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# Evaluation of Background Radiation and Related Dose Rates in Soil Samples from Yagba East Local Government of Kogi State, Nigeria

**Isa Sambo[1] and Abuh Rafiu A.[2]**
[1] *Nigeria Nuclear Regulatory Agency, Abuja*
[2] *Legacy Private Schools, Madalla, Abuja*
*Corresponding Author: Abuh Rafiu A. (Email: rafiuabuh@gmail.com)*

***ABSTRACT:*** *This study measures the concentrations of the primordial radionuclides 40K, 232Th, and 238U in the chosen sampling locations in the Yabga East local government area of Kogi state, primarily for monitoring the area's rapid identification, assessment, and measurement of radioactivity and absorbed dose rates. A total of 12 soil samples were collected from different locations in the study area with the help of GIS mapping and were taken to the laboratory for analysis using a NaI (Tl) detector. The activity profile of radionuclides has clearly showed the existence of high level activity in the study area. The arithmetic mean activity concentrations of $^{40}K$, $^{238}U$ and $^{232}Th$ are 1853.58±90.45 Bq.kg$^{-1}$, 181.85±14.24 Bq.kg$^{-1}$ and 34.91±2.04 Bq.kg$^{-1}$ respectively as derived from all the soil samples studied. While the activity concentrations of 232Th in the samples were found to be lower than the global average values, the activity concentrations of $^{238}U$ and $^{40}K$ were found to be greater than the global average values. The fact that the soil samples were taken from places close to industrial or agricultural fields may be the cause of the elevated activity of 40K in the samples. The radiological hazards indices have a mean of 373.10 Bqkg$^{-1}$ for the Radium equivalent activity (Raeq), 182.94 Gyh$^{-1}$ for the absorbed dose rate (DR), 1268.11mSvy$^{-1}$, for the annual gonadal dose equivalent (AGDE), 0.225 mSvy$^{-1}$ for the annual effective dose rate (AEDE), 1.503 for the internal hazard index (Hin), 1.012 for the external hazard index (Hex) and 0.788 × 10$^{-4}$ for the Excess Lifetime Cancer Risk (ELCR). The average values of indices are well above their permissible limit.*
**Key words:** Background Radiation, Soil, NaI (Tl) detector crystal, Radiological Indices, Yagba East

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## I. INTRODUCTION

Ionizing radiation exposure has two main origins: naturally occurring sources and man-made sources. The naturally occurring radioactivity found in the crust of the planet can be further divided into two groups: virgin natural sources and modified natural sources. Virgin sources of radiation have been present on the earth since the beginning of time and are either cosmogenic or primordial (terrestrial) in nature. Natural resources that have been modified typically result from processes like mining, burning fossil fuels, making fertilizer, or using natural materials in construction. TENR, or technologically enhanced natural radiation, is the latter (TENR). The main source of the total global radiation dose rate is natural radiation. Inhalation of radon and its offspring is the main cause of large doses of natural radiation in places with background radiation that is typically acceptable (UNSCEAR, 2000).

The primary external source of irradiation to the human body is gamma radiation from radionuclides like the 40K and 232Th family, as well as their decay products. At sea level, the absorbed dose rate from cosmic radiation in the air is around 30 nGyh-1 (UNSCEAR, 2000). Terrestrial radionuclides, which are present in all rock formations at trace amounts, are the cause of external exposures to gamma radiation outdoors. Hence, geological and geographic conditions have a major influence on natural environmental radiation (Nagaraja and Sathish, 2010). They directly affect the level of absorbed dose received at a location by altering the soil composition and natural radioactivity concentration levels. Igneous rocks like granite have higher radiation levels, while sedimentary rocks have lower radiation levels. However, there are some exceptions because some shale and phosphate rocks contain radionuclides in relatively high concentrations (Ramachandra et al, 1995). The environment around humans has always included ionizing radiation. In addition to cosmic radiation and naturally occurring radioactive sources found in the earth's crust. With the development of technology came the discovery of atomic and nuclear energy by man. As technology advanced, so did the uses for radiation produced by man, particularly in the creation of elastic power (Agbalaje, 2010).

