Gamma Index ($I_\gamma$)**

The gamma index $I_\gamma$ is expressed mathematically using the eq. (7) [24]

$$I_\gamma = \frac{A_{Ra}}{150} + \frac{A_{Th}}{100} + \frac{A_k}{1500} \quad (8)$$

**The excess lifetime cancer risk (ELCR).**

The likelihood of growing additional malignant growth in a populace inside a lifetime after openness to radionuclides can be calculated from the values obtained from eq. (5) and (6) [25]

$$ELCR_{(outdoor)} = E_{(out)} \times DL \times RF \quad (9a)$$

$$ELCR_{(indoor)} = E_{(indoor)} \times DL \times RF \quad (9b)$$

where $AEDR$ is Annual effective dose equivalent, DL is duration of life (70yrs), RF is risk factor (0.05 $Sv^{-1}$). For stochastic effects, ICRP 60 uses values of 0.05 $Sv^{-1}$ [25].

**Table 1**. concentrations of radionuclides for different soil samples with calculated dose rate

| Locations | Activity concentration (Bq/Kg) | | | Radium equivalent (Bq/kg) | Absorbed Dose rate (nGy/h) |
|---|---|---|---|---|---|
| | $^{238}U$ | $^{232}Th$ | $^{40}K$ | $Ra_{eq}$ | ERD |
| GS-1 | 21.43 | 32.37 | 467.54 | 103.72 | 48.95 |
| GS-2 | 36.15 | 21.56 | 538.53 | 108.45 | 52.18 |
| GS-3 | 45.21 | 52.12 | 327.61 | 144.97 | 66.03 |
| GS-4 | 13.34 | 38.67 | 339.51 | 94.78 | 43.68 |
| GS-5 | 47.01 | 42.34 | 198.83 | 122.87 | 55.58 |
| GS-6 | 41.23 | 71.23 | 790.12 | 203.93 | 95.02 |
| GS-7 | 54.37 | 51.31 | 674.54 | 179.68 | 84.24 |
| GS-8 | 36.41 | 45.23 | 472.84 | 137.50 | 63.86 |
| GS-9 | 18.35 | 38.67 | 321.65 | 98.42 | 45.25 |
| GS10 | 30.37 | 47.24 | 531.32 | 138.83 | 64.72 |
| GS-11 | 39.45 | 35.88 | 351.65 | 117.84 | 54.56 |
| GS-12 | 19.56 | 67.32 | 742.32 | 172.99 | 80.65 |
| GS-13 | 30.21 | 51.28 | 582.47 | 148.39 | 69.22 |
| GS-14 | 22.36 | 65.42 | 635.62 | 164.85 | 76.35 |
| GS-15 | 52.12 | 31.32 | 532.53 | 137.91 | 65.20 |
| GS-16 | 25.32 | 46.23 | 465.84 | 127.29 | 59.05 |
| GS-17 | 43.18 | 53.64 | 692.51 | 173.20 | 81.23 |
| GS-18 | 38.67 | 36.25 | 798.67 | 152.01 | 73.07 |
| GS-19 | 26.53 | 58.76 | 891.63 | 179.21 | 84.93 |
| GS-20 | 53.12 | 23.41 | 468.34 | 122.66 | 58.21 |
| mean±σ | 34.7±12.4 | 45.5±13.8 | 541.2±192 | 141.5±30.4 | 66.1±14.4 |

σ = standard deviation

## III. Results and Discussion

The activity concentration of $^{238}U$, $^{232}Th$, and $^{40}K$ for all sand samples from the riverbank of Goronyo dam, have been determined and the summary is presented in table 1. The activity concentration of $^{238}U$, $^{232}Th$, and $^{40}K$ ranged from 13.34 Bq/kg -54.37 Bq/kg with a mean value of 34.7 Bq/kg ±12.4 Bq/kg, 21.56 Bq/kg - 71.23 Bq/kg with a mean value of 45.5±13.8 Bq/kg, and 198.83 Bq/kg -891.63 Bq/kg with a mean value of 541.2±192 Bq/kg, respectively as presented in table 1. The calculated absorbed dose rate ranges from 43.68-95.02 nGy/h with a mean value of 66.1±14.4 nGy/h, which slightly surpasses the global average of 51 nGy/h 51 nGy/h [26].

