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*Full Length Research*

# Analysis of the radiological dose and hazards assessment around swampy agricultural soil in Keffi, Nasarawa State, Nigeria

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**ABSTRACT:** The present study analyzes radiological dose and hazard around the swampy agricultural soil in Keffi Local Government Area of Nasarawa State, using determined activity concentration (AC) of $^{238}$U, $^{232}$Th and $^{40}$K obtained from swampy agricultural soil samples, systematically collected from Ten (10) sampled points. Samples collected were further analyzed using a sodium iodide detector for activity concentrations of $^{238}$U, $^{232}$Th and $^{40}$K. The average AC of $^{238}$U, $^{232}$Th and $^{40}$K were 26.73±4.64, 9.77±2.57 and 1115.52 ±67.43 Bq/kg, respectively. The gamma absorbed dose rate ($D_{abs}$) ranges from 6.37E-01 to 2.33E+01 nGy/hr with a mean value of 6.10E+00 nGy/hr. The annual effective dose equivalent (AEDE) ranges from 8.12E-03 to 2.97E-01 *mSv/yr* with an estimated mean value of 7.77E-02 *mSv/yr*. The annual gonadal dose equivalent ranges from 4.48E-02 to 1.72E+01 *mSv/yr* with a mean value of 4.49E-01 *mSv/yr*. The calculated radium equivalent activity ranges from 1.44E+01 to 4.49E+02 Bq/kg with a mean value of 1.18E+02 Bq/kg, which falls below the recommended standard value of 3.7E+02 Bq/kg. The external and internal hazard index ranges from 3.89E-02 to 1.21E+00 *mSv/yr* with a mean value of 3.20E-01 *mSv/yr*, and 3.90E-02 to 1.41E+00 *mSv/yr* with a mean value of 3.70E-01 *mSv/yr*. The gamma hazard index ranges from 5.24E-02 to 1.84E+00 *mSv/yr* with a mean value of 4.83E-01 *mSv/yr*. The activity utilization index ranges from 8.65E-02 to 1.34E+00 *mSv/yr* with a mean value of 3.82E-01 *mSv/yr*, excess life cancer risk (ELCR) for both adult and child was found to be 1.94E-01 and 2.72E-01, respectively, higher than the recommended world average value of 0.29E-03. The high value of ELCR implies that residents around the study area have a high chance of developing cancer over a lifetime. Hence periodic radiological dose and hazard analysis is recommended to keep the exposure as low as reasonably achievable.

**Keywords:** Activity concentration, ALARA, natural occurring radionuclides, radiological dose, radiation exposure, radiological hazard, radiation protection.

## INTRODUCTION

Human activities such as commerce, agriculture, and industry, among others on the earth's surface, have become a major source of concern to the ecosystem and man, in terms of their effects on the environment and human health (Mundi *et al*., 2019; Sangari and Fanen, 2011). The negative health impact of human industrial activities on the environment has been a subject of discussion in contemporary times (Ugbede and Benson, 2018). Presently the human environment is faced with many problems, prominent among which is exposure to background gamma radiation emitted from the natural radioactivity sources that are all over the earth due to substantial primordial radionuclides (Bahreini *et al*., 2020; Haghparast *et al*., 2022).

The human environment has always been exposed daily to natural radionuclides such as $^{238}U$, $^{232}Th$ and $^{40}K$ (Odeleye *et al*., 2019). Natural radioactivity exists in various geological formations such as rocks, soils, water and air. In addition to natural sources, soil radioactivity is also affected by anthropogenic activities (Abbady *et al.,* 2005). The radioactivity concentration in the soil gives information on both natural and man–made sources which are important in radiological monitoring, assessment of radiation dose for the public and also their ability to act as excellent biochemical and geochemical traces in the environment.

Measurement of natural radioactivity is very important to determine the amount of change of the natural background activity with time as a result of radioactivity release (UNSCEAR, 2000). The fluctuation of the background ionizing gamma radiation level depends on the percentage of radio nuclei concentration in the soil, the altitude, and the variation in the geographical conditions of different regions (Shahbazi-Gahrouei *et al*., 2013). The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has reviewed and evaluated global and regional exposures to ionizing radiation sources and the report provides data on individual annual average doses and the ranges of background ionizing gamma radiation from various sources (UNSCEAR, 2000). The background ionizing gamma radiation exposures may be of little or no radiological concern in most parts of the world (UNSCEAR, 2000; Boucher, 2008). In such places, the significance of assessing levels of radiation exposure from various natural components could therefore be to establish the relative importance of each component, or/and to provide baselines against which the radiological impacts of the practices that generate artificial ionizing radiation exposures could be measured (Okeyode *et al*., 2019).

Although the studies of atomic bomb survivors provide strong evidence of health effects such as cancer and non-cancer diseases associated with single acute exposure to moderate and high doses of ionizing radiation, the effect of low dose rates on health and cancer risks after exposure to ionizing radiation is, as yet, unclear (UNSCEAR, 2000; Eka *et al.*, 2021). However, it is encouraged that investigations are made to some of these regions where a high level of background ionizing gamma radiation is observed to evaluate its hazard and long-term effect as a result of exposure to both high and low-level exposures to this occurring natural radiation (Emmanuel *et al*., 2020, Ugbede and Benson, 2018).