Using a 76x76mm NaI (Tl) detector crystal, this study measures the concentrations of the primordial radionuclides 40K, 232Th, and 238U in the chosen sampling locations in the Yabga East local government area of Kogi state, primarily for monitoring the area's rapid identification, assessment, and measurement of radioactivity and absorbed dose rates. The results of this investigation will create a baseline data collection that will make population exposure estimates possible. The information would also help map the soil radiation levels in Yagba east LGA.

## II. MATERIALS AND METHOD

### 2.1 STUDY AREA

The current study was conducted in the Yagba East Local Government Area of Kogi State, which is in the state's northeastern region. At the villages of Igbagun, Isanlu/Otedor, and Isanlu Makutu, samples have been collected. The climate belongs to the Koppen-AW climatic category and is tropical savannah. The region has two seasons, one dry from November to March/April and the other rainy from April to October. In the Sahara, the dry season is marked by a cold stretch from December to February that is accompanied by a dry wind (Harmattan). The dry season, which begins in March, is characterized by extreme heat. Extreme temperatures (37 °C in April and 20 °C in January) are reached throughout this time period. Moreover, between 900 and 1100 mm of rain fall occurs on average each day throughout the rainy season.

A survey meter placed one meter above the ground was used in earlier research in the subject region to measure the background radiation (see Isa *et al.,* 2021). The research made it possible to pinpoint specific areas with rather significant background radioactivity where it has been advised to conduct radioanalytical studies. The current study is being conducted for greater accuracy and to determine the kind and quantity of radionuclides present in the study region, and soil samples have been taken to the laboratory for analysis using a NaI (Tl) detector.

### 2.2 SAMPLE COLLECTION AND PREPARATION

As shown in Table 1, soil samples were taken from several study areas utilizing GIS mapping in order to determine the natural radioactivity in the soil. To obtain the natural soil, a square area (1 m x 1 m) was measured, a hole was drilled, and samples were taken at a depth of around 0.75 m from the ground. In order to maintain balance, four soil samples from each of the three study's regions were gathered, hence a total of twelve (12) samples were collected, which were then packaged in plastic bags. The samples were initially labeled for quick identification and division.

**Table 1: Description of the sample villages and their coordinates**

| Sample Villages | Latitude | Longitude | Sample codes |
|---|---|---|---|
| Igbagun | 5.72734667128 | 7.84640153026 | YE 01 |
| | 5.73665308148 | 7.84342024662 | YE 02 |
| | 5.73976919245 | 7.84390421030 | YE 03 |
| | 5.73651364086 | 7.84904013865 | YE 04 |
| Isanlu/Otedor | 5.99387533734 | 8.34873673588 | YE 05 |
| | 6.00463130734 | 8.34678812632 | YE 06 |
| | 6.01184115520 | 8.34873790680 | YE 07 |
| | 6.00285766163 | 8.35762493432 | YE 08 |
| Isanlu Makutu | 5.77167425979 | 8.41354811925 | YE 09 |
| | 5.78006696422 | 8.41380719189 | YE 10 |
| | 5.78379717659 | 8.41309183050 | YE 11 |
| | 5.77691563249 | 8.41996576436 | YE 12 |

By manual mixing, collected samples were homogenized, then let to dry in the air. The samples were then oven dried for 24 hours at 383 K (110 C) to remove moisture. Using a mortar and pestle, dried samples were ground into a fine powder, and a scientific sieve with a mesh size of 150 microns was used to get the samples' fine

quality. Before examination, each sample is placed in an airtight PVC container and stored for around three weeks (seven Rn222 half-lives, or 3.82 days), to allow radioactive equilibrium between Radon (222Ra) and Thoron (220Ra) daughter products and their rapidly decomposing byproducts. For each sample, 0.25 kilogram of soil are typically used (IAEA, Measurement of Radionuclides, 1989). The samples were stored in a lead shield, which has a shielding efficacy of 95%, to limit the contribution from background radiation while recording the spectra in the lab (Beck, 1972).