The $Ra_{eq}$ is the weighted sum of activities concentration of $^{238}U$, $^{232}Th$, and $^{40}K$ in a material and from assumptions, eq. (3) Produces the same dose rate of gamma-radiation [27].

The calculated values of $Ra_{eq}$ range from 94.78-203.93 Bk/kg with a mean value of 141.5±30.4 Bq/kg less than the world's average of 370 Bq/kg [28] and are within recommended limits set by [29]. The calculated values of $Ra_{eq}$ are shown in table 1 from sand samples of the riverbank of Goronyo. These results assured the safe uses of the soil for farming, building, and other purposes.

**Table 2** Radiological parameters for the soil samples

| Locations | Absorbed Dose rate (ERD)(nGy/h) | Hazard indices | | Activity utilization Index I | AEDE (mSv/y) | | | ELCR*10$^{-3}$ |
|---|---|---|---|---|---|---|---|---|
| | | Hex | Hin | | Outdoor | Indoor | Total | |
| GS-1 | 49 | 0.28 | 0.34 | 0.78 | 60.03 | 240.12 | 300.15 | 1.1 |
| GS-2 | 52 | 0.296 | 0.39 | 0.82 | 63.99 | 255.98 | 319.97 | 1.1 |
| GS-3 | 66 | 0.39 | 0.51 | 1.04 | 80.97 | 323.91 | 404.89 | 1.4 |
| GS-4 | 44 | 0.26 | 0.29 | 0.70 | 53.57 | 214.26 | 267.83 | 0.9 |
| GS-5 | 56 | 0.33 | 0.46 | 0.87 | 68.17 | 22.67 | 340.84 | 1.1 |
| GS-6 | 95 | 0.55 | 0.66 | 1.51 | 116.53 | 466.13 | 582.66 | 2.0 |
| GS-7 | 84 | 0.49 | 0.63 | 1.32 | 103.31 | 413.24 | 516.55 | 1.8 |
| GS-8 | 64 | 0.37 | 0.47 | 1.01 | 78.31 | 313.26 | 391.58 | 1.3 |
| GS-9 | 45 | 0.27 | 0.32 | 0.72 | 55.50 | 221.96 | 277.46 | 0.9 |
| GS10 | 65 | 0.37 | 0.46 | 1.02 | 79.37 | 317.49 | 396.86 | 1.4 |
| GS-11 | 55 | 0.32 | 0.42 | 0.86 | 66.91 | 267.66 | 334.57 | 1.1 |
| GS-12 | 81 | 0.47 | 0.52 | 1.30 | 98.91 | 395.65 | 494.56 | 1.7 |
| GS-13 | 69 | 0.40 | 0.48 | 1.10 | 84.89 | 339.56 | 424.45 | 1.4 |
| GS-14 | 76 | 0.45 | 0.51 | 1.22 | 93.63 | 374.53 | 468.17 | 1.6 |
| GS-15 | 65 | 0.37 | 0.51 | 1.01 | 79.97 | 319.86 | 399.82 | 1.3 |
| GS-16 | 59 | 0.34 | 0.41 | 0.94 | 72.41 | 289.65 | 362.07 | 1.2 |
| GS-17 | 81 | 0.47 | 0.58 | 1.28 | 99.61 | 398.45 | 498.07 | 1.7 |
| GS-18 | 73 | 0.41 | 0.52 | 1.15 | 89.60 | 358.42 | 448.03 | 1.5 |
| GS-19 | 85 | 0.48 | 0.56 | 1.35 | 104.15 | 416.62 | 520.78 | 1.8 |
| GS-20 | 58 | 0.33 | 0.47 | 0.90 | 71.38 | 285.55 | 356.95 | 1.2 |
| Mean±σ | 66.1±14.4 | 0.38±0.1 | 0.48±0.1 | 1.05±0.2 | 81.06±17.6 | 342.25±70.4 | 405.31±88 | 1.4±0.3 |

σ = standard deviation

The external and internal radiation hazard index ($H_{ex}$ and $H_{in}$) are presented in Table 2. From the soil samples, the average external and internal radiation hazard index ($H_{ex}$ and $H_{in}$), were found to be 0.38 ± 0.1 and 0.48±0.1 respectively. These values obtained are less than the unity recommended [30]. The average representative level index is found to be 1.05 ± 0.2 as shown in table 2.

