# ASSESSMENT OF NATURAL RADIOACTIVITY AND ITS ASSOCIATED RADIOLOGICAL HAZARD INDICES AND DOSE PARAMETERS IN SOIL SAMPLES FROM COASTAL COMMUNITIES OF OKRIKA, NIGERIA

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***ABSTRACT***

***Nine (9) Coastal communities of Okrika Local Government Area of Rivers State was assessed, in each of the community two soil samples were obtained, giving a total of Eighteen (18) samples. These samples were Analysed using NaI(Ti) Gamma-Ray Spectroscopy at the Nigerian Nuclear Regulatory Authority. The mean values of the activity concentration of the radioisotopes varied 73.63 -128.18 with a mean value of 121.87±50.53, 2.60 to 27.05 with mean value of 10.14±7.28 and 4.59 to 7.45 mean value of 6.32±1.03 for $^{40}$K,$^{238}$U and $^{232}$Th respectively. The Gamma index ranged from 0.06 to 0.24 with a mean value of 0.122±0.05. The external hazard ($H_{ex}$) ranged from 0.04 to 0.14 with mean value of 0.08±0.03. The internal hazard ($H_{in}$) varied from 0.05 to 0.13 with mean value of 0.10±0.05. The absorbed dose varied from 7.04 nGy/h to 25.5 nGy/h with mean value of 13.58±5.47. The annual effective dose equivalent varied from 0.01 mSv/y to 0.03 mSv/y with mean value of 0.02±0.01 mSv/y. The gonadal dose varied from 50.34 to 179.45 mSv/y with mean value of 96.02±38.30 mSv/y. The excess life cancer risk ranged from 0.03x10$^{-3}$ to 0.11x10$^{-3}$ with a mean value of 0.06±0.02x10$^{-3}$. The activity Utilization index ranged from 0.09 to 0.34 with a mean value of 0.18±0.07. The Radiological Hazard Indices and Dose Parameters are within the safe limits. Therefore, the populace of the study area is radiologically free, and soil samples of the Coastal communities of Okrika can be utilize as building materials.***

***Keywords: Coastal Communities, Natural Radionuclides, Radiological Hazard Indices, Dose Parameters, Excess Life Cancer Risk.***

## Introduction

Soil is widely used as building material in domestic, industrial, and engineering constructions. The constructions of homes, offices, roads, high-rise buildings, bridges and so, intensively make use of large amount of soil samples to achieve their various tasks. These soil samples contain $^{238}$U, $^{232}$Th, $^{40}$K and other forms of radionuclides. Since the populace of the coastal community of Okrika make intensive use of soil samples in areas like domestic buildings, it is of great importance to assess the radiation levels and related radiological hazard indices to which the residents of Okrka are exposed to. Having good knowledge of the concentration levels of natural radionuclides in soil and their distribution pattern in the environment have shown great importance in several fields of study (El-Aydarous, 2007). The levels of natural radioactivity in geological materials such as rocks, sediments and soil samples occurs in varying concentrations and locations (Tzortzis and Tsertos 2004; Santos *et al.,* 2005). Radionuclides are elements with unstable nucleus which releases high energetic particles such as photons, alpha, beta or gamma radiation and the release of energy whenever its disintegrates. The unstable nucleus breaks down to release radiation; this spontaneous disintegration of these radionuclides is described by radioactivity.

Radionuclides come in various forms, it can be eaten, drinking, swallowed or inhaled. Primordial radionuclides are those classified as naturally occurring and have been in existence since the beginning of the earth formation (Obed *et al.,* 2005). Radon gas, emanating from the decay series of thorium and uranium, which usually gain path to indoor dwelling and as a result of these disintegration radon gas concentration in indoor environment can be elevated, when inhaled it may likely result to lung cancer when a certain threshold has been exceeded (UNSCEAR 2000). Rocks sediments and soil materials used in construction of building is one possible way of exposing both indoor and outdoor environment to ionizing radiation. Measurement of natural radioactivity is of great importance in implementing precautionary measures. Whenever the radiological hazards it is found to exceed the permissible limit (ICRP,1991; UNSCEAR, 2000). Due to the health risks related with the exposure to natural occurring radioactive materials, international bodies and organizations -such as International Commission on Radiological Protection and Environmental Protection Agency ((ICRP 1991; EPA 2007) have proposed strong measures at minimizing radiation exposure to as low as reasonably achievable (UNSCEAR, 2000).

Soil plays an active role in road, bridges, residential and office structure and so on. Based on this fact, the exposure to these radionuclides is of great concern as it may give rooms to radiological health threat especially in areas where the concentration is significantly high. Various research has been reviewed in soil in different locations and Tabulated in Table 1. Therefore, this research is focus at assessing the radiological hazard indices and dose parameters with the use of Soil of the coastal communities of Okrika and to determining its suitability as building materials.

## Materials and Methods

### Study Area

Okrika town is one of the coastal communities in River State. It lies within latitude: 40.43'44" N to 40.45'57" N and longitude range of 70.3'20" E to 70.6'42" E (Sokari, 2018). Okrica Local Government Area is bounded to the north by Port Harcourt City, to the east by Ogu-Bolo and Eleme, to the south by Bonny and to the west by Degema L.G.A. respectively. The town plays a host to few few multinational companies operating within and arounds its environs. The sampled locations are indicated in Figure 1.

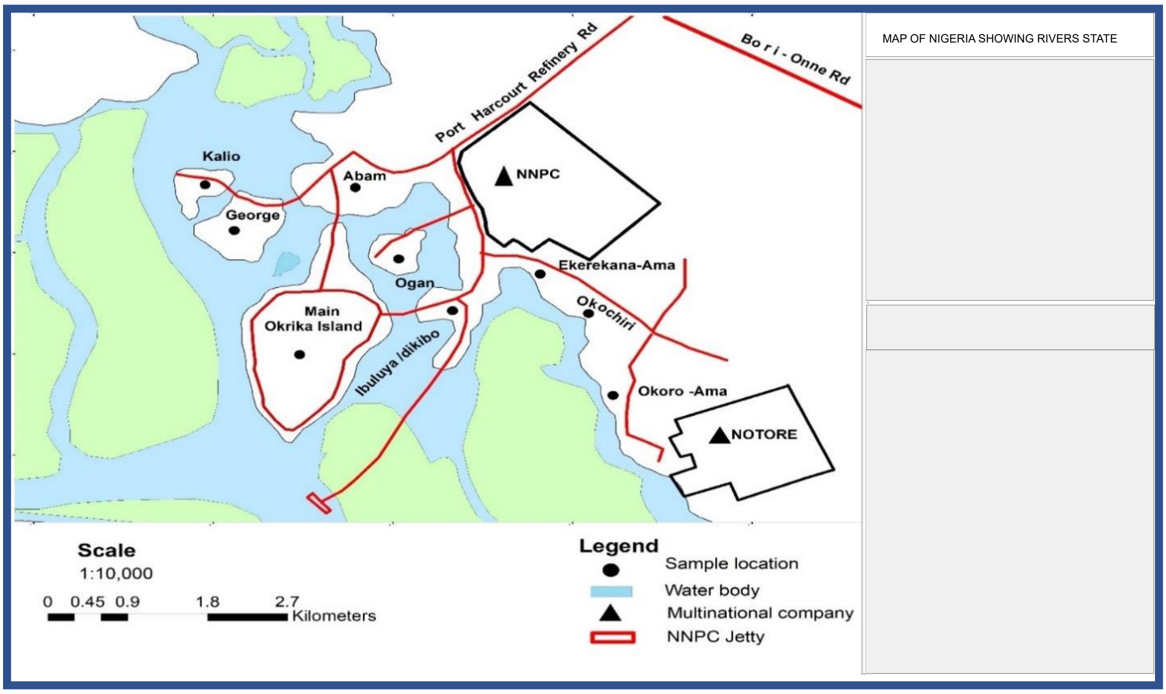


**Figure 1: Modified Google Map of Okrika LGA Showing the Study Area**

## Preparation of Samples

In each of the 9 communities 2 soil samples were collected at a depth of 1m below the surface of the ground with the use of a geological auger. These samples were sundried and then crushed to fine grains to ensure homogeneity and weighted to 300 grams per sample. Each sample was well package and labelled and later taken to Nigeria Nuclear Regulatory Authority (NNRA) in University of Ibadan. The samples were kept for several days for its radon its daughter progenies to attain secular equilibrium, prior to NaI(Ti) Gamma-Ray Spectroscopy analysis.

## Gamma-Ray Spectroscopy

The activity concentration measurement was determined using a thallium activated Canberra vertical high purity 2″×2″ Sodium iodide NaI(TI) detector connected to ORTEC 456 Digi base amplifier. The detector was connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes according to IAEA standard. The detector was shielded by 15cm thick lead on all four sides and 10 cm thick on top. The energy resolution of 2.0 keV and relative efficiency of 33% at 1.33Mev was achieved in the system with the counting time of 10800 seconds. Sodium iodide detector were used.