**2.3 RADIOACTIVE MEASUREMENTS**

The activity of the radionuclides 238U, 232Th, and 40K was measured using an 8k multi-channel analyser (model PCA-II) in conjunction with a 300-size sodium iodide [NaI(Tl)] crystal detector. Lead shielding that was 10 cm thick on top and 15 cm thick on all four sides of the detector allowed for a nearly 98% reduction in cosmic ray background. In order to block lead X-rays and Cadmium X-rays, respectively, the inner sides of the lead shielding are lined with 2mm thick Cadmium and 1mm thick Copper. The background radiation is further decreased by this graded liner shield, especially in the low energy area.

**2.4 CALCULATION OF THE RADIOLOGICAL HAZARD INDICES**

**2.4.1 RADIUM EQUIVALENT ( $Ra_{eq}$)**

A radiological risk index called the Radium equivalent ($Ra_{eq}$) activity is used to evaluate the negative impact of ionizing radiation on human health. This indicator relates to the radon and its offspring's internal and exterior exposure. By assuming that equal gamma doses of 370BqKg of 238U, 259BqKg of 232Th, and 4810BqKg of 40K are produced, the expression of Raeq is derived. The mathematical definition of the Radium equivalent activity is provided by UNSCEAR (2000):

$$Ra_{eq}\ (BqKg^{-1}) = AU + 1.43ATh + 0.077AK \quad (1)$$

Where AU, ATh, and AK represent, respectively, the specific activity concentrations of 238U, 232Th, and 40K. 370 BqKg1 is the suggested upper limit value for Raeq activity.

**2.4.2 ABSORBED DOSE ( $D_R$)**

The amount of gamma radiation energy generated by radionuclides per unit of exposure time and mass is calculated as the gamma dose rate. It measures how much radiation is being absorbed by the body and is represented in Gray per hour (Gyh). The specific activity of a radionuclide can be used to calculate the absorbed dose at one meter (1m) above the ground as a result of that radionuclide. The following formula expresses the relationship between specific activity and gamma dose rate that has been established through theoretical calculations UNSCEAR (2000):

$$DR(\eta Gy\ h^{-1}) = 0.462AU + 0.604ATh + 0.042AK \quad (2)$$

**2.4.3 ANNUAL EFFECTIVE DOSE EQUIVALENT (AEDE)**

The amount of gamma radiation generated by a radioactive source that accounts for the radiosensitivity of various human organs is known as the annual effective dose equivalent. It is represented by the connection given by UNSCEAR (2000):

$$AEDE(mSvy^{-1}) = DR(\eta Gyh^{-1}) \times 0.00123 \quad (3)$$

**2.4.4 ANNUAL GONADAL DOSE EQUIVALENT (AGDE)**

An estimate of the annual equivalent dose received in the gonads is provided by the annual gonadal dose equivalent (reproductive organ). The AGDE gives an explanation of the UNSCEAR formula (2000):

$$AGDE(Svy^{-1}) = 3.09AU + 4.18ATh + 0.314AK \quad (4)$$

**2.4.5 RADIATION HAZARD INDEX**

External hazards Index( Hex ): The external hazard index is a metric used to assess the radiological dangers associated with materials when exposed to gamma radiation from the outside. Hex's suggested value must be smaller than 1mSvy1, and the following relation provides its expression UNSCEAR(2000):

$$H_{ex} = \frac{A_U}{370 BqKg^{-1}} + \frac{A_{Th}}{259 BqKg^{-1}} + \frac{A_K}{4810 BqKg^{-1}} \quad (5)$$

### 2.4.6 EXCESS LIFETIME CANCER RISK (ELCR)

An estimation of the likelihood that cancer will develop during a certain lifetime characterizes the carcinogenic effects of gamma radiation caused by ingestion, inhalation, and external exposure to radioactive sources. The computation of the increased lifetime cancer risk yields this probability (ELCR). The relationship shown below provides its expression ICRP, (2009):

$$ELCR = AEDE \times DL \times RF \quad (6)$$

In this expression, DL stands for the life expectancy (70 years), and RF for the cancer risk factor taking into account stochastic factors. For the general population, RF is equal to 0.05 Sv1 (ICRP, 2009); (Taskin et al., 2009).

