**Natural Radionuclide Distribution in Surface Soil and Water within Doma LGA, Nasarawa State, NorthCentral, Nigeria**

**Abstract**

It is a known fact that man is exposed to radiation from both natural and artificial sources, which may have short and long-term effects on man and his environs. This study investigates the distributions of natural radionuclides (40K, 238U, and 232Th) in surface soil and water at Doma, Nasarawa State. Twenty (20) surface soil and water samples were randomly collected and analysed using a NaI(TI) detector. Multivariate statistics were employed in data analysis. Results revealed that in the surface soil, mean activity concentrations of radionuclides (40K, 238U, and 232Th) are below the acceptable limits (400, 35, and 30 Bq/kg, respectively). However, in the surface water, they are above the safe limits (10.0, 1.0, and 1.0 Bq/L, respectively). This depicts radiological contamination of the surface water, making it unsuitable for drinking. We tend to attribute the high 40K to the leaching of inorganic potassium fertilizers used to enrich farmlands, while 238U and 232Th may be due to minerals in the bedrock. Alternative water sources should be provided to mitigate the implications of exposure to the contaminated surface water. Generally, the activity concentration observed varied across the sampled points, which suggests they are not evenly distributed. Furthermore, a significant relation was observed between radionuclide and radiological hazard indices at p < 0.05. The insight from this study can be employed in the monitoring of environmental contamination of radionuclides from both natural and artificial sources.

**Keywords**: activity concentration, radionuclide, soil, natural radioactivity, radiological parameters

1. **Introduction**

One of the major challenges facing the general public that is of concern to scientists is man exposure to radiation especially ionizing radiation. This is due to the harmful effects of radiation which depend on the type, concentration, and the exposure time. It is a known fact that natural constituents of our environment such as rocks, soils, water, and air are found to contain varying quantities of naturally occurring radionuclide materials (NORMs). Natural radionuclides such as radon, thorium, uranium, potassium, and so on are of concern in radiation protection (Ghada and Arafat, 2018; Rangaswamy *et al.,* 2019).

Radionuclides are radioactive isotopes occurring naturally (e.g., from cosmic rays, earth’s crust) or man-made sources. They are therefore present in soil and rocks and can be found in ground and surface waters. Besides the presence of radionuclide in surface water from natural sources, radionuclides from fertilizer application and dump sites, among others due to human activities are of concern. Radiation exposure may be through ingesting, inhaling, injecting or absorbing radioactive materials (Kehinde *et al.,* 2019).

Soil is the part of the earth’s crust formed as a result of deformation of rock by physical and chemical weathering, decomposition, organic and inorganic matter addition and water movement (Kahinde *et al.,* 2019). It consists of organic and inorganic compounds and some may consist of radionuclides such as uranium, thorium, radium, actinium and potassium. All radionuclides constitute a background radiation. The background radiation represents a considerable fraction of the total radiation exposure to the individual (Manjulata *et al.,* 2016).

Several works have been carried out to assess radionuclides in soil samples collected from different locations both within and outside Nigeria with significant results reported (Issa, 2013; Abu-samreh et al 2015; Aziz et al., 2014; Bekelesi, 2015; Faanu et al., 2016; Rangaswamy et al., 2016; Ajayi et al., 2017; Mann et al., 2017; Kumar et al., 2018; Masok and Winkler, 2018; Olowookar et al., 2019). Kehinde *et al.* (2019) worked on natural radioactivity in soil using gamma spectrometric technique observed average activity concentration for 40K, 226Ra, and 232Th as 1190.10±373.62 , 64.64±28.1015 and 110.18±46.12 Bqkg-1 respectively. Their results were higher than the recommended values. They concluded that, the soil within the study area was radiologically not safe.

Using gamma spectrometry to assess radionuclides concentration in soil samples, Quazi *et al.* (2015) observed activity concentration of 226Ra, 232Thand 40K as 11 - 25 , 38 - 59 , and 246 - 414 Bqkg-1 respectively. The outdoor gamma exposure rate, radium equivalent activity, and excess of lifetime cancer risk observed were 40.6 – 63.8 nGyh-1, 90 - 140 Bqkg-1, and 0.2110-3 respectively. Marius *et al.* (2020) reported mean activity concentration of 238U (27.84 Bqkg-1), 232Th (41.08 Bqkg-1) and 40K (511.27 Bqkg-1) in stream sediments using gamma-ray spectrometry with a high purity germanium (HpGe) detector. Most of the radiological hazards parameters estimated based on radionuclides activity concentrations were lower than the recommended values.

Works have also been carried out on natural radionuclides in water samples at different locations. Sombo *et al.*( 2018) assessed the radioactivity of surface water sources in selected areas of Benue State, North-Central, Nigeria using a gamma-ray spectrometer detector (Model: 802) coupled to a multichannel analyzer. Their result indicates that the activity concentration of radionuclides in the study area falls within the permissible limit of 100 Bq/L set by the Radiological Protection Adviser. Ajayi *et al*. (2017) recorded the highest (0.61 mSvy-1) and lowest (0.32 mSvy-1) activity concentration of 226Ra, 232Th and 40K in dug-well and streams in Ondo State, South Western Nigeria. However, the average total annual effective doses were still within the tolerance level based on ICRP reference limit of 1.0 mSvy-1.