## Parameters for Sediments Samples

## Radium Equivalent Activity ($Raeq$)

The absorbed activity dose is not provided as an exact indication of radiation hazard associated with sediments or any other materials because the concentration of $^{238}$U, $^{232}$Th and $^{40}$K are not uniformly. The radium equivalent concept allows a single index or number to describe the gamma output from different mixture of the aforementioned radioisotopes distributed in rocks particles sediments or soil and most of environmental materials throughout the world. So that, for uniformity with respect to the exposure to gamma. radiation UNSCEAR (2000), has defined the radium equivalent activity as expressed in equation 1.

$$Raeq\ (Bq/kg) = A_U + 1.43\ A_{Th} + 0.077\ A_K \quad (1)$$

Where $AU$, $ATh$ and $AK$ are the activity concentration of U-238, Th-232 and K-40 in ($Bq/kg$) respectively. 1, 1.43 and 0.077 are the activity conversion rates of uranium, thorium and potassium respectively which outcome in same gamma dose rate 10 Bq/kg of $^{226}$U, 7Bq/kg of $^{232}$Th and 130 Bq/kq of $^{40}$K produce equal gamma dose (Omowumi, 2020).

**Representative Gamma Index (*Iγ*)**

The gamma index (Iγ) is a screening parameter for materials of possible radiation health challenge (Jibiri and Okeyode, 2012). It is calculated using the equation (Ravisankar *et al.,* 2014).

$$I\gamma = \frac{A_U}{300} + \frac{A_{Th}}{200} + \frac{A_K}{3000} \qquad (2)$$

where $A_U$, $A_{Th}$, and $A_K$ are the specific activity concentrations of 226Ra, 232Th, and 40K, respectively, in Bq/kg, $I\gamma < 1$, which corresponds to an annual effective dose of <1 mSv, to satisfy the dose criteria

**External and Internal Hazard Indices**

**External Hazard Index *(H<sub>ex</sub>)***

Other radiological hazards are external ($Hex$) and internal ($Hin$) hazard indices. $Hex$ is the radiation hazard due to external exposure to gamma radiation in ambient air. The external hazard index can be calculated from the following equation (UNSCEAR,2000)

$$H_{ex} = \frac{A_U}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (3)$$

**Internal Hazard Index ($H_{in}$)**

The internal radiation exposure is quantified by the Internal Hazard Index ($Hin$) given by UNSCEAR (2000)

$$H_{in} = \frac{A_U}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \qquad (4)$$

The internal exposure to radon Rn-222 and its decay products is controlled by internal hazard index ($Hin$) and for safe use UNSCEAR (2000) provided that the value of the above indexes must be less than unity for the radiation hazard to be negligible.

**Absorbed Dose Rate $D$**

Absorbed dose is a measure of the energy deposited in a medium by ionizing radiation. It is equal to the energy deposited per unit mass of medium, measured in of unit J/kg or gray (Gy) where lGy = l J/kg. The absorbed dose rates (D) due to gamma radiations in air at lm above the ground surface for the uniform distribution of the naturally occurring radionuclides ($^{238}$U, $^{232}$Th and $^{40}$K) will be calculated using equation the equation below.

$$D(nGyh\text{-}1) = 0.462AR_u + 0.621\ A_m + 0.0417A_K \qquad (5)$$

Where $A_u$, $A_n$, and $A_K$ are the activity concentrations of $^{226}$Ra, $^{232}$Th and $^{40}$K respectively (UNSCEAR, 2000).

**Annual Effective Dose Equivalent ($AEDE$)**

The annual effective dose equivalent was estimated to convert the outdoor absorbed dose in air to effective dose (UNSCEAR, 2000) reported the value 0.7 *SvGy-1* as conversion coefficient from absorbed dose in the air to the effective dose received by adults and 0.2 was used as the outdoor occupancy factor.

$$AEDE = D(nGyr/h) \times 8760hyr'^{1} x0.7x(10^3 mSv/10^9)\ nGy \times 0.2 \qquad (6)$$

**Annual Gonadal Dose Equivalent ($AGDE$)**

The United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR (1988) has been interested active bone marrow and bone surface cells as organs. Therefore, the annual gonadal dose equivalent ($AGDE$) due to the specific activities of U-238, Th-232 and K-40 and conversion factors 3.09, 4.18 and 0.3144 $\mu Sv/y\ per\ Bqkg{-1}$ respectively, was calculated using the following equation (Taskin, 2009).

$$AGDE = 3.09AU + 4.18ATh + 0.314AK \quad (7)$$

**Life-Time Cancer Risk ($ELCR$)**

The excess life-time cancer risk ($ELCR$) was computed from annual effective dose equivalent using the equation (Taskin *et al.,* 2009; Ravisankar *et al.,* 2014)

$$ELCR = AEDE \times DL \times RF \quad (8)$$

Where AEDE, $DL$, and $RF$ are the annual effective dose equivalent, the duration of life (70 years), and risk factor (0.05/$Sv$). This parameter defined the risk factor as fatal cancer risk per Sievert, which according to Taskin et al. (2009) is assigned a value of 0.05 by ICRP 60 for the public for stochastic effects.

**Activity Utilization Index (AUI)**

This is the model that enables us to determine the dose rates in air of the radionuclides (U, Ra, Th) from the sediments samples. This is given as (Omowumi,2020).

$$AUI = \left(\frac{A_U}{50Bq/Kg}\right) F_U + \left(\frac{A_{Th}}{50Bq/Kg}\right) F_{Th} + \left(\frac{A_K}{50Bq/Kg}\right) F_K \quad (9)$$

Where $A_U$, $A_{Th}$ and $A_K$ are the activity concentration in Bg/Kg for $^{238}U$, $^{232}Th$ and $^{40}K$ respectively. $F_U$, $F_{Th}$ and $F_k$ are the fractional contributions to the total dose rate in air due to gamma radiation from the actual concentrations of these radionuclides (Omowumi,2020). The values of $F_U$, $F_{Th}$ and $F_k$ are given as 0.462. 0.604 and 0.041 for uranium, thorium and potassium respectively. Substituting the fractional contribution values, the equation becomes;

$$AUI = \left(\frac{A_U}{50Bq/Kg}\right) \text{x } 0.462 + \left(\frac{A_{Th}}{50Bq/Kg}\right) \text{x } 0.604 + \left(\frac{A_K}{50Bq/Kg}\right) \text{x } 0.0401 \quad (10)$$

If *AUI* is less than 1 it then means that the effect is negligible (Sivakumar *et al.;* 2014).

**Results and Discussions**

The results of the activity concentration of soil samples are presented Table 2. The average activity concentration of radionuclides in each of the respective Coastal community is presented in Table 3. The radionuclide $^{40}K$ ranged from 231.55 in George-Ama to 56.91in Abam/Igbiri with a mean value of 121.87±50.53 which is below the standard limit of 400 Bq/Kg (UNSCEAR) as shown in Figure 10. $^{238}U$ radionuclide varied from 27.05 in George-Ama to 2.60 in Main Okika Island with a mean value of 10.14±7.28 which is below the standard limit of 35 Bq/Kg (UNSCEAR) as indicated in Figure 11. $^{232}Th$ radio- isotope has a minimum value of 4.59 in Main Okrika Island to 7.45 in Ekerekana-Ama with a mean value of 6.32±1.03 which is below the permissible limit of 30 Bq/Kg (UNSCEAR) as shown in Fig. 12. The radium equivalent ($Ra_{eq}$) ranged from 11.71 in Main Okika Island to 35.26 in Ekerekana with a mean value of 27.60±12.22 Bq/Kg. These values are less than the safe limit of 370 Bq/Kq as recommended by UNSCEAR, as indicated in Fig 13. Since these values are below the permissible limits, it could be attributed that the geologic settings of the study area are not influence from man-made activities. The activity concentration in this work is of the order $^{40}K > ^{238}U > ^{232}Th$ and this result is in agreement to previously research done by Avwir (2014) in mini Okoro/Ogoniba creek in Port Harcourt and Orosun *et al.,* (2014) in University of Ilorin Kwara State.

The is a higher concentration of $^{40}K$ and $^{238}U$ of the North-East area of the study location but there is a general decrease as towards the South-East direction as indicated in the contour map in Fig. 2 and 3. There is higher concentration of $^{232}Th$ along the North-East and South-West direction concentrating towards the centre of the study location, but a general decrease of the activity concentration is located on the North-West and the South-East axis. This spatial distribution is shown in Fig. 4. The Raeq has a higher value of the North-West direction but uniformly decrease throughout the study location and the least value is observed within the South-East region of the study area as seen in Fig.5.

Fig. 6 and 7 shows a strong correlation of $^{40}K$ and $Ra_{eq}$ activity and $^{238}U$ and $Ra_{eq}$ activity in soil samples activity in soil concentration with correlation coefficient of $R^2 = 0.9273$ and $R^2 = 0.9319$ respectively, this suggest that the origin of these radionuclide might originate from the same source. Fig.8. shows a weak correlation of $^{232}Th$ and $Ra_{eq}$ with correlation coefficient of $R^2 = 0.0769$. The percentage contribution of $^{38}U$, $^{232}Th$ and $^{40}K$ in soil samples is shown in Fig.9, it follows the order $^{238}U = {}^{40}K > {}^{232}Th$.

Table 4 gives the summary of the radiation hazard indices and dose parameters in Soil samples of the Coastal communities of Okrika. The Gamma index ($I\gamma$) ranged from 0.06 in Main Okrika Island to 0.24 in George-Ama with a mean value of 0.122±0.05 which is below the permissible limit of 1.0 as recommended (UNCEAR, 2000). The gamma index accounts for screening parameter for material of possible radiation health challenge to the populace. In this case the effect is neglected since the value is less than unity. The external hazard *($H_{ex}$)* varied from 0.04 in Main Okrika Island to 0.14 in George-Ama with a mean value of 0.08±0.03. Since this value is below the permissible limit of 1.0 it implies that the external hazard due to gamma radiation in ambient air has no impact. The internal hazard *($H_{in}$)* ranged from 0.05 in Main Okrika Island to 0.22 in George-Ama with a mean value of 0.10±0.05. The internal Hazard due to lung cancer incidence to exposure to radon $^{222}Rn$ and its progenies is totally negligible so long as *($H_{in}$)<1.* The absorbed dose ranged from from 0.01 in Main Okrika Island to 25.50 in George-Ama with a mean value of 13.58±5.47 which is lesser than the acceptable limit of 59 nGy/h, see Fig 14.