The evaluation of radiation exposure and its effects on the environment has drawn significant attention on a global scale. This is because ionizing radiation harms biological tissues and has a negative impact on health. Leukaemia, chronic lung cancer, cataracts, acute leucopoenia, anaemia necrosis of the mouth, and chronic lung illness are some of the health consequences due to long-term radiation exposure. It is customary to monitor and assess the radiation level to keep the exposure as low as reasonably achievable in accordance with the ALARA principle due to human activities that increase the radionuclide content and radiation level of the environment (Joseph *et al*., 2022; Oduh *et al.*, 2022; Ugbede and Benson, 2018).

The purpose of this present study is to analyze radiological dose and hazard around the swampy agricultural soil in Keffi Local Government Area (LGA) of Nasarawa State, Nigeria using the determined activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ obtained from swampy agricultural soil sample. Radiological dose assessment was evaluated for absorbed dose rate, annual effective dose equivalent and annual gonadal dose equivalent while radiological hazard assessment was evaluated for radium equivalent activity, external and internal hazard index, gamma index, activity utilization index as well as excess life cancer risk. The present study is limited to the analysis of radiological dose and hazards around swampy agricultural soil in Keffi LGA.

Several studies were conducted on the determination of activity concentration and dose analysis from soil and rock samples in different regions around the world. However, there seems to be no data or any related research conducted on radioactivity concentration from swampy agricultural soil within the chosen area of study considering the fact that a lot of mining activities have been going on in the region for quite a long period which may give rise to radiation exposure in the area (Azhdarpoor *et al.,* 2021; Najam *et al.,* 2022; Joseph *et al.,* 2023; Hamoo *et al*., 2020; Yusuf *et al.,* 2022; Soja *et al.,* 2023; Dauda *et al*., 2022; Reuben *et al*., 2023)

Famous international organizations like the International Commission on Radiological Protection (ICRP) and the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) have established standards and implemented stringent procedures to prevent such exposure for both workers and the general public (UNSCEAR, 2000; ICRP, 2007). According to current ICRP recommendations, which are based on thorough research, there is no safe level of radiation exposure and even very small doses of radiation have the potential to cause stochastic effects like cancer. The fundamental standard of protection at all exposure levels is ALARA, which keeps exposure below public dose limits.

$^{238}U$ is a naturally occurring radioactive substance having a wide variety of daughter radionuclides, the majority of which are short-lived. For radiation protection and safety, the most important radionuclides are $^{210}Pb$, $^{210}Po$, $^{230Th}$, $^{226}Ra$, $^{234}U$ and $^{238}U$ because of their long half-life. Gaseous decay of Radon ($^{222}Rn$), Thoron ($^{220}Rn$), and its progenies are alpha emitters and contribute to inhalation exposure dose with a half-life ($T_{1/2}$) of 3.6 days. The $^{214}Bi$, which has a gamma energy peak of 609 KeV,