## III. RESULTS AND DISCUSSION

Twelve (12) soil samples from the Yagba East Local Government Area in Kogi state were tested for radioactivity. A variety of radionuclides from both natural and artificial sources are present in the samples. Because of the many activities taking on inside the sample area, radionuclide distribution differs from location to location. Direct counting techniques utilizing nuclear instruments were used to determine the activity concentration of various radionuclides, including 238U, 232Th, and 40K. The outcomes are displayed in Table 2.

Using a NaI detector, the activity concentration of 238U, 232Th, and 40K was determined in a variety of soil samples that were taken from the Yagba East Local Government Council at depths up to 0.75 meters. In Table 2, the individual activity values and the corresponding radiation danger indices are calculated.

### 3.1 SPATIAL DISTRIBUTION

**Table 2: Activity Concentration of Selective Radionuclides and Radiological Parameters in the Soil Samples**

| S/N | Sample Code | Activities in Bq/kg | | | Ra_eq in Bq/kg | Dose rate (D) (nGy/h) | AGDE (mSv/y) | AEDE (mSv/y) | Hazard indices | | ELCR mSv |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | $^{40}K$ | $^{238}U$ | $^{232}Th$ | | | | | $H_{in}$ | $H_{ex}$ | |
| 1 | YE 01 | 598.82 ±28.82 | 43.54 ±3.23 | 27.10 ±1.51 | 128.4 | 61.64 | 435.85 | 0.076 | 0.464 | 0.347 | 0.266 |
| 2 | YE02 | 1094.75 ±54.15 | 63.56 ±6.37 | 15.21 ±1.51 | 169.61 | 84.53 | 603.73 | 0.104 | 0.631 | 0.459 | 0.364 |
| 3 | YE03 | 3385 ±164.43 | 288.73 ±22.04 | 36.68 ±2.11 | 601.83 | 297.71 | 2108.30 | 0.366 | 2.407 | 1.626 | 1.281 |
| 4 | YE04 | 466.93 ±23.41 | 149.27 ±12.77 | 28.77 ±1.65 | 226.36 | 105.95 | 728.12 | 0.130 | 1.015 | 0.611 | 0.455 |
| 5 | YE05 | 382.71 ±18.41 | 17.22 ±1.30 | 14.34 ±0.80 | 67.20 | 32.69 | 233.32 | 0.040 | 0.228 | 0.182 | 0.140 |
| 6 | YE06 | 3131.94 ±152.82 | 388.22 ±28.94 | 32.79 ±1.89 | 676.27 | 330.71 | 2320.09 | 0.407 | 2.876 | 1.827 | 1.423 |
| 7 | YE07 | 2997.82 ±145.84 | 282.80 ±21.24 | 42.17 ±2.42 | 557.23 | 281.99 | 1991.44 | 0.347 | 2.315 | 1.550 | 1.214 |
| 8 | YE08 | 2750.54 ±134.15 | 360.76 ±26.67 | 45.42 ±2.61 | 637.50 | 309.62 | 1682.10 | 0.381 | 2.697 | 1.722 | 1.334 |
| 9 | YE09 | 2515.55 ±123.60 | 203.42 ±17.76 | 39.51 ±2.28 | 453.62 | 223.49 | 1583.60 | 0.275 | 1.776 | 1.226 | 0.963 |
| 10 | YE10 | 443.95 ±21.38 | 30.23 ±2.29 | 57.30 ±3.19 | 146.35 | 67.23 | 472.32 | 0.083 | 0.476 | 0.395 | 0.291 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 11 | YE11 | 1147.70 ±57.19 | 206.64 ±16.14 | 42.99 ±2.46 | 356.49 | 169.61 | 1403.84 | 0.209 | 1.522 | 0.963 | 0.732 |
| 12 | YE12 | 3327.29 ±161.18 | 147.77 ±12.12 | 36.60 ±2.10 | 456.31 | 230.13 | 1654.60 | 0.283 | 1.632 | 1.232 | 0.991 |
| 13 | Min | 382.71 ±18.41 | 17.22 ±1.30 | 14.34 ±0.80 | 67.20 | 32.69 | 233.32 | 0.040 | 0.228 | 0.182 | 0.140 |
| 14 | Max | 3385 ±164.43 | 388.22 ±28.94 | 57.30 ±3.19 | 676.27 | 330.71 | 2320.09 | 0.407 | 2.876 | 1.827 | 1.423 |
| 15 | Mean | 1853.58 ±90.45 | 181.85 ±14.24 | 34.91 ±2.04 | 373.10 | 182.94 | 1268.11 | 0.225 | 1.503 | 1.012 | 0.788 |