The effect of energy deposited in human tissue from ionizing radiation is negligible as D(nGy/h)is less than unity. The annual effective dose equivalent varied from 0.01 in Main Okrika Island to 0.03 George-Ama with a mean value of 0.02±0.01. This accounts the fact that the exposure to soil samples to the populace of the Coastal community per year is radiologically free, as illustrated in Fig 15. The gonadal dose varied from 50.34 in Main Okrika Island to 179.45 in George-Ama with a mean value of 96.02±38.30 which is below the acceptable limit of 300 mSv/y. This result implies that the effect to bone marrow, bone surface, testis, spermatozoa, ovaries, and ovum are radiological free of the exposure to Soil samples of the coastal communities of Okrika, see Fig 16. The excess life cancer risk has a minimum value of $0.03x10^{-3}$ in Main Okrika Island and a maximum value of $0.11x10^{-3}$ in Ekerekana-Ama with a mean value of $0.06±0.02x10^{-3}$ which is below the permissible limit of $0.29 x10^{-3}$. Based on this result the probability of contracting health issues relating to cancer is negligible. The excess lifetime cancer risk of all communities with word standard is plotted in Fig 17.

The Activity Utilization Index (AUI) ranged from 0.09 mSv/y in Main Okrika Island to 0.34 mSv/y in George-Ama with an overall mean of 0.18±0.07 mSv/y which is below the permissible limit of 1.0 mSv/y. The AUI determines the dose rate received in air of $^{40}K$,$^{238}U$ and $^{232}Th$, from the use of sediments. Based on this model, the effect of ionizing radiation has no impact to the populace of the Coastal communities of Okrika. The radiological indices are shown in Fig. 18.

Consequently, since the *AUI*, $I\gamma$, $H_{ex}$ and $H_{in}$ indices are within the recommended limits. This implies that the use of soil samples of the Coastal communities of Okrika Local Government Area pose no risk and is safe to be utilized as building material.

Table 5 gives the Spearman rank correlation of radionuclides, radiological hazard indices and dose parameters of the soil samples of the Coastal communities using two tail analysis and significant level of 0.5.

**Table 1: Comparison of activity concentration in Soil with other Authors**

| Location | Sample | Activity Concentration Bq/Kg | | | Reference |
|---|---|---|---|---|---|
| | | $^{40}K$ | $^{238}U$ | $^{232}Th$ | |
| Mini Okoro/oginigba Creek, Port Harcourt | Soil | 16.25±0.19 | 4.76±0.14 | 3.92±0.02 | Avwiri, 2014 |
| Soil sample Ogun State | Soil | 243.35±14.04 | 1.67±1.67 | 46.91±1.87 | Usikalu et *al.,* 2014 |
| Abakaliki, Nigeria | Soil | 68.45 ± 20.40 | 6.84 ± 3.76 | 3.44 ± 1.52 | Ugbede, 2021 |
| University of Ilorin, kwara State | Soil | 456.1975 | 29.0245 | 26.2080 | Orosun *et al.,* 2021 |
| **Okrika, Nigeria** | **Sediment** | **551.47±336.50** | **13.67±14.47** | **8.81±3.32** | **This work** |

**Table 2: Activity concentration in Soil samples**

| | | | ACTIVITY CONCENTRATION (Bq/Kg) | | | |
|---|---|---|---|---|---|---|
| **S/N** | **Location** | **SOIL** | **K-40** | **U-238** | **Th-232** | **Raeq** |
| 1 | Main Okika Island-1 | MOI/S-1 | 69.41±4.98 | BDL | 4.45±0.43 | 11.71 |
| 2 | Main Okika Island-2 | MOI/S -2 | 77.85±5.61 | 2.60±0.58 | 4.73±0.46 | 15.36 |
| 3 | Ogan-Ama-1 | OGA/S -1 | 74.13±5.32 | BDL | 6.44±0.63 | 14.92 |
| 4 | Ogan-Ama-2 | OGA/S -2 | 98.19±7.04 | 7.63±1.67 | 4.87±0.47 | 22.15 |
| 5 | Kalio-Ama-1 | KAL/S -1 | 158.79±11.38 | 1.50±0.33 | 5.50±0.53 | 21.58 |
| 6 | Kalio-Ama-2 | KAL/S -2 | 100.92±7.25 | 14.05±3.04 | 5.07±0.49 | 29.07 |
| 7 | Okochiri-1 | OKC/S -1 | 83.49±5.87 | 10.16±2.07 | 7.45±0.72 | 27.24 |
| 8 | Okochiri-2 | OKC/S -2 | 152.75±10.97 | 5.90±1.31 | 5.98±0.60 | 26.21 |
| 9 | Ibuluya/Dikibo-1 | IBU/S -1 | 104.88±7.53 | 10.50±2.30 | 8.52±0.83 | 30.76 |
| 10 | Ibuluya/Dikibo-2 | IBU/S -2 | 177.35±12.72 | 7.92±1.74 | 6.62±0.64 | 31.04 |
| 11 | Abam/Igbiri-1 | ABM/S -1 | 58.18±4.18 | 3.47±0.77 | 5.95±0.58 | 16.46 |
| 12 | Abam/Igbiri-2 | ABM/S -2 | 55.63±4.00 | BDL | 7.72±0.75 | 15.32 |
| 13 | George-Ama-1 | GEG/S -1 | 267.86±19.15 | 14.70±3.19 | 3.683±0.36 | 40.59 |
| 14 | George-Ama-2 | GEG/S -2 | 195.23±13.98 | 39.40±8.31 | 7.40±0.72 | 65.01 |
| 15 | Okoro-Ama-1 | OKR/S -1 | 127.21±8.94 | 15.38±3.13 | 7.50±0.72 | 35.90 |
| 16 | Okoro-Ama-2 | OKR/S -2 | 129.14±9.27 | 6.66±1.49 | 6.98±0.68 | 26.59 |
| 17 | Ekerekana-1 | EKE/S -1 | 122.89±8.86 | 9.17±2.05 | 7.15±0.70 | 28.86 |
| 18 | Ekerekana-1 | EKE/S -2 | 139.80±9.83 | 19.80±4.03 | 7.75±0.75 | 41.65 |
| 19 | Control-1 | CON/S-1 | 17.26±1.24 | BDL | 4.74±0.46 | 8.11 |
| 20 | Control-2 | CON/S-2 | 90.45±6.48 | 7.52±1.64 | 3.70±0.36 | 19.78 |

**BDL= below detectable limit**

**Table 3: Mean activity concentration in Soil samples**

| | | MEAN ACTIVITY CONCENTRATION (Bq/Kg) | | | |
|---|---|---|---|---|---|
| **S/N** | **Location** | **K-40** | **U-238** | **Th-232** | **Reaq** |
| 1 | Main Okika Island | 73.63 | 2.60 | 4.59 | 11.71 |
| 2 | Ogan-Ama | 86.16 | 7.63 | 5.66 | 18.54 |
| 3 | Kalio-Ama | 129.86 | 7.78 | 5.29 | 25.34 |
| 4 | Okochiri | 118.12 | 8.03 | 6.72 | 26.73 |
| 5 | Ibuluya/Dikibo | 141.12 | 9.21 | 7.57 | 30.90 |
| 6 | Abam/Igbiri | 56.91 | 3.47 | 6.84 | 15.89 |
| 7 | George-Ama | 231.55 | 27.05 | 5.54 | 52.80 |
| 8 | Okoro-Ama | 128.18 | 11.02 | 7.24 | 31.25 |
| 9 | Ekerekana | 131.35 | 14.49 | 7.45 | 35.26 |
| | **Mean** | **121.87±50.53** | **10.14±7.28** | **6.32±1.03** | **27.60±12.22** |
| | **UNSCEAR (2000)** | **400** | **35** | **30** | **370** |
| | **BDL = below detectable limit** | | | | |