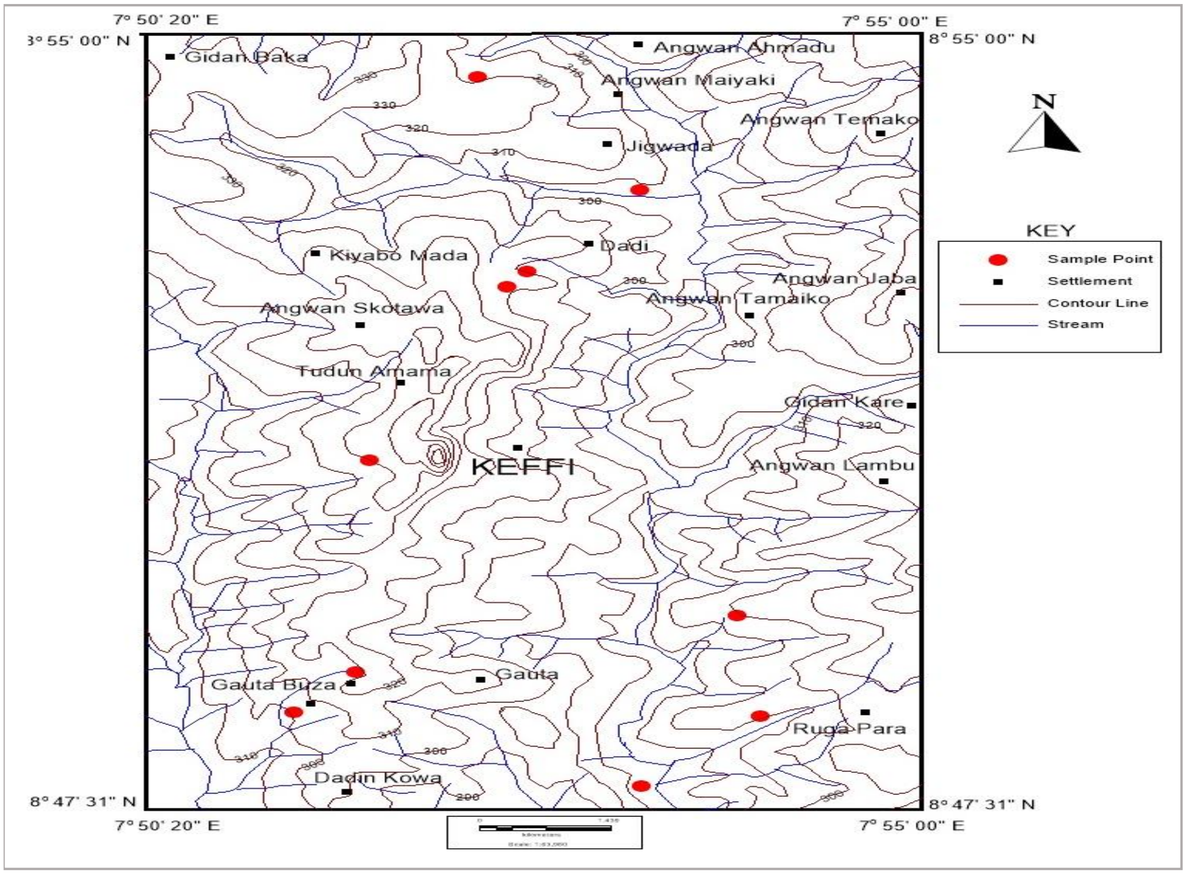


**Figure 1.** Map of the study area.

contributes to external exposure. In the thorium decay chain, radionuclides of interest include $^{232}$Th, $^{228}$Ra, and $^{228}$Th, as well as $^{220}$Rn and its daughter radionuclide. In comparison to the daughter radionuclides of the $^{238}$U decay, $^{232}$Th have short half-lives. The airborne concentrations of $^{232}$Th, $^{228}$Ra, $^{228}$Th, and $^{220}$Rn are used to calculate the inhalation dosage for the thorium series. Only long-lived radionuclides such as $^{232}$Th, $^{228}$Ra, and $^{228}$Th are used to compute the ingestion dose. Naturally occurring potassium contains only a modest amount of radioactive $^{40}$K (approximately 0.012 %). In addition to $^{40}$K, there are several other radioactive isotopes of potassium. Because these isotopes all have half-lives of less than one day, they are less important in dose calculations. It decays to $^{40}$Ca and $^{40}$Ar by emitting 89% beta particle and 11% gamma ray. (IAEA, 2013; Haridasan, 2015; Bajoga *et al.,* 2019).

## METHODOLOGY

### Description of the study

Keffi Local Government Area (LGA) is located in Nasarawa State, North-Central Geopolitical Zone of Nigeria and lies between latitude: 8° 50' 47.44" N and longitude: 7° 52' 24.74" E and occupies a total area of 138 square kilometres with an average temperature of 30 degrees centigrade. The town is approximately 50 km away from the Federal Capital Territory, Abuja. The area witnesses two major seasons, dry and rainy seasons while the average humidity level is put at 42 percent. Several mineral deposits are present including tin and columbite amongst others. Farming constitutes one of the major economic activities in the area in addition to trading, animal rearing and craftsmanship. The Geographical map of Keffi, showing the description of the study area and the geopoints is presented in Figure 1.

### Sample collection and analysis

Soil samples were collected at strategic locations around the swampy agricultural area using a systematic random sampling technique, at a depth of 15 cm. A shovel, cutlass and hoe were used for sample collections. Soil samples were systematically collected from ten (10) sampling points and the corresponding geographical coordinates, as well as the exposure rate reading, were taken using a

**Table 1.** Comparison between Radon ($^{222}$Rn) and Thoron ($^{220}$Rn).

| Isotope | Radon | Thoron | Potassium |
|---|---|---|---|
| Origin of nuclide | U-238 | Th-232 | K-40 |
| Short-lived progeny | $^{218}$Po, $^{214}$Pb, $^{214}$Bi ($^{214}$Po) | $^{212}$Pb, $^{212}$Bi ($^{212}$Po) | $^{40}$Ar, $^{40}$Ca |
| Decay mode | Alpha Decay | Alpha Decay | Beta and Gamma |
| Half life | 3.8 days | 55.6 sec | 1.3 billion years |
| Significant alpha energy | 6.0 MeV ($^{218}$Po)<br>7.7 MeV ($^{214}$Po) | 6.1 MeV ($^{212}$Bi)<br>8.8 MeV ($^{212}$Po) | - |
| Equilibrium factors | 0.2 to 0.6 | 0.02 | - |