Radiation has both deterministic and stochastic effects based on type, concentration and exposure time. Exposure to radionuclides beyond the recommended safety limits has significant effects such as bone cancer, cataracts, leukemia, kidney disease and an increase in blood pressure (Ghada and Arafat, 2018). Hence, there is need to assess radionuclide in surface water.

Despite these studies, no work has been carried out in the study area. Hence, the aim of this study is to investigate natural radiological content in surface soil and water in Doma Local Government Areas (LGA) and the possible associated health risks. The findings of this study will be of importance to radiation regulatory bodies such as Nasarawa State Waste Management and Sanitation Authority (NASWAMSA), Environmental Protection Agency (EPA), and National Environmental Standard and Regulations Enforcement Agency (NESREA) on the concentration of radionuclides in the surface soil and water in the study area.

1. **Materials and Method**
2. **Study Area**

Doma is one of the in Nasarawa State, North Central Nigeria, located at Latitude 8.4009 oN and Longitude 8.3581 oE. It has an area of about 2,714 km2 with a population of about 139,609. The geographical map of Nasarawa State and that of Doma LGA where the sample were obtained are shown in Figure 1.

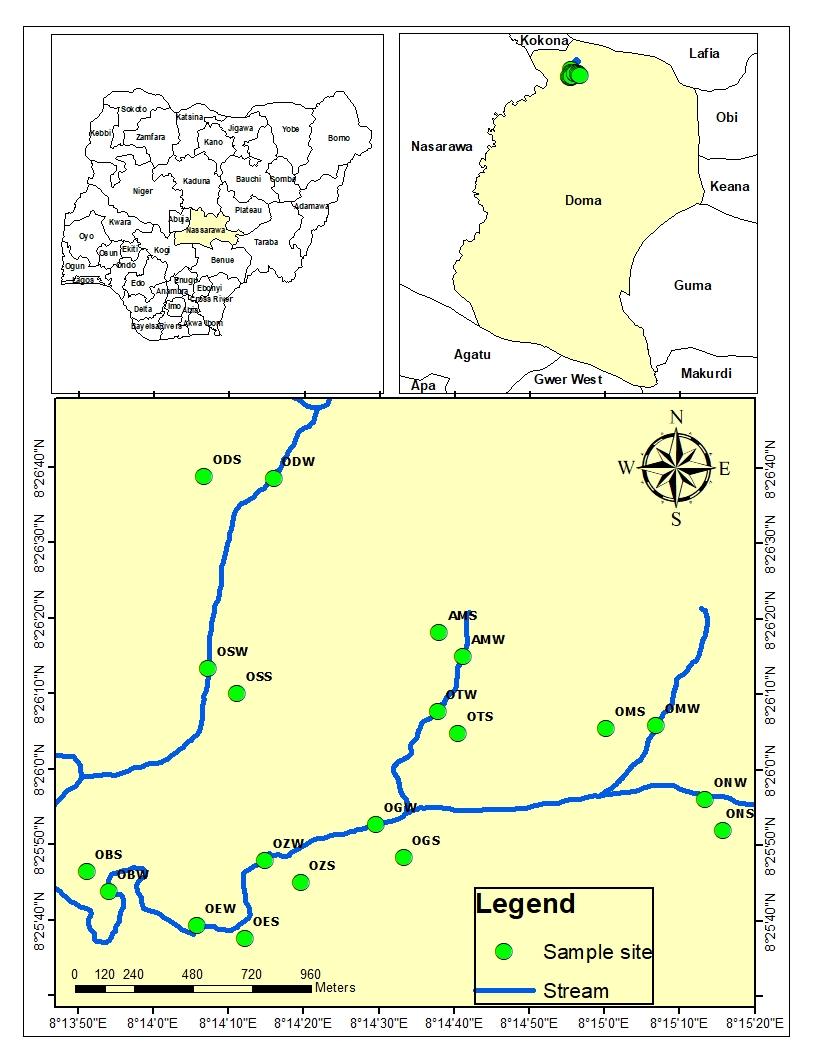


Figure 1: Map of Nigeria showing Nasarawa State, Doma LGA and the sample sites

1. **Sample Collection, Preparation and Analysis**

A total of 20 samples (10 each for surface soil and water) were randomly collected within the study area. The soil samples (500 g) and water samples (500 ml) were package in 10 separate plastic containers. The soil samples were air-dried for about 5 days and then oven-dried for 3 to 4 hours at 105 0C. The samples were then ground and sieved with a 2 mm size mesh. The fine powder was then sealed, weighed and kept for 4 weeks for the short-lived daughters to attain equilibrium.

About 500 ml of each of the water samples was acidified in 1 ml of concentrated HNO3 and evaporated to near dryness on a hot plate in a fumhood. The residue in the beaker was rinsed with 1 M HNO3 and evaporated again in near dryness. The residue was dissolved in minimum amount of 1 M HNO3 and transferred into a weighed 25 mm stainless planchet. The planchet with its content was heated until all moisture evaporated. It was store in a desiccator and allowed to cool and prevented from absorbing moisture. Both samples were analysed usingCit NaI(TI) detector at the National Institute of Radiation Protection and Research (NIRPR), Ibadan.