The values obtained using eq. (6) and (7) are outdoor and indoor AEDE values and are presented in Table 2. 53.57 mSv/y, 116.53 mSv/y and 81.06±17.6 mSv/y are the calculated minimum, maximum and average values of outdoor and 22.67 mSv/y -466.13 mSv/y and 342.25±70.4 mSv/y are the calculated minimum, maximum and average values of indoor respectively. Also, the average annual effective dose equivalent (outdoor and indoor) 1.4±0.3 were higher than the world recommended value [29].
The Excess lifetime cancer risk (ELCR) is calculated from eq. (9a) and (9b) as shown in table 2. The minimum, maximum and average value of the ELCR is $0.9 \times 10^{-3}$, $2.0\times 10^{-3}$, and $1.4 \pm 0.3 \times 10^{-3}$respectively.

**Table 3.** Comparison of activity concentrations obtained with similar studies

| S/N | Country | Average activity concentration (Bq/kg) $^{238}U$ | $^{232}Th$ | $^{40}K$ | Reference |
|---|---|---|---|---|---|
| 1 | Nigeria (Goronyo Sokoto) | 34.7±12.4 | 45.5±13.8 | 541.2±192 | present study |
| 2 | Nigeria (Wurno Sokoto) | - | 53.76 | 679.7 | [31] |
| 3 | Nigeria (Zaria Kaduna) | - | 215.18±8.70 | 476.04±28.07 | [32] |
| 4 | Nigeria (Port Harcourt) | 24.1±2.8 | 30.45±5.8 | 368.3±3.5 | [33] |
| 5 | Nigeria (Kogi) | 74.3±5.0 | 110.3±24.8 | 974.7±6.8 | [19] |

The activity concentration for $^{238}U$, $^{232}Th$, and $^{40}K$ are compatible with the results reported from other locations in Nigeria as shown in Table 3.

## IV. Discussion

This study present the radiological assessment carried out on riverbank of Goronyo dam of Sokoto Nigeria. Goronyo dam is the biggest lenctic water body in Sokoto. It was developed to serve as surge control and utilized for dry farming irrigation system [34]. The mean activity concentrations of $^{238}U$, $^{232}Th$, and $^{40}K$, Radium equivalent ($Ra_{eq}$) found in all samples and representative level indices based on the findings from the study, for all measured samples, the concentrations of $^{238}U$ and $^{40}K$ were slightly higher than the global average 35 Bq/kg and 400 Bq/kg, respectively for $^{238}U$ and $^{40}K$. However, the mean activity concentration of $^{232}Th$ level are within world standard as reported by [35] that a global activity concentration of $^{232}$Th is 45.03 Bq/kg according to UNSCEAR (2000). The high level of $^{40}$K activity concentrations are likely due to existence of monazite at that sampling site, presence of phosphate rock and the fertilizers used for farming in the study region [36]. Based on table 3, the radioactivity levels in the sample differ from region to region; however, it is vital to keep in mind that these values are not representative of the country but only for the region. According to Table 1, The samples have an average absorbed dose rate slightly greater than the global average value 50 (nGh/y) [35].

The average mean activity concentrations of $^{238}$U, $^{232}$Th, and $^{40}$K is of the order $^{40}$K>$^{232}$Th>$^{238}$U. The average ELCR ($1.4 \pm 0.3 \times 10^{-3}$), is slightly higher than the world average, the results of this study indicate a cancer risk thus, making the sediment unsafe for use as building materials

## V. Conclusion

The average activity concentrations of $^{238}$Uand $^{40}$K and potassium in the sand samples of riverbank of Goronyo dam is higher than the world reported average values. $^{232}$Th average activity concentration from the samples were found to be slightly greater than the world average. The sediment mostly used as building materials, farming and rearing of animals do post a radiological risk within the environs. Therefore, locals should avoid using the sediment from the riverbank of Goronyo dam as construction materials.

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## Conflicts of interest

The authors declared no conflict of interest

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