Global Positioning System (GPS) with model number German 301. Background ionizing radiation was measured using a hand-held factory-calibrated inspector Alert Nuclear radiation survey meter with serial number 35440, manufactured by SE International Inc, USA. The meter sensitivity is 3500 CPM/mRh$^{-1}$ referenced to Cs-137 with maximum alpha and beta efficiencies of 18 and 33% respectively and radiation monitoring instruments at each sampling point were recorded. It has a 45 mm effective diameter halogen-quenched Geiger-Muller detector tube with a mica window density of 1.5 to 2.0 mg. The measurement was performed using a cm$^2$ that, according to the operational manual, is capable of detecting x-rays and subatomic particles in the temperature range of -10 to 50°C. The environmental measurement capabilities of the Inspector Alert Nuclear radiation survey monitor were noted. With a 5 per cent error value, the equipment has a high degree of precision. It has exceptionally high levels of sensitivity and dependability. Despite being portable, it offers specified information on detection, weather protection, and ease of use. Samples collected were placed in a sealed labelled polythene bag to avoid cross-contamination during transportation and numbered accordingly. The samples were dried at room temperature in the open air for seven days to remove moisture, while stony samples were grinded into powdery form using mortar and pestle and sieved with a wire mesh with holes of thickness 0.5 mm to attain homogeneity of sample size. Approximately 500 g mass was retained in ziplock polythene bags for 28 days to attain secular equilibrium between Ra-226 and Th-232 and their progeny before being taken to the laboratory for analysis. The attainment of secular equilibrium is vital since the NORM radionuclides considered in this present study have extremely long half-lives. Soil samples collected were analyzed to determine the radioactivity concentration levels of $^{238}$U, $^{232}$Th, and $^{40}$K using Gamma-ray spectroscopy with a well-calibrated NaI (Tl) detector system at the Centre for Energy Research and Training (CERT) Laboratory, at Ahmadu Bello University Zaria. The summary table showing the properties of $^{238}$U, $^{232}$Th and $^{40}$K radionuclides alongside a comparison of their Progeny is presented in Table 1.

## Radiological dose assessment

### *Absorbed dose rate*

The Absorbed Dose Rate ($\mathrm{D_{abs}}$) in the air measured at 1 m above the ground from the ground surface assesses the external exposure of gamma radiation from the measured activity concentration (AC) of $^{238}$U, $^{232}$Th and $^{40}$K by applying the conversion factors of 0.462, 0.604 and 0.0417 for $^{238}$U, $^{232}$Th and $^{40}$K respectively using equation 1 expressed by UNSCEAR (2000).

$$\mathrm{D_{abs}}(\mathrm{nGy}.hr^{-1}) = 0.462\mathrm{AC}_{U-238} + 0.604\mathrm{AC}_{\mathrm{Th}-232} + 0.0417\mathrm{AC}_{\mathrm{K}-40} \quad (1)$$

The absorbed dose limit was 60 nGy/hr (UNSCEAR, 2000).

### *Annual effective dose equivalent*

The annual effective dose equivalent (AEDE) γ-rays for adult exposure was estimated using equation (1) and is expressed as equation 2. This equation (2) takes into account the conversion factor $F_\gamma$ value of 0.7 SvGy$^{-1}$ of absorbed dose in the air to the effective dose an adult received and the annual exposure time ($T_{exp}$) of 1820 hr y$^{-1}$ (7hr/d x 5d/wk x 52wk/yr) as expressed by Hilal *et al*. (2014).

$$AEDE_{eq} = D_{abs} \times \mathrm{F}_{\gamma} \times \mathrm{T}_{exp} \quad (2)$$

For occupational exposure, the AEDE (*mSv/yr*) resulting from the absorbed dose values ($D_{abs}$) can be calculated using equation (3):

$$\mathrm{AEDE}(mSv/yr) = \mathrm{D_{abs}}(\mathrm{nGy}.hr^{-1}) \times 0.2 \times 1820\ (\mathrm{h.}yr^{-1}) \times 0.7\ (Sv.Gy^{-1}) \times 10^{-6} \quad (3)$$

Where 0.2 represents the occupational factor. The annual effective dose of g-rays must be less than the global average of 0.460 mSv. y$^{-1}$ (UNSCEAR, 2000).

### *Annual gonadal dose equivalent*

Annual gonadal dose equivalent ($AGDE_G$) represent the annual equivalent dose received each year by gonads for the exposed population (Fall *et al*., 2023), and can be calculated from the measured activity concentration (AC) of $^{238}U$, $^{232}Th$ and $^{40}K$ obtained from swampy agricultural soils using conversion factorst of 3.09 for AC of $^{238}U$, 4.18 for AC of $^{232}Th$ and 0.314 for AC of $^{40}K$ using equation (4) (Morsy *et al*., 2012; Kolo *et al*., 2015).

$$\mathrm{AGDE_G}(\mu Sv.y^{-1}) = 3.09\mathrm{AC}_{U-238} + 4.18\mathrm{AC_{Th-232}} + 0.314\mathrm{AC_{K-40}} \quad (4)$$

**Radiological hazard analysis**

Studies have shown that about 98% of radiological effects linked to $^{238}U$ and $^{232}Th$ decay series are a result of gaseous decay products resulting in the emission of alpha (α) which is harmful when inhaled. Usually from swampy agricultural soil, natural activity concentration is determined by $^{238}U$, $^{232}Th$ and $^{40}K$ (Hilal *et al*., 2014; Fall *et al*., 2023). In order to analyse the radiological hazards, certain parameters including radium equivalent activity ($Ra_{eqv}$), external and internal hazard indices ($H_{ex}$, $H_{in}$), gamma index (Iγ) and activity utilization index (AUI) were estimated. These indices contribute significantly to health risk if they are greater than the world recommended avaerage value (Fall *et al*., 2023).