### 3.2. ACTIVITY CONCENTRATIONS OF 238U, 232TH, AND 40K

Table 1 lists the estimated activity concentrations of the three primordial radionuclides 238U, 232Th, and 40K for each sample taken from the research area. 232Th activity ranged from 14.34Bqkg-1 to 57.30Bqkg-1 with a mean of 34.91Bqkg-1, and 40K activity ranged from 382.71Bqkg-1 to 3385Bqkg-1 with a mean of 1853.58Bqkg1. The activity of 238U in the soil ranged from 17.22Bq/kg to 388.22Bqkg=1, with a range of 181.85Bqkg-1. The average global activity concentrations for 238U, 232Th, and 40K are 32, 45, and 420Bqkg-1, respectively (UNSCEAR., 2000). While the activity concentrations of 232Th in the samples were found to be lower than the global average values, the activity concentrations of 238U and 40K were found to be greater than the global average values. The fact that the soil samples were taken from places close to industrial or agricultural fields may be the cause of the elevated activity of 40K in the samples. The 40K activity was the highest and contributed the most to the total activity (238U + 232Th + 40K) in soil, while the mean activity of 232Th was lower than that of 238U. This is consistent with the well-known fact that potassium in the earth's crust is of the order of percentage while U and Th are in ppm level (Ramasamy, Suresh, Meenakshisundaram, & Ponnusamy, 2011).

Figure 1 displays the soil sample activity concentrations for 238U, 232Th, and 40K from the study area. In Table 3, the mean values obtained in the current study were compared to those from similar research of soils in other nations. The comparison demonstrates that the soil values under examination were comparable higher to others within the UNSCEAR (2000) -reported global average values. The variations in radioactivity concentrations in soil across the globe, is largely due to the geological and geographical features of the region (UNSCEAR, 2000).

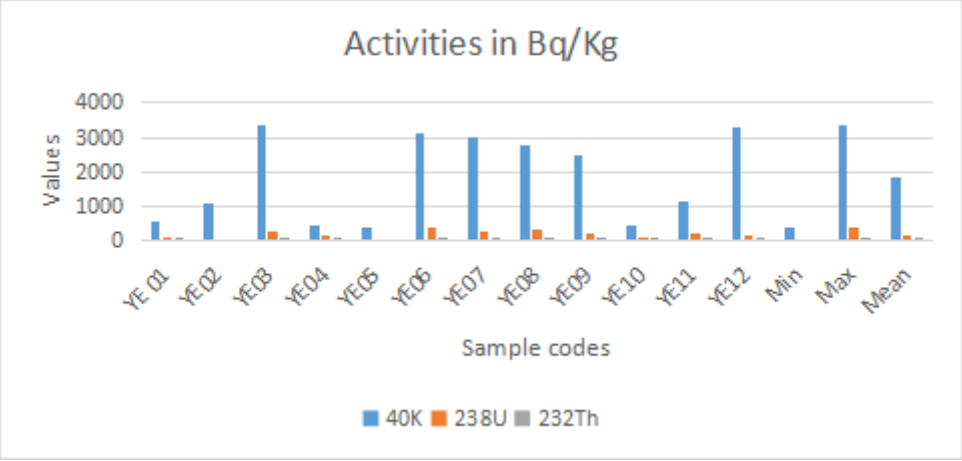


Figure 1: Activities Concentration of Soil Samples in the Study area

Table 3: Comparison of the Mean Values Obtained in the Present Work and World Investigations