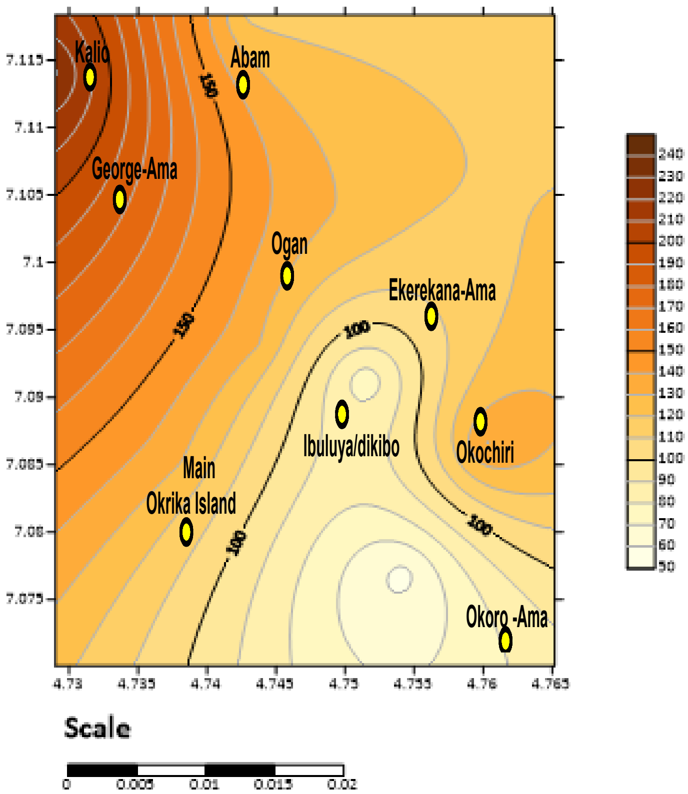


**Fig 2. Contour map of the spatial distribution of $^{40}K$ in sediments of study area**

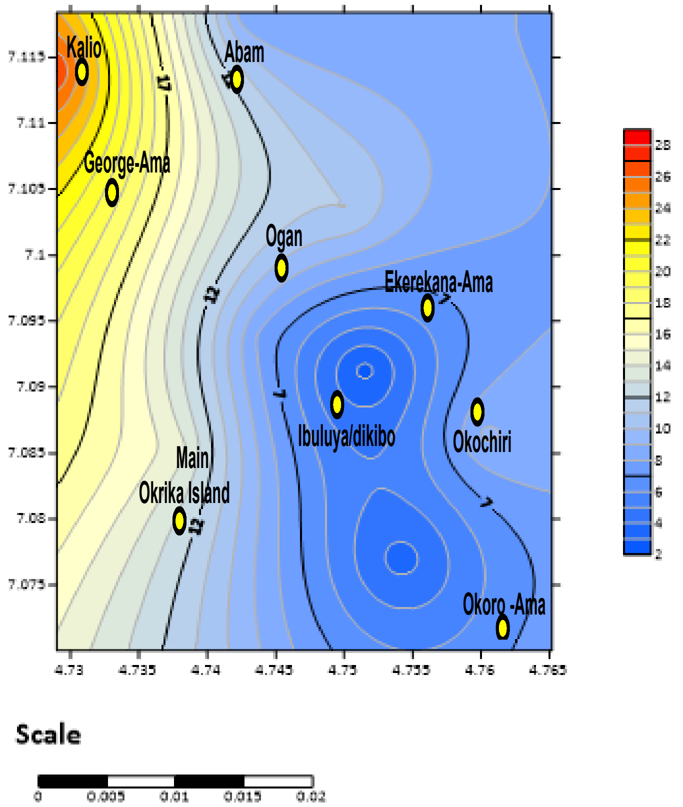


Fig 3: Contour map of the spatial distribution of $^{238}U$ in sediments of study area

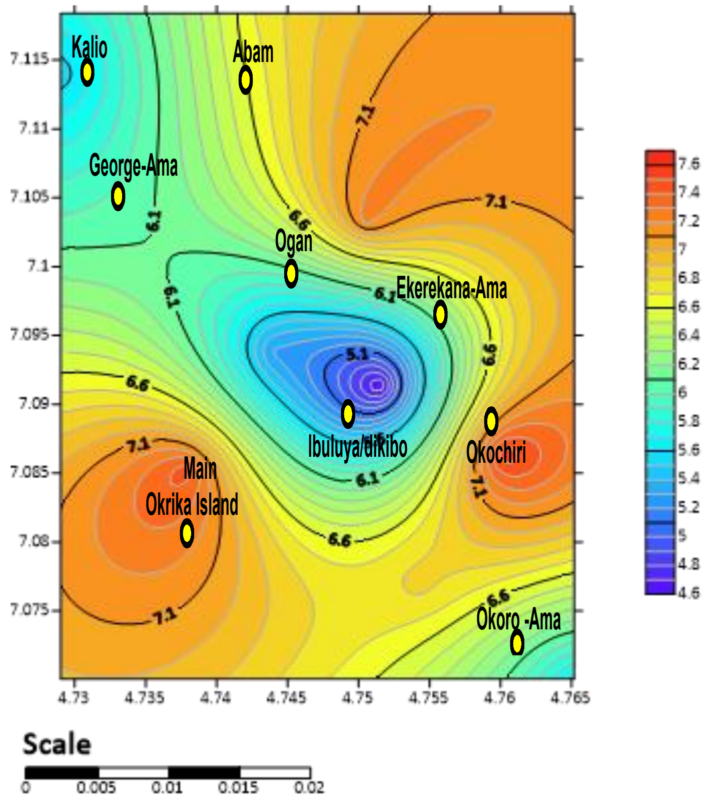


Fig 4: Contour map of the spatial distribution of $^{232}Th$ in sediments of study area

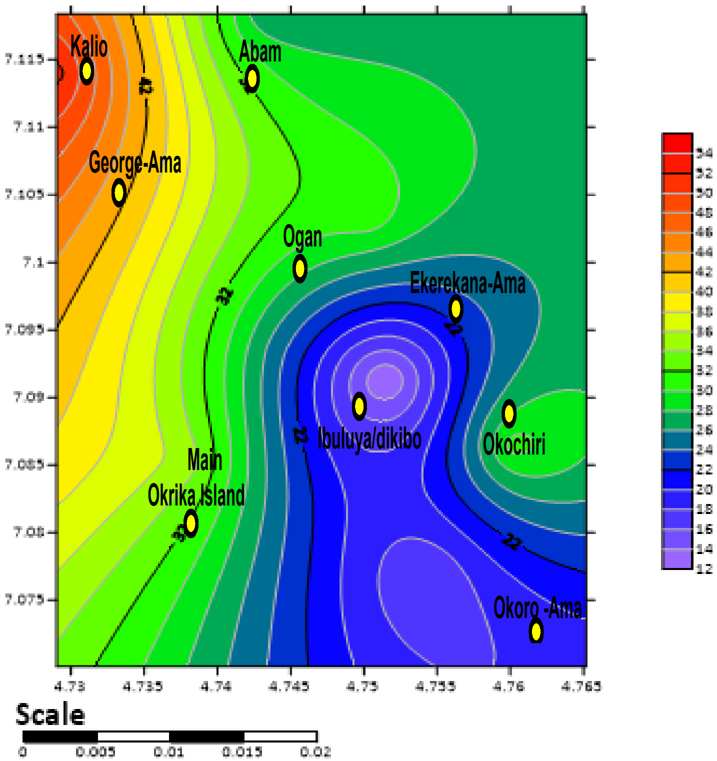


Fig 5: Contour map of the spatial distribution of Raeq in sediments of study area