***Radium Equivalent Activity***

Radium equivalent activity ($Ra_{eq}$) accounts for the non-uniform distribution of radionuclides in the soil samples. Radioactivity was defined in terms of radium-equivalent which constitutes one of the most calculated parameters in determination of radiological hazards and can be determined using the weighted sum of activity concentrations (AC) of $^{232}U$, $^{232}Th$ and $^{40}K$ as expressed by equation 4 (Berekta *et al*., 1985, Mantazul *et al*., 1998).

$$Ra_{eq}(Bq.kg^{-1}) = AC_{U-238} + 1.43\mathrm{AC}_{Th-232} + 0.077\mathrm{AC}_{K-40} \quad (5)$$

Where $AC_{U-238}$, $AC_{Th-232}$ and $AC_{K-40}$ are the specific activities of $^{238}U$, $^{232}Th$ and $^{40}K$ in $Bqkg^{-1}$ respectively.

***External and Internal Hazard Index***

External Hazard Index ($H_{ex}$) evaluates the external hazard due to emmited gamma rays which is produced from radium equivalent activity and is evaluated to limit the activity concentration (AC) of *$^{238}U$, $^{232}Th$* and *$^{40}K$* to ensure that a permissible dose rate of less than 1 mSv/y as expressed by equation 6 (Fall *et al*, 2023; Iqbal, 2000).

$$\mathrm{H_{ex}} = \frac{\mathrm{AC_{U-238}}}{370\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{Th-232}}}{259\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{K-40}}}{4810\mathrm{Bq.kg}-1} \leq 1 \quad (6)$$

Where $AC_{U-238}$, $AC_{Th-232}$ and $AC_{K-40}$ are the specific activities of $^{238}U$, $^{232}Th$ and $^{40}K$ in $Bq.kg^{-1}$ respectively.

The Internal Hazard index was used to assess internal exposure to carcinogenic radon and can be extimated using equation 7 as expressed by Fall *et al*. (2023).

$$\mathrm{H_{in}} = \frac{\mathrm{AC_{U-238}}}{185\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{Th-232}}}{259\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{K-40}}}{4810\mathrm{Bq.kg}-1} \leq 1 \quad (7)$$

Where $AC_{U-238}$, $AC_{Th-232}$ and $AC_{K-40}$ are the specific activities of $^{238}U$, $^{232}Th$ and $^{40}K$ in $Bq.kg^{-1}$ respectively.

***Gamma Index***

By using the gamma index (Iγ), it is possible to assess the levels of natural radionuclides in a sample of damp agricultural soil in order to assess the risks imposed on by gamma radiation. It serves as a noble test parameter for radionuclides that might be detrimental to human health. The gamma index was determined using Equation (8) as expressed by the European commission (Abdelbary *et al*., 2019).

$$\mathrm{I}_\gamma = \frac{\mathrm{AC_{U-238}}}{300\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{Th-232}}}{200\mathrm{Bq.kg}-1} + \frac{\mathrm{AC_{K-40}}}{3000\mathrm{Bq.kg}-1} \quad (8)$$

Where $AC_{U-238}$, $AC_{Th-232}$ and $AC_{K-40}$ are the specific activities of $^{238}U$, $^{232}Th$ and $^{40}K$ in $Bq.kg^{-1}$ respectively.

The European commission recomends that the exemption dose criterion of 0.3 *mSv/yr* correspond to Iγ lower than 0.5 and the 1 *mSv/yr* exemption dose correspond to Iγ lower than 1. However, these dose criteria are accepted if Iγ is less than unity corresponding to the effective annual dose (Abdelbary *et al*., 2019). Hence, it is recommended to controls dose between 0.3 and 1 *mSv/yr* (El-Gamal *et al*., 2018).

***Activity Utilization Index***

The activity utilization index ($AUI_a$) represents the ambient air dose rate of several combinations of the three radionuclides *$^{238}U$, $^{232}Th$* and *$^{40}K$* in the swampy agricultural soil sample. It can be estimated using Equation (9) by applying a seemly conversion factors for each corresponding radionuclides as expressed by Kolo *et al*., (2015).

$$\mathrm{AUI}_a = \frac{\mathrm{AC_{U-238}}}{50\mathrm{Bq.kg}-1}\mathrm{CF_{U-238}} + \frac{\mathrm{AC_{Th-232}}}{50\mathrm{Bq.kg}-1}\mathrm{CF_{Th-232}} + \frac{\mathrm{AC_{K-40}}}{500\mathrm{Bq.kg}-1}\mathrm{CF_{K-40}} \quad (9)$$

$Cf_{U-238}$ (0.462) $Cf_{Th-232}$ (0.604) and $Cf_{K-40}$ (0.041) represent the appropriate conversion factors from the measured activities of the radionuclides to the dose rate of gamma radiation in the air (Fall *et al*., 2023; Abdelbary *et al*., 2019). The permissible levels for specific activities per unit weight of U-238, Th-232 and K-40 in the NORM scale residue of swampy agricultural soil are 50, 50 and 500 Bq/kg respectively (Fall *et al*., 2023; Abdelbary *et al*., 2019; NEA, 1979).