| Country | Mean activity concentration (Bqkg−1) | | | |
|---|---|---|---|---|
| | 238U | 232Th | 40K | References |
| Nigeria (Kogi) | 181.85 | 34.91 | 1853.58 | Present study |
| Saudi Arabia | 16.73 | 10.40 | 419.78 | Al-Ghamdi (2019) |
| Nigeria | 8.8 | 17.5 | 102.8 | Ademola, Bello, and Adejumobi (2014) |
| Yemen | 14. 34 | 25.78 | 566.05 | Nafee et al. (2017) |
| Turkey | 24.5 | 51.8 | 344.9 | Durusoy and Yildirim (2017) |
| India | 30.24 | 29.89 | 291.06 | Amanjeet, Kumar, Singh, Singh, and Bajwa (2017) |
| China | 19.5 | 36.8 | 728.1 | Li et al. (2017) |
| Egypt | 8.64 | 13.77 | 141.64 | Fares (2017) |
| Malaysia | 92.23 | 61.82 | 621.84 | Ismail et al. (2018) |
| World average | 32 | 45 | 420 | UNSCEAR., 2000 |

### 3.3 RADIOLOGICAL HAZARD INDICES

Along with the average values of the other indices, the computed values of (Raeq) were reported in Table 1. From Table 1, the following observations can be made:

1) The mean value of the radiation equivalent (Raeq) in soil samples from the research region ranged from 67.20 to 676.27Bqkg−1 with a mean value of 373.10Bqkg−1. Some of the values of Raeq in the studied samples specifically from samples areas of YE03, YE06, YE07, YE08, YE09 and YE12 are found to be higher than the critical limit of370 Bqkg−1 while samples from areas YE01,YE02, YE04,YE05, YE10 and YE11 were found to be lower than the critical limit of 370 Bqkg−1 recommend by UNSCEAR, 2000.
2) The research area's external danger index ranged from 0.182 to 1.827, with a mean value of 1.012. The average value exceeds the one-limit (UNSCEAR, 2000).
3) The observed range of the air absorbed dose rate in the research area's soil samples is 32.69 to 330.71nGyh1, with a mean value of 182.94nGyh. Air absorption dose rate is seen to be higher than the population-weighted average value of global primordial radiation, which is 59nGyh (UNSCEAR, 2000).
4) The computed AGDE values in this study range from 233.32 to 2320.09 mSv y1, with an average value of 1268.11 mSvy-1, which clearly shows that the AGDE values of all soil samples in the present investigation are higher than the global average value of 300 mSvy-1 (Xinwei, Lingqing, & Xiaodan, 2006).
5) The yearly effective dose equivalent found in soil samples ranges from 0.040 to 0.407 mSvy-1, with an average value of 0.225 mSvy-1, or about 22.5% of the 1.0 mSv year-1 maximum annual dosage advised by UNSCEAR, 2000 for a single member of the public.
6) The computed increased lifetime cancer risk values vary from 0.140 10-3 to 1.42 10-3, with a mean of 0.788 10-3. These numbers exceed the 0.29x103 global average that UNSCEAR (2000) recorded.

The majority of the readings are over the normal radiation levels, which puts the soil radioactivity at a high risk for both the environment and human health, leading one to conclude that the study region poses a health risk based on these radiological hazard results. Figure 2 shows a comparison of the soil sample data for the radium equivalent (Raeq), absorbed dose (D), and annual effective dose (Deff). According to Figure 3, the relative contribution to dosage attributable to 238U and 232Th was 8.8% and 1.7%, respectively. The relative contribution attributable to dose attributable to 40K was 89.50%.