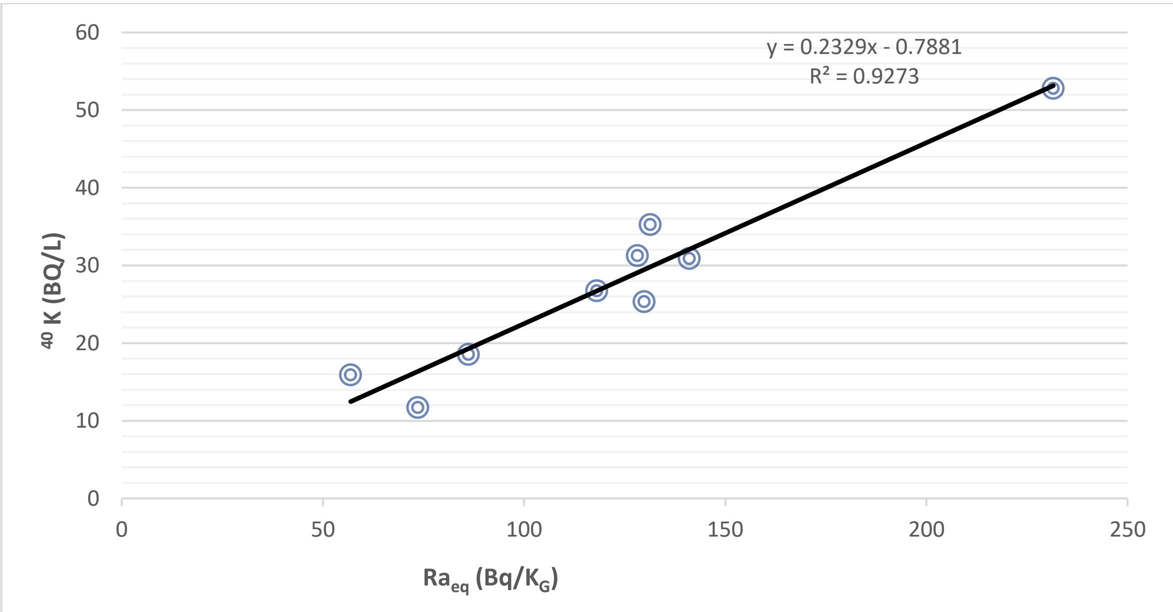


Fig 6: Correlation of $^{40}$K and $Ra_{eq}$ activity in soil samples

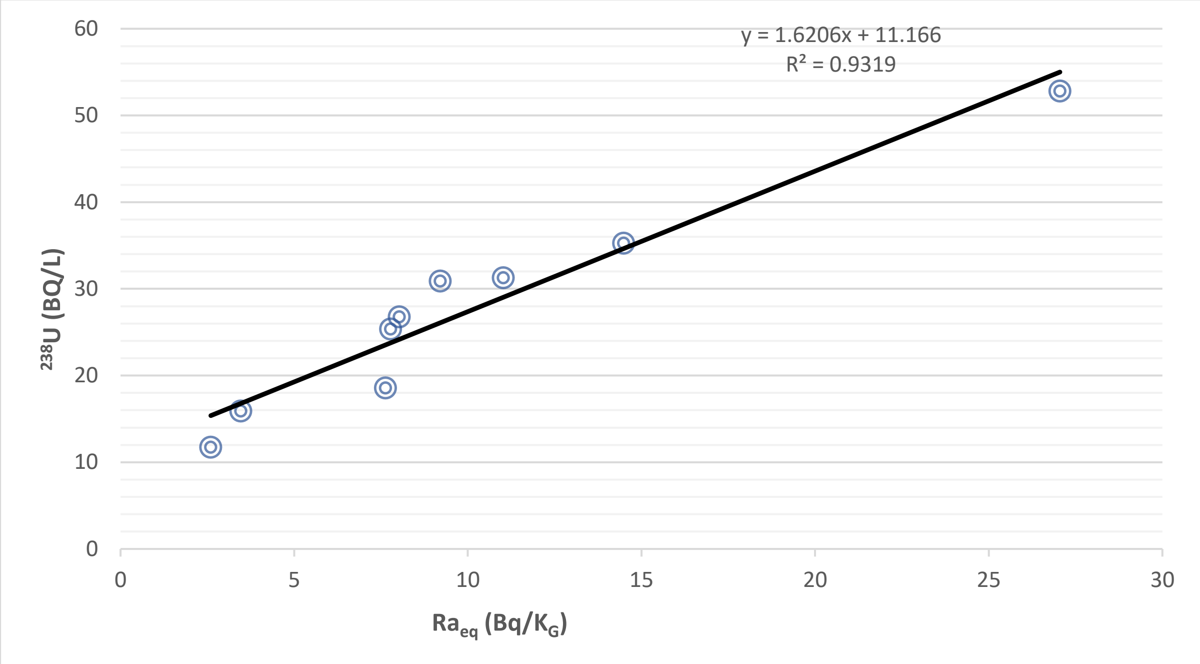


**Fig 7: Correlation of $^{238}$U and $Ra_{eq}$ activity in soil samples**

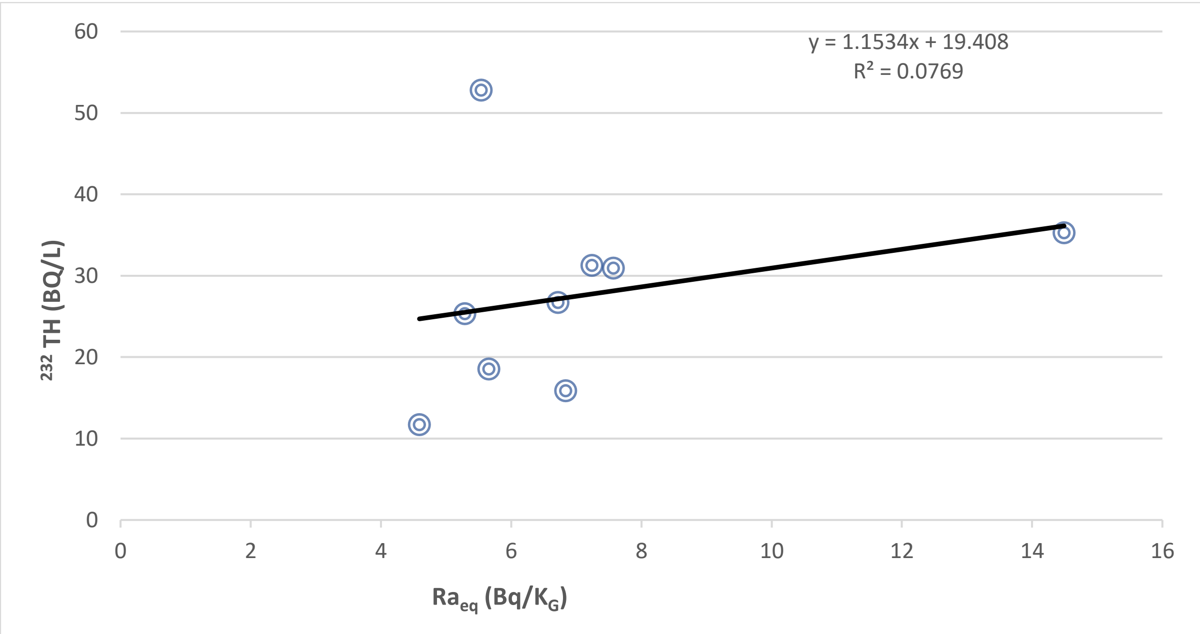


**Fig 8: Correlation of $^{232}$Th and $Ra_{eq}$ activity in Soil samples**

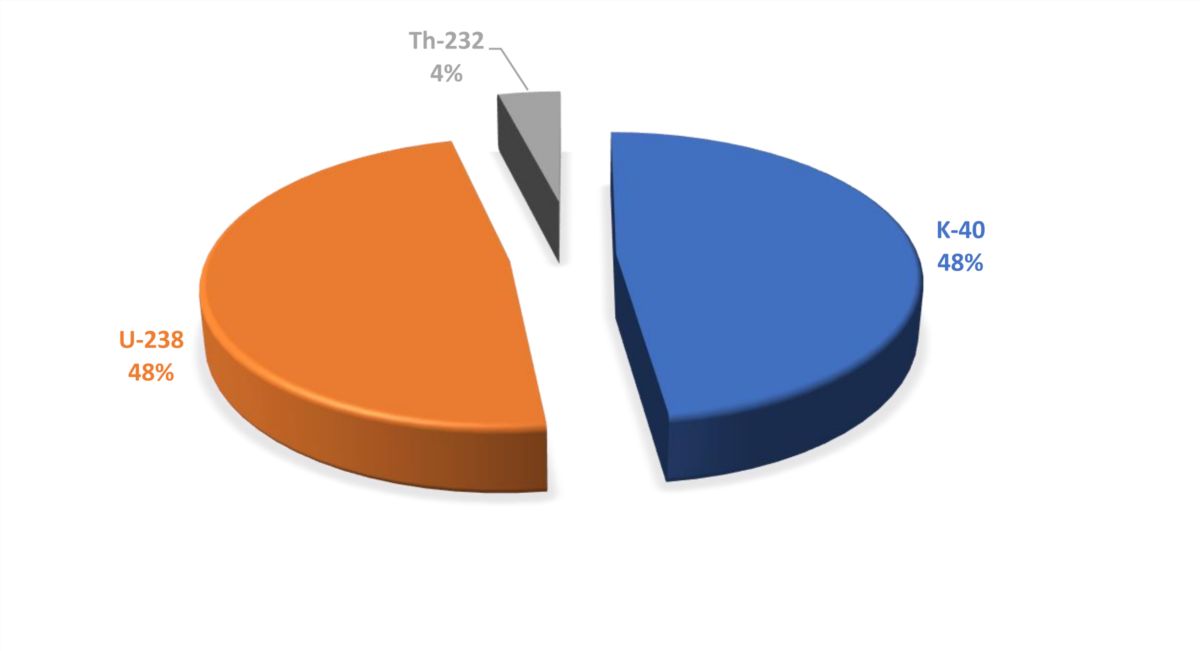


Fig 9: Percentage Contribution of $^{38}$U, $^{232}$Th and $^{40}$K activity in Soil samples

Table 4: Radiation Hazard indices and Dose Parameters in Soil samples in Soil samples

| S/N | location | $I\gamma$ | $H_{ex}$ | $H_{in}$ | D (nGy/h) | AEDE (mSv/y) | Gonadal (mSv/y) | ELCR x10 $^{-3}$ | AUI (mSv/y) |
|---|---|---|---|---|---|---|---|---|---|
| 1 | Main Okika Island | 0.06 | 0.04 | 0.05 | 7.04 | 0.01 | 50.34 | 0.03 | 0.09 |
| 2 | Ogan-Ama | 0.10 | 0.06 | 0.08 | 10.53 | 0.01 | 74.27 | 0.05 | 0.15 |
| 3 | Kalio-Ama | 0.11 | 0.07 | 0.09 | 12.20 | 0.01 | 86.89 | 0.05 | 0.15 |
| 4 | Okochiri | 0.11 | 0.07 | 0.09 | 12.69 | 0.02 | 89.97 | 0.05 | 0.17 |
| 5 | Ibuluya/Dikibo | 0.13 | 0.08 | 0.11 | 14.71 | 0.02 | 104.41 | 0.06 | 0.19 |
| 6 | Abam/Igbiri | 0.07 | 0.05 | 0.06 | 8.10 | 0.01 | 57.16 | 0.03 | 0.12 |
| 7 | George-Ama | 0.24 | 0.14 | 0.22 | 25.50 | 0.03 | 179.45 | 0.11 | 0.34 |
| 8 | Okoro-Ama | 0.13 | 0.08 | 0.11 | 14.81 | 0.02 | 104.56 | 0.06 | 0.20 |
| 9 | Ekerekana-Ama | 0.15 | 0.10 | 0.13 | 16.67 | 0.02 | 117.14 | 0.07 | 0.23 |
| **Mean** | | **0.122±0.05** | **0.08±0.03** | **0.10±0.05** | **13.58±5.47** | **0.02±0.01** | **96.02±38.30** | **0.06±0.02** | **0.18±0.07** |
| **UNCEAR (2000)** | | **1** | **1** | **1** | **59** | **1** | **300** | **0.29** | **1** |