### *Excessive Life Cancer Risk*

Excess life cancer risk (ELCR) is determined by the product of determined AEDR with the duration of life (DL), 70 years for children and 50 years for adults and low dose background radiation risk factor (RF) of 5% for public exposure considered to produce the stochastic effect (Abba and Sanni, 2023).

$$\mathrm{ELCR} = \mathrm{AEDE} \times \mathrm{RF} \times \mathrm{DL} \qquad (10)$$

## RESULTS AND DISCUSSIONS

### Measured exposure rate and geographical coordinates

The measured exposure rate and geographical coordinates of swampy agricultural soil samples systematically collected from ten (10) sampled points alongside measured exposure rate and elevation from Keffi LGA are presented in Table 2. The measured exposure rate ranges from 0.013 to 0.230mR/hr with an average value of 0.0527mR/hr.

### Measured activity concentration

The activity concentrations of of $^{238}$U, $^{232}$Th and $^{40}$K were determined using sodium iodide detector and the results are presented in Table 3. It shows the average activity concentration (AC) of $^{238}$U, $^{232}$Th and $^{40}$K obtained from swampy agricultural soil samples from Keffi LGA. The average AC of $^{238}$U, $^{232}$Th and $^{40}$K were 26.73±4.64, 9.77±2.57 and 1115.52 ±67.43 Bq/kg, respectively. The values of $^{238}$U and $^{232}$Th are lower than the UNSCEAR recommended values of 32 Bq/kg and 45 Bq/kg, respectively while that of $_{40}$K is higher than the world recommended value of 420 Bq/kg. The distribution of AC of $^{238}$U, $^{232}$Th and $^{40}$K varies based on the geological and geophical formation of the sampling area. Higer AC value of $^{40}$K was reported at the first and sixt sampling locations with sampling code KF1 and KF6, which corresponds to the higher dose rate of 0.230 mR/hr and 0.16 mR/hr when compared to the other sampling points.

### Radiological dose assessment

From Table 4, the Gamma absorbed dose rate obtained within the swampy agricultural land in Keffi site using equation 1 ranges from 6.37E-01 to 2.33E+01 nGy/hr with mean value of 6.10E+00 nGy/hr. The mean value is above the recommended standard value of 6.00E+00 nGy/hr. The variation in distribution of the gamma absorbed dose rate around the sampling point may be due to high radinuclide concentration of $^{238}$U, $^{232}$Th and $^{40}$K and their decay products widely distributed around the swampy agricultural land in Keffi.The radionuclides associated with them are redistributed thereby enhancing the radiation level within the swampy agricultural soil. Conclusively, the measured gamma absorbed dose rates are slightly lower than global average natural dose of background ionizing radiation as reported by UNSCEAR (2008).

Also from Table 4, the AEDE obtained from the swampy agricultural soil in Keffi using equation 3 ranges from 8.12E-03 to 2.97E-01 *mSv/yr* with an estimated mean value of 7.77E-02 *mSv/yr* are as a result of elevated concentration of natural radionuclides of $^{238}$U, $^{232}$Th and $^{40}$K and their decay products are widely spread within the swampy agricultural soil as reported by Ugbede *et al*. (2017). These radionuclides and the radiation they emit are primarily influenced by the environment's geological and geophysical circumstances. The values are lower than the permissible public dose limit of 1.00 *mSv/yr* as recommended by ICRP (2007) and UNSCEAR (2008).This shows that there are no acute radiological health effects from the swampy agricultural soil obtained from Keffi on the general public as a result of background ionizing radiation (BIR) exposure in the studied locations, which are in good accord with the permissible limit. However, in order to ensure that radiation exposure within the areas is kept to as low as reasonably achievable, periodic evaluations of the activity concentration of natural radionuclides and BIR levels in the study area should be conducted.

The AGDE obtained from the swampy agricultural soil in Keffi using equation 4 ranges from 4.48E-02 to 1.72E+01 *mSv/yr* with an estimated mean value of 4.49E-01 *mSv/yr* as a result of elevated concentration of natural radionuclides of $^{238}$U, $^{232}$Th and $^{40}$K and their decay products are widely spread within the swampy agricultural soil (Yani *et al*., 2023). These radionuclides are primarily influenced by the geological and geophysical nature of the environment. The values are lower than the permissible public dose `limit of 0.3 *mSv/yr* as recommended by UNSCEAR (2008).