1. **Estimation of Radiological Parameters**
2. **Activity concentration**

The activity concentration of radionuclide, C , is the ratio of the net gamma counting rate for peak energy to the product of detected efficiency of a speciﬁc γ-ray and the intensity of the γ-line as given in equation 1 (Sombo *et al.*, 2018).

where, , ε, , and are the net gamma counting rate (counts per second), detected effciency of a speciﬁc γ-ray, intensity of the γ-line in radionuclides, and net weight of the sample (in kilogram, kg or litre, L) respectively.

**iii. Radium equivalent activity** (Raeq), in or of the radionuclides (238U, 232Th, and 40K) is express as (Onjufu et al., 2022a):

1. **Absorbed Dose Rate (D)**

The absorbed dose rate in air (D) is given in equation 3 (Onjufu *et al*., 2022a).

where 0.427, 0.662, and 0.043 are the dose rate conversion factors to convert the activity concentrations of 238U, 232Th, and 40K and radionuclides into absorbed dose rates as proposed by UNSCEAR (Onjufu *et al*., 2022a).

1. **Annual Effective Dose Equivalent** (AEDE)

The AEDE (indoor) consider radiation risks from building materials within a house, whereas AEDE (outdoor) is concern with radiation emitted from radionuclide in the environment (Ononugbo et al., 2013). The AEDE (indoor and outdoor) are given by equations 4 and 5 (Avwiri *et al*., 2014; Liu *et al*., 2021; Onjufu *et al*., 2022b).The AEDE (outdoor) is used for the soil samples consider in this study.

The AEDE for water samples is giving by the expression (Ononugbo et al., 2013):

where I, A, and C are water intake per day (assumed to be 2 ld-1), daily intake of radionuclide, and ingestion coefficient of the specific radionuclide. The ingestion coefficient for K, U and Th are SvBq-1 respectively (Ononugbo et al., 2013).

1. **Annual gonadal equivalent dose (AGDE)**

The annual gonadal equivalent dose (AGDE) in mSvy-1is given as (Onjufu *et al.*, 2022b):

1. **External radiation hazard index**

The corresponding to natural radionuclides(238U, 232Th and 40K) is express as (Shams *et al.* 2013; Ojelabi et al., 2018; Onjufu *et al*., 2022b).

1. **Internal Radiation Hazard Index** (Hin)

The hazard levels from the inhalation of alpha particles emitted from the radon short-lived radionuclides such as 222Rn can be quantiﬁed by the Hin express as (Shams *et al.,* 2013; Ojelabi *et al*., 2018; Onjufu *et al*., 2022b):

1. **Activity Concentration Index (Iγ)**

The Activity Concentration Index (Iγ) is given in equation 10 (Shams *et al.,* 2013; Ojelabi *et al.*, 2018).

1. **Excess Lifetime Cancer Risk (ELCR)**

The Excess Lifetime Cancer Risk (ELCR) is expressed as (Narayana *et al.,* 2017):

where ELCR, AEDE (outdoor), AEDE, DL, and RF are excess life cancer risk, annual effective dose equivalent (for soil), annual effective dose equivalent (for water), period of life (i.e. 70 years), and fatal risk factor per sievert (0.05 Sv-1) respectively.

1. **Results and Discussion**

In Table 1, OGS, OSS and OGS recorded the lowest activity concentrations of 40K, 238U and 232Th, whereas; the highest was recorded at OMS, OZS and OBS respectively. The values for 40K, 238U and 232Th ranges between 101.40±10 - 367.54±12 , 13.54±51 - 40.65±21 and 21.16±45 - 28.62±00 Bq/kg, respectively. Worthy of note is that the activity concentrations at some sampled points for 40K (AMS, OMS and OSS), 232Th (OBS, ODS, ONS, OSS, and OZS) and 238U (OBS, OES, OMS, and OTS) are relatively high; they were however below the recommended limits (Table 1). This depicts that the activity concentration varied across the sampled points, and this suggested that for a given study area, activity concentration may not be uniformly distributed. This can be attributed to several factors such as the underlying parent rock (geological formation of the area).

The mean activity concentrations of 40K, 238U and 232Th observed from the descriptive statistics (Table 1), are 261.29±87.46, 28.62±7.47 and 25.22±2.78 Bqkg-1 respectively. These values are however, below the recommended average values of 400, 35 and 30 Bqkg-1 for 40K, 238U and 232Th, respectively (UNSCEAR, 2000; Ghada and Arafat, 2018; Onjefu et al., 2022b). This depicts that the natural radionuclides in the sampled surface soil are below the worldwide recommended limits.

Mean activity concentration ofnatural radionuclide in surface soil have been reported in different study areas such as riverine soil sediment, beach sand and soil along the coastline, shore sediments along the coastline, soil near mining site, and so on. The observed results generally depend on the study site. Bashiru *et al*. (2018) reported mean activity concentration of 40K, 238U, 232Th for surface soil in Oju LGA (8211.358±668.544, 191.812±9.046 and 76.478±7.478 Bqkg-1), in Otukpo LGA (176.792 ± 18.632, 25.514 ± 5.772 and 42.544 ± 4.662 Bqkg-1) and in Ogbadibo LGA (644.466±53.516, 43.468±9.312 and 46.756 ± 4.60 Bqkg-1) respectively. This shows that activity concentration ofnatural radionuclide vary based on study site.