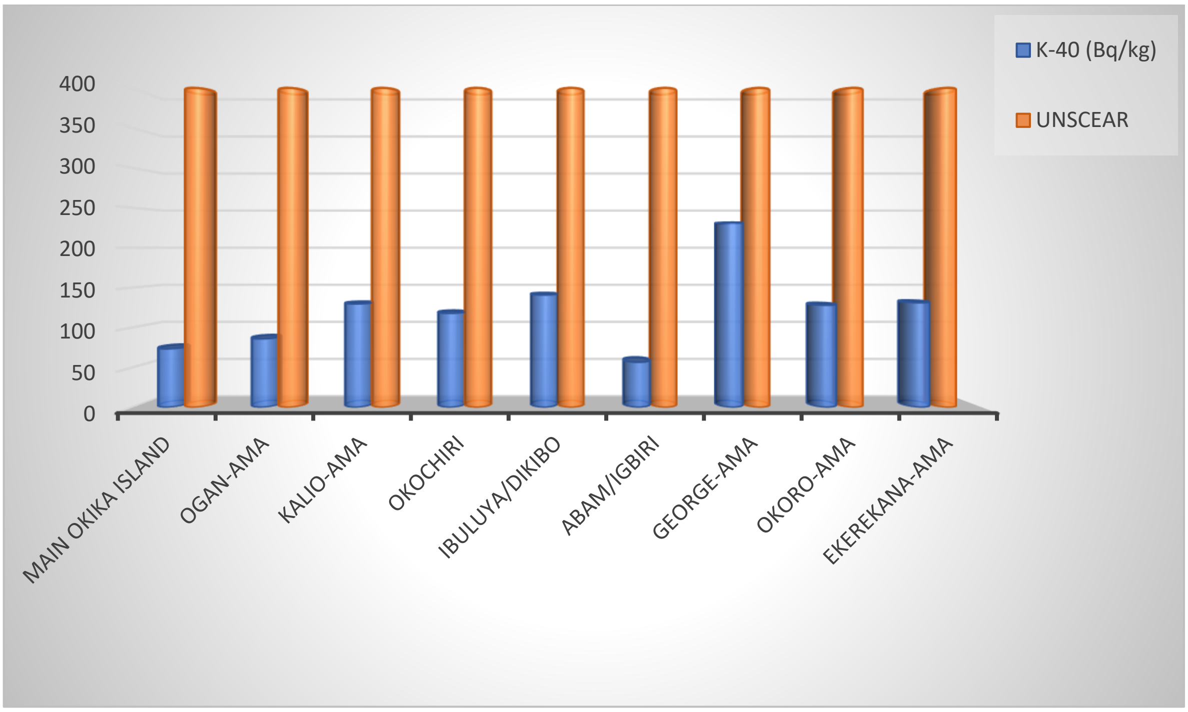


**Fig 10: Comparison of $^{40}$K activity concentration (Bq/Kg) in soil samples with world average., UNSCEAR, 2000**

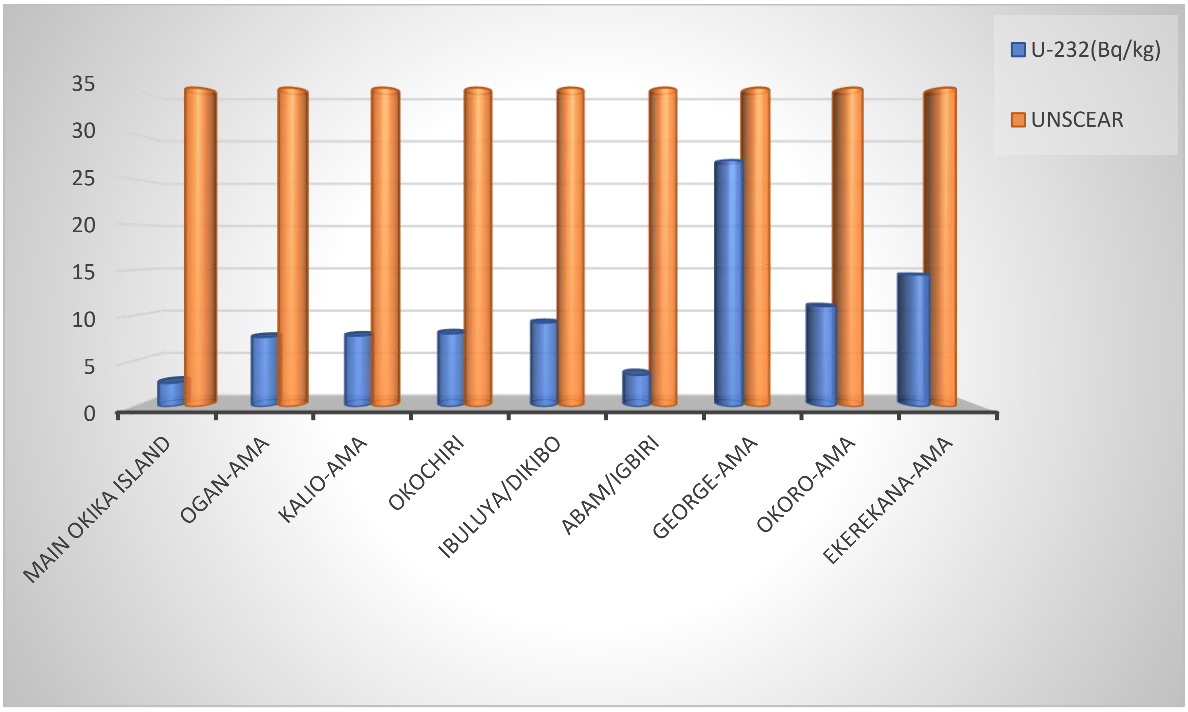


**Fig 11: Comparison of $^{238}$U activity concentration (Bq/Kg) in soil samples with world average., UNSCEAR, 2000**

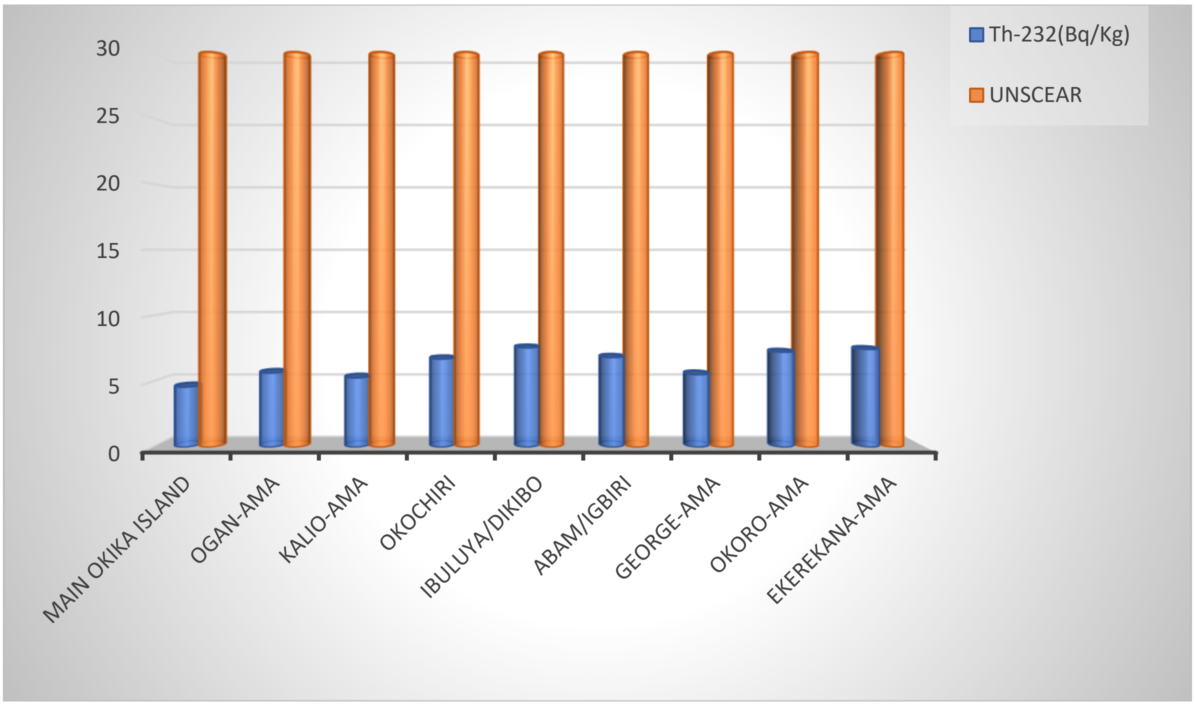


**Fig 12: Comparison of $^{232}$Th activity concentration (Bq/Kg) in soil samples with world average., UNSCEAR, 2000**

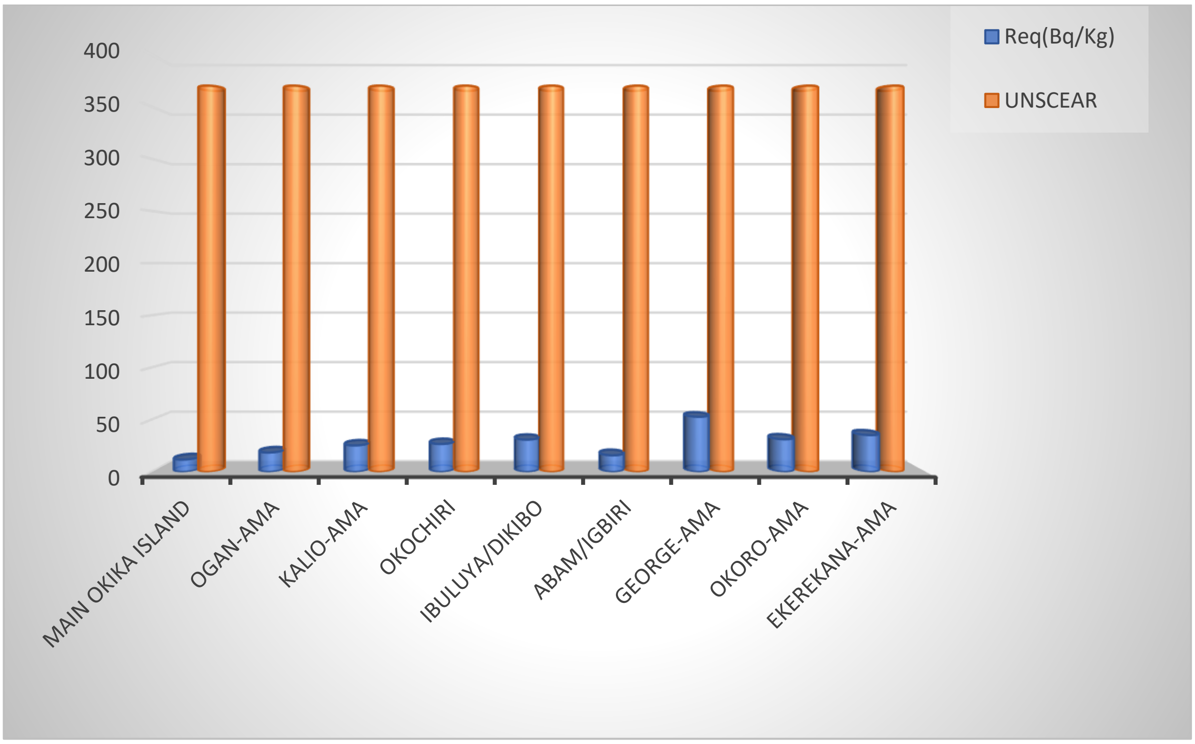


**Fig 13: Comparison of Radium equivalent and world standard., UNSCEAR, 2000**

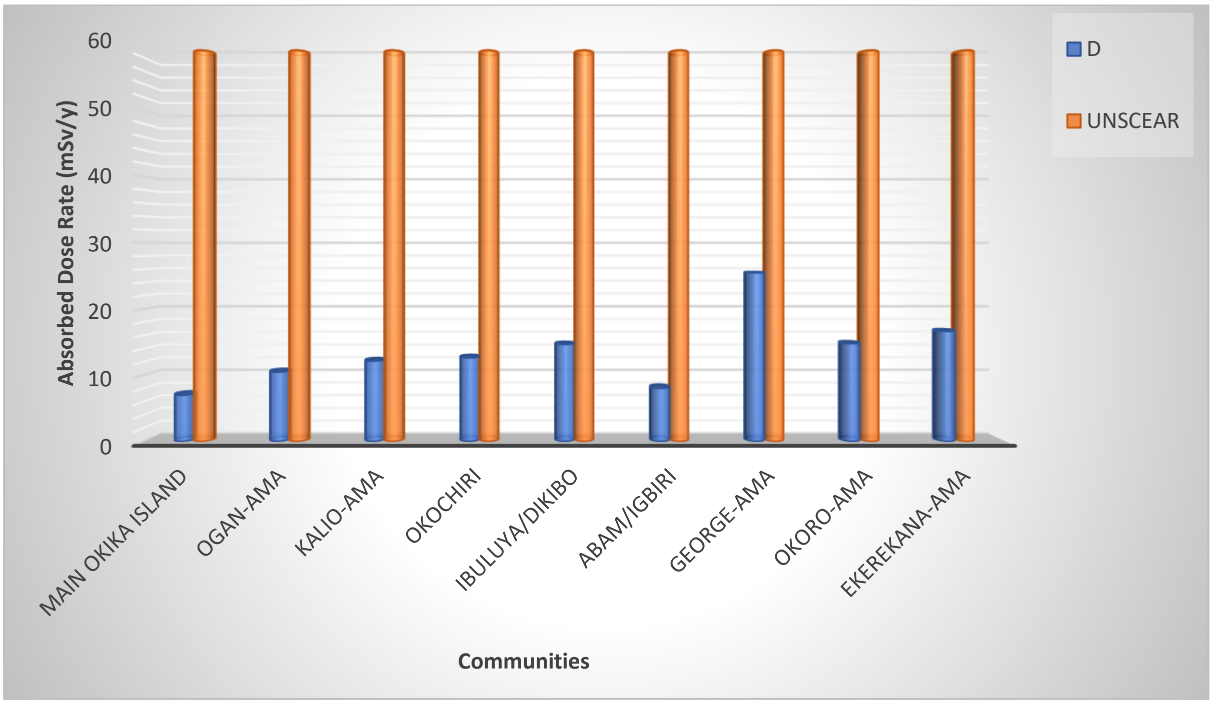


**Fig 14: Comparison of Absorbed Dose Rate ($mSvy^{-1}$) in sediments with world average., UNSCEAR, 2000**

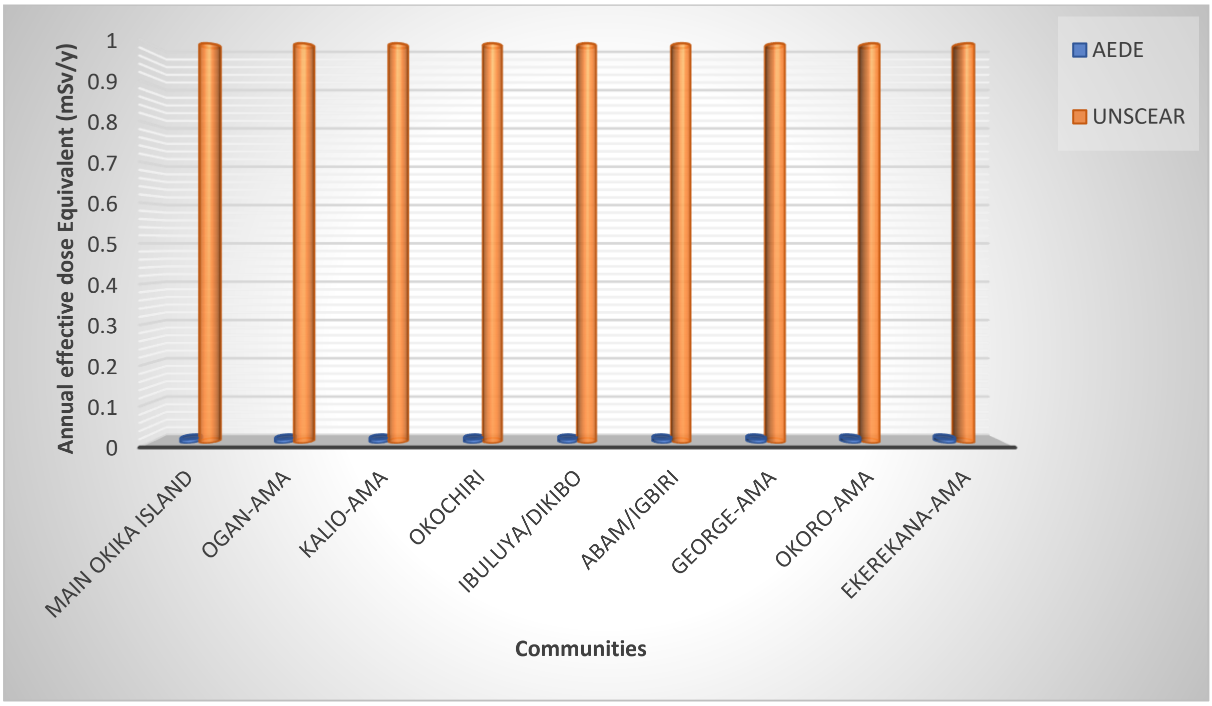


**Fig 15: Comparison of annual effective dose equivalent (mSv/y) in sediments with world average ICRP, 2003**

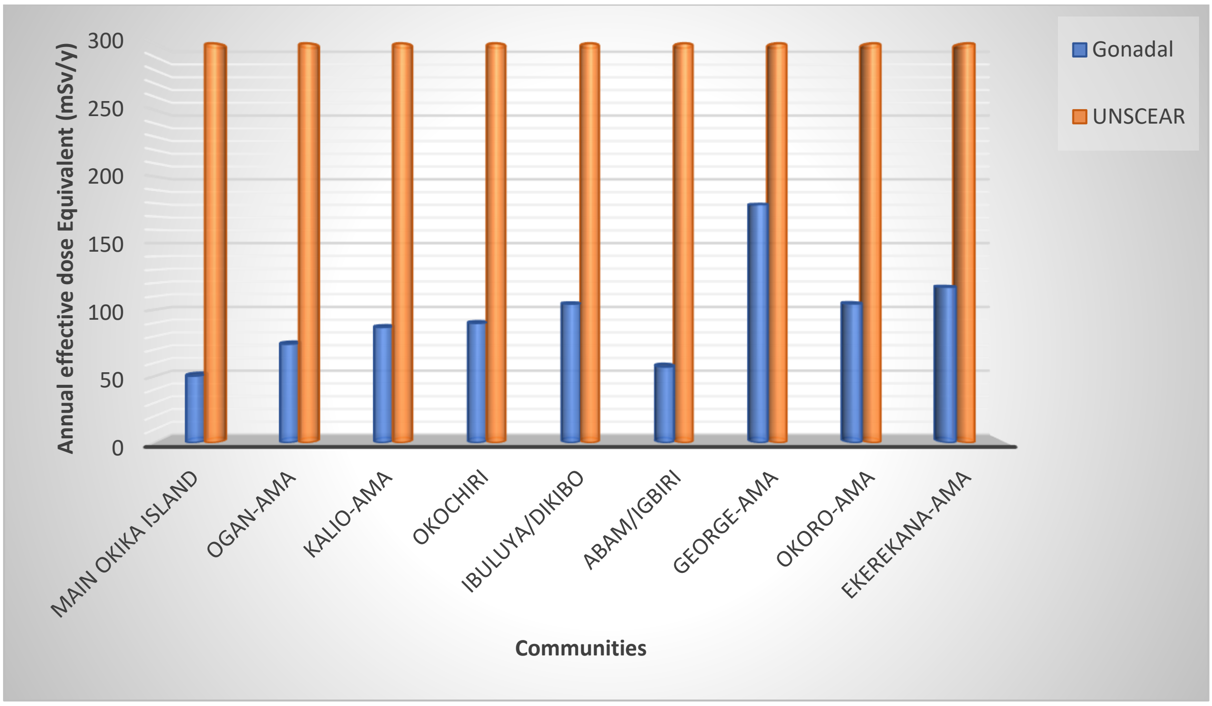