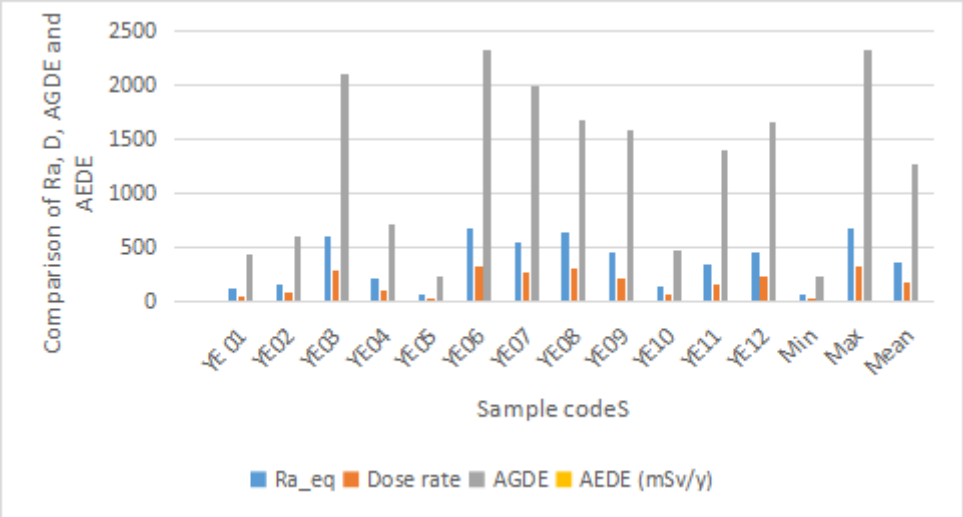


Figure 2:Comparison of Radiological Hazard Indices

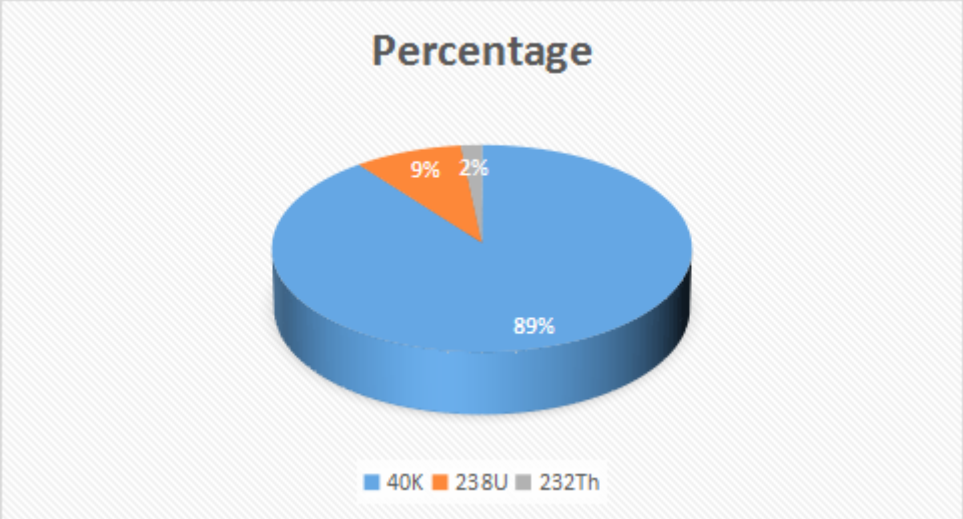


Figure 3: Contribution to dose due to 40K, 238U and 232Th

## IV. CONCLUSION

In conclusion, 238U, 232Th, and 40K had average activity concentrations of 181.85, 34.91, and 1853.58Bq/kg, respectively. The analysis revealed that while the activity concentration of 232Th is lower than the value in the soil across the globe, the measured values for 238U and 40K in the samples are higher than the global average values. Radium equivalent was measured at 63.93 Bq/kg, while the absorbed dose rate was measured at 31.68 nGy/h. These values fell below the permitted limits of 59 nGy/h for absorbed dose rate and 370 Bq/kg for radium equivalent. It was discovered that the external hazard index (Hex) was higher than the allowable limit of unity. The results of this study are greater than the values that pose a major radiation hazard to both the environment and human health, and they are above the range of values recorded in comparable studies carried out around the world. As a result of the radioactive risk, the soil in the vicinity may be hazardous to use as a building raw material or for other human activities. Nonetheless, this information might offer a general background level for the region under study and might potentially be used as a benchmark for future measurements and evaluations of potential radiological threats to human health in this area.

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