Similarly, the activity concentrations of 40K, 238Uand 232Th and in the sampled surface water ranges from 211.47 - 343.32, 15.13 - 35.11 and 13.97 - 27.17 with mean value of 277.45±41.34 26.69±6.25 and 20.99±4.10 respectively. The highest activity concentrations of 40K, 232Th and 238U were observed in ODW, ONW and OZW sampled points (Table 1). This depicts that the radionuclide are not uniformly distributed in the studied location. It is pertinent to note that the activity concentrations measured were far above the world average values of 10.0, 1.0 and 1.0 for 40K, 238U and 232Th in surface water recommended by UNSCEAR and WHO (Ugbede *et al*., 2020). This suggests that the surveyed surface water is unsafe for drinking, as it is radiologically contaminated.

It is interesting to note that among the radionuclide considered, 40K has the highest concentrations. This could be attributed to leaching of inorganic potassium fertilizers from thereby farmlands. Farming is the major activity of the people of Doma LGA and inorganic potassium fertilizers are normally used to boost soil nutrients for bountiful harvest. The high 238U and 232Th may be due to uranium as well as thorium-bearing minerals in granite rocks in the area.

Activity concentrations of 40K, 238U and 232Th for surface water have been reported from different study areas. Ibikunle *et al*. (2017) reported 61.015 ±15.5, 8.165±2.05 and 5.24±1.57 in Osun, Nigeria; Khandaker *et al*. (2019) recorded 35.1±4.2, 2.8±0.4and 1.2±0.4 in Kuala Lumpur; Akpolile and Ugbede *et al*. (2019) found 61.55±4.17, 14.51±1.69 and 26.90±7.27 in Burutu, Nigeria; Sombo *et al.* (2018) reported 3.534± 0.366, 2.703±0.372 and 1.395 ± 0.138 in Otukpo LGA, 2.478±0.316, 1.543±0.324 and 2.024±0.224 in Ogbadibo LGA; and Ugbede *et al*. (2020) observed 120.45 ±6.51, 5.49 ±0.70 and 0.14 ±0.01 in Nkalagu, Nigeria respectively. This indicates that the distribution of natural radionuclides vary based on the study area.

From the descriptive statistics, it is seen that the activity concentrations of 238U and 232Th are close to each other as compared to 40K. 40K, 238U and 232Th have negative skewness showing a negatively skewed distribution, while a positive skewness indicates a positively skewed distribution. The observed negative and positive kurtosis which depicts flat distribution and normal distribution respectively clearly show the distribution of 40K, 238U and 232Th in the study area (Table 1). A value of zero kurtosis index corresponds to a normal distribution. Positive values indicate a distribution that is more pointed than a normal distribution and a negative value indicates a flatter distribution (Ghada and Arafat, 2018). This implies that the activity concentrations vary across the sampling points.

Radiological hazard indices for the soil samples show that the absorbed dose rate (D) ranges between 30.44 and 47.15 nGyh-1 with an average value of 40.157 nGyh−1 (Table 2). It is interesting to note that these values are below the world average absorbed dose rate of 57 nGyh−1 (Ghada and Arafat, 2017; Onjefu et al., 2022a). The mean annual effective dose equivalent (AEDE) of 0.049±0.04 mSvy-1 observed is below the permissible value of 0.07 mSvy-1for public (Ghada and Arafat, 2017; Onjefu et al., 2022a). The estimated Raeq varied from 66.400 to 100.79 Bqkg-1 with a mean value of 84.815 Bqkg-1 (Table 2). The observed value of Raeq is also below the maximum permissible limit of 370 Bqkg-1 (UNSCEAR, 2000; Onjefu *et al*., 2022b).

The annual gonadal dose equivalent (AGDE) ranged between 207.93 - 326.16 µSvy-1 with a mean value of 275.935 µSvy-1. The recommended average value of AGDE is 300 µSvy-1 (Ghada and Arafat, 2017). It is seen from Table 2 that the value of AGDE at AMS, OBS, ODS and OTS are relatively high with OMS and OZS above the recommended value. This implies health risk to the residents due to prolong exposure. According to Ghada and Arafat (2017), an increase in AGDE affects bone marrow, causing destruction of red blood cells that are then replaced by white blood cells resulting in leukemia.

The observed external and internal radiation hazard index (Hex and Hin) ranges from 0.179 - 0.272 and 0.258 - 0.382 with mean values of 0.229±0.03 and 0.306±0.04 respectively. These values are lower than the recommended value of unity (Onjufu *et al*., 2022b). This depicts no potential health risk. Similarly, the minimum, maximum and average values of the activity concentration index, (Iγ) are 0.470, 0.730 and 0.617 mSvy-1 respectively, which is below the maximum permissible value of unity (Onjufu *et al*., 2022b). This implies that the surface soils in Doma LGA are safe.