**Fig 16: Comparison of Gonadal (mSv/y) in sediments with world average ICRP, 2003**

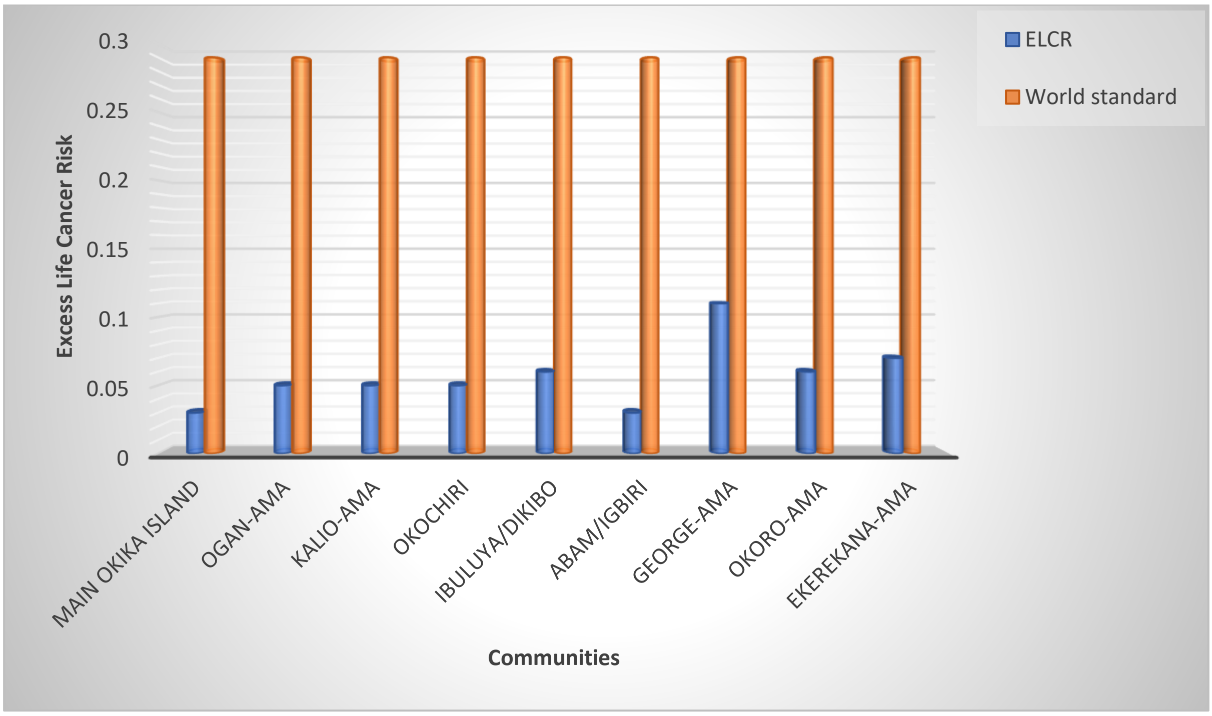


**Fig 17: Comparison of Excess Life Cancer Risk in sediments with world average., UNSCEAR, 2000**

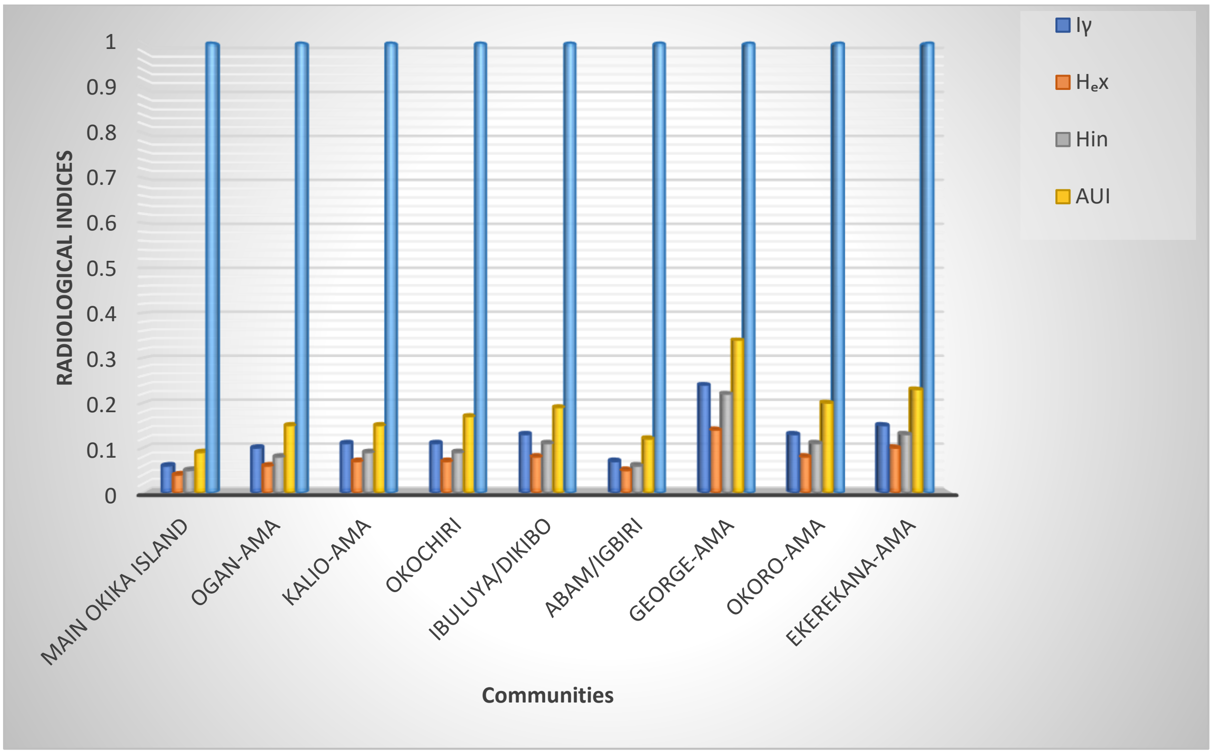


**Fig 18: Comparison Radiological Indices of Soil samples with UNSCEAR, 2000**

**Table 5: Spearman rank correlation of Radionuclides, Radiological hazard indices and Dose parameters**

| S/N | $^{40}$K | $^{238}$U | $^{232}$Th | Raeq | Iγ | $H_{ex}$ | $H_{in}$ | D (nGy/h) | AEDE (mSv/y) | Gonadal (mSv/y) | ELCR x10 $^{-3}$ | AUI (mSv/y) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **$^{40}$K** | 1 | | | | | | | | | | | |
| **$^{238}$U** | 0.867 | 1 | | | | | | | | | | |
| **$^{232}$Th** | 0.283 | 0.450 | 1 | | | | | | | | | |
| **Raeq** | 0.867 | 1.000 | 0.450 | 1 | | | | | | | | |
| **Iγ** | 0.916 | 0.992 | 0.445 | 0.992 | 1 | | | | | | | |
| **$H_{ex}$** | 0.916 | 0.992 | 0.445 | 0.992 | 1.000 | 1 | | | | | | |
| **$H_{in}$** | 0.916 | 0.992 | 0.445 | 0.992 | 1.000 | 1.000 | 1 | | | | | |
| **D (nGy/h)** | 0.867 | 1.000 | 0.450 | 1.000 | 0.992 | 0.992 | 0.992 | 1 | | | | |
| **AEDE (mSv/y)** | 0.767 | 0.913 | 0.420 | 0.913 | 0.884 | 0.884 | 0.884 | 0.913 | 1 | | | |
| **Gonadal (mSv/y)** | 0.867 | 1.000 | 0.450 | 1.000 | 0.992 | 0.992 | 0.992 | 1.000 | 0.913 | 1 | | |
| **ELCR x10 $^{-3}$** | 0.906 | 0.975 | 0.419 | 0.975 | 0.983 | 0.983 | 0.983 | 0.975 | 0.862 | 0.975 | 1 | |
| **AUI (mSv/y)** | 0.845 | 0.996 | 0.469 | 0.997 | 0.983 | 0.983 | 0.983 | 0.996 | 0.917 | 0.996 | 0.979 | 1 |

## Conclusion

The calculated radiological parameters are within the range of the recommended safe limits; this implies that the exposure or use of soil samples to the populace of the Coastal communities of Okrika is radiologically free. In addition, the results of the calculated radiological indices indicates that the soil samples of the Coastal communities of Okrika are radiological safe and can be use as building materials.

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