### Radiological hazard analysis

From Table 5, the calculated Radium Equivalent Activity within the swampy agricultural soil in the Keffi site using equation 5 ranges from 1.44E+01 to 4.49E+02 Bq/kg with a mean value of 1.18E+02 Bq/kg. The mean value is below the recommended standard value of 3.7E+02 Bq/kg. The disparity in the dissemination of the values obtained around the sampling point may be due to the geological

**Table 2.** Measured exposure rate and their geopoints and elevation for swampy agricultural soils in Keffi, Nasarawa State.

| Sampling code | Geopoints | | Elevation (m) | Exposure rate (mR/hr) |
|---|---|---|---|---|
| | Longitude | Latitude | | |
| KF1 | $8^0$52'33.48'' N | $7^0$52'30.52'' E | 308 | 0.230 |
| KF2 | $8^0$52'42.21'' N | $7^0$52'37.35'' E | 322 | 0.020 |
| KF3 | $8^0$54'35.29'' N | $7^0$52'19.49'' E | 315 | 0.017 |
| KF4 | $8^0$53'28.86'' N | $7^0$53'17.74'' E | 294 | 0.016 |
| KF5 | $8^0$50'53.57'' N | $7^0$51'40.68'' E | 330 | 0.015 |
| KF6 | $8^0$48'50.72'' N | $7^0$51'35.90'' E | 317 | 0.160 |
| KF7 | $8^0$48'27.46'' N | $7^0$52'26.15'' E | 298 | 0.019 |
| KF8 | $8^0$47'44.42'' N | $7^0$53'18.24'' E | 274 | 0.021 |
| KF9 | $8^0$49'03.18'' N | $7^0$53'49.55'' E | 280 | 0.013 |
| KF10 | $8^0$49'23.48'' N | $7^0$53'52.69'' E | 295 | 0.016 |

**Table 3.** Measured activity concentration and elevation for swampy agricultural soils in Keffi, Nasarawa State.

| Sampling code | Activity Concentration (Bq/kg) | | | Elevation (m) |
|---|---|---|---|---|
| | U-238 | Th-232 | K-40 | |
| KF1 | 73.37 ±8.97 | 25.22±1.50 | 4404.21±226.33 | 308 |
| KF2 | 36.53±4.32 | 12.78 ±0.76 | 849.12±144.13 | 322 |
| KF3 | BDL | 9.48 ± 0.56 | 525.75 ±27.44 | 315 |
| KF4 | 7.46±0.92 | 4.34±0.26 | 292.87±15.36 | 294 |
| KF5 | BDL | 9.55±10.55 | 812.66±41.07 | 330 |
| KF6 | 19.77±2.28 | 6.04±0.36 | 1171.31± 60.27 | 317 |
| KF7 | BDL | 8.45 ± 0.50 | 30.09±1.59 | 298 |
| KF8 | 25.61±13.08 | 9.47±0.56 | 1757.88±90.19 | 274 |
| KF9 | 23.67±2.85 | 8.27 ±0.49 | 944.84±48.80 | 280 |
| KF10 | 0.71± 0.09 | 4.13 ±10.25 | 366.50 ±19.15 | 295 |
| Mean | 26.73±4.64 | 9.77±2.57 | 1115.52 ±67.43 | |
| UNSCEAR World Average | 32 | 45 | 420 | |

Note: BDL – Below Detection Limit.

**Table 4.** Calculated radiological dose assessment from swampy agricultural soils in Keffi, Nasarawa State.

| Sampling code | $D_{abs}$ (nGy/hr) | AEDE (*mSv/yr*) | AGDE (*mSv/yr*) |
|---|---|---|---|
| KF1 | 2.33E+01 | 2.97E-01 | 1.72E+00 |
| KF2 | 6.00E+00 | 7.64E-02 | 4.33E-01 |
| KF3 | 2.77E+00 | 3.52E-02 | 2.05E-01 |
| KF4 | 1.83E+00 | 2.33E-02 | 1.33E-01 |
| KF5 | 3.97E+00 | 5.05E-02 | 2.95E-01 |
| KF6 | 6.16E+00 | 7.85E-02 | 4.54E-01 |
| KF7 | 6.37E-01 | 8.12E-03 | 4.48E-02 |
| KF8 | 9.04E+00 | 1.15E-01 | 6.68E-01 |
| KF9 | 5.53E+00 | 7.05E-02 | 4.04E-01 |
| KF10 | 1.81E+00 | 2.31E-02 | 1.35E-01 |
| **Mean** | **6.10E+00** | **7.77E-02** | **4.49E-01** |
| Min | 6.37E-01 | 8.12E-03 | 4.48E-02 |
| Max | 2.33E+01 | 2.97E-01 | 1.72E+00 |
| World Standard | 6.00E+00 | 1 | 0.3 |