It is seen that the minimum, maximum and average values of excess life cancer risk, are which are below the world average permissible value of 0.29 × 10-3 (Onjefu *et al*., 2022a). The ELCRis the probability of developing cancer over a lifetime at a given exposure level (Ghada and Arafat, 2017). The ELCR obtained suggests lower potential of developing cancer; however, the potential may be high over time if one is exposed to the surveyed soil due to cumulative effect.

Daily intake of radionuclide and AEDE from ingestion of water was estimated and it was observed to vary across the sampled points (Table 3). The AEDE values ranges between 4.56 and 6.74 mSvy-1 with a mean value of 5.66±0.03 mSvy-1. The value is far below the maximum permissible value of 1000 μSvy-1 for public. Radiological hazard indices for the sampled water is shown in Table 4. We observed that D due to the presence of 40K, 232Th and 238U ranges between 32.62 - 44.06 nGyh-1 with a mean value of 37.22±3.78 nGyh-1. This is lower than the world average value of 55 nGyh-1 (Onjefu *et al*., 2022a).

The Raeq varies from 67.860 - 92.03 Bqkg-1 with a mean value of 78.08±8.2 Bqkg-1 (Table 4), which is below the maximum permissible limit of 370 Bqkg-1 (UNSCEAR, 2000, Onjefu *et al*., 2022a). The AGDE varies between 226.47 - 304.52 µSvy-1 with a mean value of 257.35±26.07 µSvy-1. The estimated mean is almost close to the recommended average value of 300 µSvy-1 (UNSCEAR, 2000; Onjefu *et al*., 2022a), thus, adequate measures should be taking to avoid threat to the bone marrow and bone surface of the residents in the study area.

The Hex and Hin ranges from 0.18 - 0.25 and 0.22-0.33 with average values of 0.21±0.02 and 0.28±0.02 respectively, which is lower than the recommended value of unity (Onjefu *et al*., 2022a). Thus, exposure to the natural radionuclides may not pose significant radiological health risks. The **Iγ** varies from 0.500 - 0.680 mSvy-1 with an average value of 0.57±0.06 mSvy-1 which does not exceed the permissible value of unity (Ghada and Arafat, 2017). The ELCR ranges from 16.83×10-3 - 21.91×10-3 with an average value of 19.81×10-3 which is lower than the world average permissible value of 0.29 × 10-3 (Onjefu *et al*., 2022a).

Statistical analysis was employed to assess the degree of association between 40K, 238U and 232Th and the radiological parameters using Pearson correlation (Tables 5 and 6). Strong positive correlation was observed between 40K, 238U and 232Th and all the radiation hazard parameters except for the relationship between 238U and 40K, 232Th and 40K, 232Th and 238U which have negative correlation (Tables 5). Similarly, strong positive correlation was observed between 40K, 238U and 232Th and all the radiation hazard parameters except for the relationship between the NORMs, (i.e. 238U and 40K, 232Th and 238U) which have negative correlation (Tables 6). Interestingly, the correlation between radiation hazard parameters and 238U are stronger than the correlation between radiation hazard parameters and 40K and 232Th (Table 5). Thus, 238U plays a significant role in radiation hazard compared to 40K and 232Th. Also, the correlation between radiation hazard parameters and 40K are higher than that between 238U and 232Th except for Hex (Table 6). This suggests that 40K has more effects on the radiation hazard parameters than 238U and 232Th (p < 0.05). Generally, the relations among the natural radionuclides (40K, 238U and 232Th) suggest that they may not have direct influence on each other (Tables 5 and 6).

The dendogram in Figure 2 shows clustering of activity concentrations of radionuclide (238U, 232Th, and 40K) and radiological hazard indices for soil and water samples using Ward’s linkage method of clustering. From Figure 2i, at the start, two major clusters were formed; cluster 1 (AEDE, Hin, Hex, Iᵧ, ELCR, U-238, Th-232, D) and Raeq, and cluster 2 (K-40 and AGDE). Similarly, two major clusters were formed from Figure 2ii; cluster 1 (AEDE, Hin, Hex, Iᵧ, AGDE, U-238, Th-232, D) and Raeq, and cluster 2 (K-40 and ELCR). This implies that for the surface soil, K-40 and AGDE are more related while for the surface water K-40 and ELCR are more related as compared to the other parameters. The clustering observed indicate that relationship exist between activity concentrations of radionuclide and radiological hazard indices.

From the aforementioned, the natural radionuclides observed for surface soil are below the acceptable limits, whereas, for surface water; they are above. The activity concentration varied across the sampled points; which suggests that for a given study area, they are not uniformly distributed. Besides, significant relationship exist between activity concentration of 238U, 232Th, and 40K in the sampled soil and water with the radiological indices, but, this varies from one radionuclide to another. The surface soil is not radiological contaminated; however, the surface water is contaminated and not safe for drinking. To mitigate the radiological contamination of the surface water, alternative water sources should therefore be provided for the community. This study has given insight on the concentrations and distributions of radionuclide in the surveyed surface soil and water in Doma LGA, which can be employed in monitoring of environmental contamination of the study area by radionuclide.

**Table 1: Descriptive Statistics of natural radionuclides in Soil (Bqkg-1) and water () samples**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample  Code | Soil  40K 238U 232Th | | | Sample Code | Water  40K 238U 232Th | | |
| AMS | 367.54±12 | 24.61±07 | 23.96±32 | AMW | 211.47±20 | 22.33±02 | 32.39±75 |
| OBS | 244.71±31 | 33.11±00 | 28.62±00 | OBW | 311.81±60 | 22.33±04 | 31.48±62 |
| ODS | 243.36±43 | 28.43±40 | 26.44±05 | ODW | 343.32±44 | 25.04±59 | 29.79±61 |
| OES | 192.44±10 | 32.11±07 | 21.16±45 | OEW | 264.11±42 | 16.93±76 | 23.55±04 |
| OGS | 101.40±10 | 28.93±27 | 20.74±32 | OGW | 283.05±53 | 16.93±15 | 27.64±75 |
| OMS | 378.49±54 | 33.53±12 | 24.81±31 | OMW | 277.66±65 | 13.92±97 | 29.54±11 |
| ONS | 188.42±33 | 21.13±32 | 26.37±43 | ONW | 271.11±34 | 19.77±71 | 35.11±51 |
| OSS | 344.53±13 | 13.54±51 | 28.26±52 | OSW | 309.45±61 | 24.20±87 | 20.14±32 |
| OTS | 287.21±31 | 30.22±11 | 24.08±01 | OTW | 289.11±72 | 21.31±42 | 15.13±16 |
| OZS | 264.80±09 | 40.65±21 | 27.80±06 | OZW | 213.42±22 | 27.17±11 | 22.17±87 |
| Mean±SD | 261.29±87.46 | 25.22±2.78 | 28.62±7.47 | Mean | 277.45±41.34 | 26.69±6.25 | 20.99±4.10 |
| Minimum | 13.54 | 20.74 | 101.40 | Minimum | 211.47 | 15.13 | 13.92 |
| Variance | 55.93 | 7.76 | 7649.9 | Variance | 1709.1 | 39.08 | 17.00 |
| Maximum | 40.65 | 28.62 | 378.49 | Maximum | 343.32 | 35.11 | 27.17 |
| Skewness | -0.640 | -0.471 | -0.292 | Skewness | -0.376 | -0.573 | -0.297 |
| Kurtosis | 1.049 | -0.910 | -0.353 | Kurtosis | -0.074 | -0.483 | -0.651 |
| WMV | 400 | 50 | 30 | WMV | 10.00 | 1.00 | 1.00 |

WMV = World Mean Value

**Table 2: Radiological Hazard Indices in the sampled surface Soil**

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample  Code | D  (nGyh-1) | | AEDE  (mSvy-1) | | Raeq  (Bqkg-1) | | AGED  (mSvy-1) | | Hex | | Hin | | Iᵧ  (mSvy-1) | | ELCRx10-3 | |
| AMS | 42.17 | 0.052 | | 87.17 | | 291.60 | | 0.235 | | 0.302 | | 0.649 | | 0.181 | |
| OBS | 43.60 | 0.054 | | 92.87 | | 298.78 | | 0.251 | | 0.340 | | 0.670 | | 0.187 | |
| ODS | 40.10 | 0.049 | | 84.97 | | 274.78 | | 0.230 | | 0.306 | | 0.616 | | 0.172 | |
| OES | 35.99 | 0.044 | | 77.18 | | 248.09 | | 0.208 | | 0.295 | | 0.554 | | 0.155 | |
| OGS | 30.44 | 0.037 | | 66.39 | | 207.92 | | 0.179 | | 0.258 | | 0.468 | | 0.131 | |
| OMS | 47.01 | 0.058 | | 98.15 | | 326.15 | | 0.265 | | 0.356 | | 0.724 | | 0.202 | |
| ONS | 34.58 | 0.042 | | 73.34 | | 234.68 | | 0.198 | | 0.255 | | 0.530 | | 0.149 | |
| OSS | 39.30 | 0.048 | | 80.48 | | 268.14 | | 0.217 | | 0.254 | | 0.603 | | 0.169 | |
| OTS | 41.19 | 0.051 | | 86.76 | | 284.21 | | 0.234 | | 0.316 | | 0.634 | | 0.177 | |
| OZS | 47.14 | 0.058 | | 100.79 | | 324.95 | | 0.272 | | 0.382 | | 0.726 | | 0.203 | |
| Mean | 40.16 | 0.049 | | 84.82 | | 275.93 | | 0.229 | | 0.306 | | 0.617 | | 0.173 | |
| SD | 5.34 | 0.04 | | 10.83 | | 37.90 | | 0.03 | | 0.04 | | 0.08 | | 0.15 | |
| WMV | 55 | 0.07 | | 370 | | 300 | | ≤ 1 | | ≤ 1 | | < 1 | | 0.29 | |

WMV = World Mean Value; SD = standard deviation

**Table 3: Estimation of daily intake of radionuclide and AEDE from ingestion of water**

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| Sample  Code | Daily intake per person (Bqd-1)  40K 238U 232Th | | | Annual Effective Dose (AEDE)(mSvy-1)  40K 238U 232Th Total AEDE | | | |
| AMW | 211.47±20 | 22.33±02 | 32.39±75 | 0.96 | 1.06 | 3.75 | 5.77 |
| OBW | 311.81±60 | 22.33±04 | 31.48±62 | 1.41 | 1.03 | 3.75 | 6.19 |
| ODW | 343.32±44 | 25.04±59 | 29.79±61 | 1.55 | 0.98 | 4.2 | 6.74 |
| OEW | 264.11±42 | 16.93±76 | 23.55±04 | 1.2 | 0.77 | 2.84 | 4.81 |
| OGW | 283.05±53 | 16.93±15 | 27.64±75 | 1.28 | 0.91 | 2.84 | 5.03 |
| OMW | 277.66±65 | 13.92±97 | 29.54±11 | 1.26 | 0.97 | 2.34 | 4.56 |
| ONW | 271.11±34 | 19.77±71 | 35.11±51 | 1.23 | 1.15 | 3.32 | 5.7 |
| OSW | 309.45±61 | 24.20±87 | 20.14±32 | 1.4 | 0.66 | 4.06 | 6.13 |
| OTW | 289.11±72 | 21.31±42 | 15.13±16 | 1.31 | 0.49 | 3.58 | 5.38 |
| OZW | 213.42±22 | 27.17±11 | 22.17±87 | 0.97 | 0.73 | 4.56 | 6.26 |
| Mean | **277.45±41.34** | **26.69±6.25** | **20.99±4.10** | **1.26** | **0.88** | **3.52** | **5.66** |

**Table 4: Radiological Hazard Indices in Water samples**

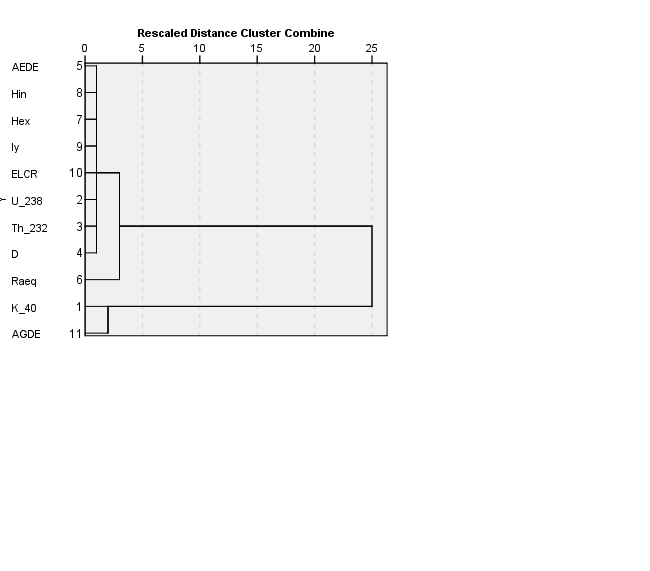
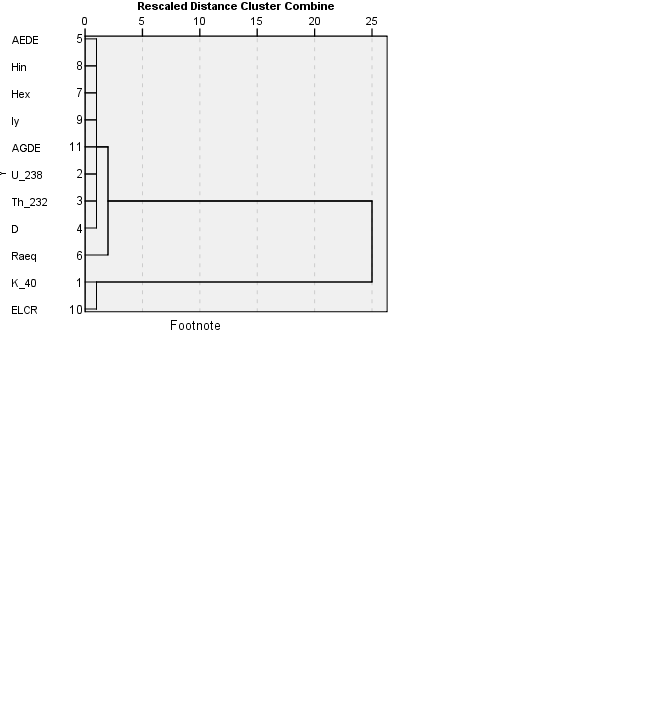
|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| Sample  Code | D  (nGyh-1) | Raeq  (Bq*l*-1) | Hex | Hin | Iy | AGED  (mSvy-1) | AEDE  (mSvy-1) | ELCR x 10-3 |
| AMW | 37.71 | 80.61 | 0.22 | 0.31 | 0.58 | 259.83 | 5.77 | 20.19 |
| OBW | 41.63 | 87.42 | 0.24 | 0.32 | 0.64 | 288.52 | 6.19 | 21.66 |
| ODW | 44.06 | 92.03 | 0.25 | 0.33 | 0.68 | 304.52 | 6.74 | 23.59 |
| OEW | 32.62 | 68.10 | 0.18 | 0.25 | 0.50 | 226.47 | 4.81 | 16.83 |
| OGW | 35.18 | 73.64 | 0.20 | 0.27 | 0.54 | 245.05 | 5.03 | 17.60 |
| OMW | 33.77 | 70.83 | 0.19 | 0.27 | 0.52 | 236.65 | 4.56 | 15.96 |
| ONW | 39.74 | 84.26 | 0.23 | 0.32 | 0.61 | 276.26 | 5.7 | 19.95 |
| OSW | 37.93 | 78.57 | 0.21 | 0.27 | 0.58 | 260.56 | 6.13 | 21.45 |
| OTW | 33.00 | 67.86 | 0.18 | 0.22 | 0.51 | 226.61 | 5.38 | 18.83 |
| OZW | 36.63 | 77.46 | 0.21 | 0.27 | 0.56 | 249.09 | 6.26 | 21.91 |
| Mean | 37.23 | 78.08 | 0.21 | 0.28 | 0.57 | 257.35 | 5.66 | 19.81 |

**Table 5: Correlation Coefficient, R for Activity Concentrations of 40K, 238U and 232Th and Radiological Hazard Indices for Soil Sample**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 40K | 238U | 232Th | D | AEDE | Raeq | Iᵧ | AGED | Hex | Hin | ELCRx10-3 |
| 40K | 1.000 |  |  |  |  |  |  |  |  |  |  |
| 238U | -0.142 | 1.000 |  |  |  |  |  |  |  |  |  |
| 232Th | 0.403 | -0.121 | 1.000 |  |  |  |  |  |  |  |  |
| D | 0.759 | 0.456 | 0.557 | 1.000 |  |  |  |  |  |  |  |
| AEDE | 0.759 | 0.456 | 0.557 | 1.000 | 1.000 |  |  |  |  |  |  |
| Raeq | 0.672 | 0.558 | 0.535 | 0.992 | 0.992 | 1.000 |  |  |  |  |  |
| Iᵧ | 0.762 | 0.470 | 0.526 | 0.999 | 0.999 | 0.992 | 1.000 |  |  |  |  |
| AGED | 0.672 | 0.558 | 0.535 | 0.992 | 0.992 | 1.000 | 0.991 | 1.000 |  |  |  |
| Hex | 0.382 | 0.833 | 0.301 | 0.872 | 0.872 | 0.924 | 0.877 | 0.924 | 1.000 |  |  |
| Hin | 0.757 | 0.463 | 0.549 | 1.000 | 1.000 | 0.993 | 1.000 | 0.992 | 0.875 | 1.000 |  |
| ELCRx10-3 | 0.759 | 0.456 | 0.557 | 1.000 | 1.000 | 0.992 | 0.999 | 0.992 | 0.872 | 1.000 | 1.000 |

**Table 6: Correlation coefficient, R for Activity Concentrations of 40K, 238U and 232Th and Radiological Hazard Indices for Water Sample**

|  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | 40K | 238U | 232Th | D | AEDE | Raeq | Iᵧ | AGED | Hex | Hin | ELCR **x10-3** |
| 40K | 1.000 |  |  |  |  |  |  |  |  |  |  |
| 238U | -0.029 | 1.000 |  |  |  |  |  |  |  |  |  |
| 232Th | -0.018 | -0.205 | 1.000 |  |  |  |  |  |  |  |  |
| D | 0.437 | 0.544 | 0.569 | 1.000 |  |  |  |  |  |  |  |
| AEDE | 0.437 | 0.544 | 0.569 | 1.000 | 1.000 |  |  |  |  |  |  |
| Raeq | 0.354 | 0.605 | 0.557 | 0.995 | 0.995 | 1.000 |  |  |  |  |  |
| Iᵧ | 0.465 | 0.591 | 0.500 | 0.997 | 0.997 | 0.992 | 1.000 |  |  |  |  |
| AGED | 0.354 | 0.605 | 0.556 | 0.995 | 0.995 | 1.000 | 0.992 | 1.000 |  |  |  |
| Hex | 0.209 | 0.864 | 0.252 | 0.891 | 0.891 | 0.923 | 0.912 | 0.923 | 1.000 |  |  |
| Hin | 0.440 | 0.557 | 0.553 | 1.000 | 1.000 | 0.995 | 0.998 | 0.995 | 0.897 | 1.000 |  |
| ELCR**x**10-3 | 0.437 | 0.544 | 0.569 | 1.000 | 1.000 | 0.995 | 0.997 | 0.995 | 0.891 | 1.000 | 1.000 |

(ii)

(i)

Cluster 2

Cluster 1

Cluster 2

Cluster 1

**Figure 2: Dendrogram using Ward’s Method of Clustering for (i) Soil and (ii) Water**

1. **Conclusion**

The conclusions drawn from this study are:

1. Natural radionuclides (40K, 238U and 232Th) are not uniformly distributed in the surveyed surface soil and water.
2. The relations among the natural radionuclides (40K, 238U and 232Th) suggested that they may not direct influence each other.
3. Significant relationship exist between activity concentration of radionuclide and radiological hazard indices (p<0.05).
4. The surface soil is not radiological contaminated; however, the surface water is contaminated (due to leaching and minerals in the bedrocks) and therefore not safe for drinking.
5. To mitigate the radiological contamination of the surface water, alternative water sources should be provided for the community.
6. Potential health risks due to cumulative effect from prolong exposure to the surveyed soil and water can be reduced if exposure time is minimized.

**Data availability**: the data used for this study is available on request.

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