**Table 5.** Calculated radiological hazard parameters from swampy agricultural soils in Keffi, Nasarawa State.

| Sampling code | Raeq (Bq.kg) | $H_{ex}$ | $H_{in}$ | Iγ | $AUI_a$ | ELCR (A) (x $10^{-3}$) | ELCR (C) (x $10^{-3}$) |
|---|---|---|---|---|---|---|---|
| KF1 | 4.49E+02 | 1.21E+00 | 1.41E+00 | 1.84E+00 | 1.34E+00 | 7.41E-01 | 1.04E+00 |
| KF2 | 1.20E+02 | 3.25E-01 | 4.23E-01 | 4.69E-01 | 5.62E-01 | 1.91E-01 | 2.68E-01 |
| KF3 | 5.41E+01 | 1.46E-01 | 1.46E-01 | 2.23E-01 | 1.58E-01 | 8.81E-02 | 1.23E-01 |
| KF4 | 3.62E+01 | 9.78E-02 | 1.18E-01 | 1.44E-01 | 1.45E-01 | 5.82E-02 | 8.15E-02 |
| KF5 | 7.63E+01 | 2.06E-01 | 2.06E-01 | 3.19E-01 | 1.82E-01 | 1.26E-01 | 1.77E-01 |
| KF6 | 1.19E+02 | 3.20E-01 | 3.74E-01 | 4.87E-01 | 3.52E-01 | 1.96E-01 | 2.75E-01 |
| KF7 | 1.44E+01 | 3.89E-02 | 3.90E-02 | 5.24E-02 | 1.05E-01 | 2.03E-02 | 2.84E-02 |
| KF8 | 1.74E+02 | 4.69E-01 | 5.35E-01 | 7.15E-01 | 4.86E-01 | 2.88E-01 | 4.03E-01 |
| KF9 | 1.08E+02 | 2.92E-01 | 3.56E-01 | 4.35E-01 | 3.96E-01 | 1.76E-01 | 2.47E-01 |
| KF10 | 3.48E+01 | 9.41E-02 | 9.60E-02 | 1.45E-01 | 8.65E-02 | 5.77E-02 | 8.07E-02 |
| **Mean** | **1.18E+02** | **3.20E-01** | **3.70E-01** | **4.83E-01** | **3.82E-01** | **1.94E-01** | **2.72E-01** |
| Min | 1.44E+01 | 3.89E-02 | 3.90E-02 | 5.24E-02 | 8.65E-02 | 2.03E-02 | 2.84E-02 |
| Max | 4.49E+02 | 1.21E+00 | 1.41E+00 | 1.84E+00 | 1.34E+00 | 7.41E-01 | 1.04E+00 |
| Standard | 370 | <1 (0.45) | <1 (0.45) | <1 (0.5) | 1 | 0.29E-03 | 0.29E-03 |

distribution of radinuclide concentrations of $^{238}U$, $^{232}Th$ and $^{40}K$ and their decay products widely distributed around the swampy agricultural soil in Keffi. Consequently, these residues pose little radiological hazards to the public. However, modern ICRP recommendations were based on the thoughtful assumption that there is no safe dose of radiation, and even the smallest dose of radiation has a tendency to result in stochastic effects in the long run.

Table 5 further shows the external and internal hazard index obtained from the swampy agricultural soil in Keffi site using equations 6 and 7 ranges from 3.89E-02 to 1.21E+00 *mSv/yr* with a mean value of 3.20E-01 *mSv/yr* for external hazard index, and 3.90E-02 to 1.41E+00 *mSv/yr* with a mean value of 3.70E-01 *mSv/yr* internal hazard index. The mean calculated values of both external and internal hazard index are less than unity and below the recommended standard limit of less than 1 (0.45 *mSv/yr*). The values show that the hazards posed by the activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ and their decay products around the swampy agricultural soil in Keffi pose minimal radiological hazards to the public and dwellers.

The gamma hazard index obtained from swampy agricultural soil in Keffi using equation 8 ranges from 5.24E-02 to 1.84E+00 *mSv/yr* with a mean value of 4.83E-01 *mSv/yr* which is below the recommended dose limit of 1 *mSv/yr* as recommended by the ICRP. The result implies that the dose from gamma radiation poses minimal hazard with no deterministic effect, however, the chances of stochastic effects is possible over time.

The activity utilization index (AUI) calculated from swampy agricultural soil in Keffi using equation 9 ranges from 8.65E-02 to 1.34E+00 *mSv/yr* with a mean value of 3.82E-01 *mSv/yr* which is below the recommended dose limit of 1 *mSv/yr* as recommended by the ICRP. The result implies that the dose from activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ alongside their decay products widely distributed around the swampy agricultural soil in Keffi poses minimal hazard with no deterministic effect, however, the chances of stochastic effects are possible over time.

The excess lifetime cancer risk is used in radiation protection assessment to determine the likelihood that a person would ever get cancer as a result of exposure to low radiation doses. Using equation 10, the average ELCR for both adults and children within the study area are 1.94E-01 and 2.72E-01. These values are higher than the recommended world average of 0.29E-03. The implication of the high value of ELCR is that residents dwelling around the study have a high chance of developing cancer over a lifetime. Also, consuming agricultural produce might also contribute to ingestion dose as a result of soil to plant transfer factor.

### Distribution of radiological dose assessment

Figure 2 shows the distribution of annual effective dose equivalent and annual gonaldal dose equivalent calculated from determined activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ obtained around the swampy agricultural soil in Keffi. The AGDE obtained from sampling point 1 (KF1) is higher than the recomended dose limit when compared with other sampling points. The high AGDE is due to the difference in geological formation of the study area which influence the distribution of radionuclides within the study area. The overal assessment from the ten (10) sampling points shows that AGDE are higher than the AEDE with AEDE all lower than the recommended public dose limit of 1 *mSv/yr*.

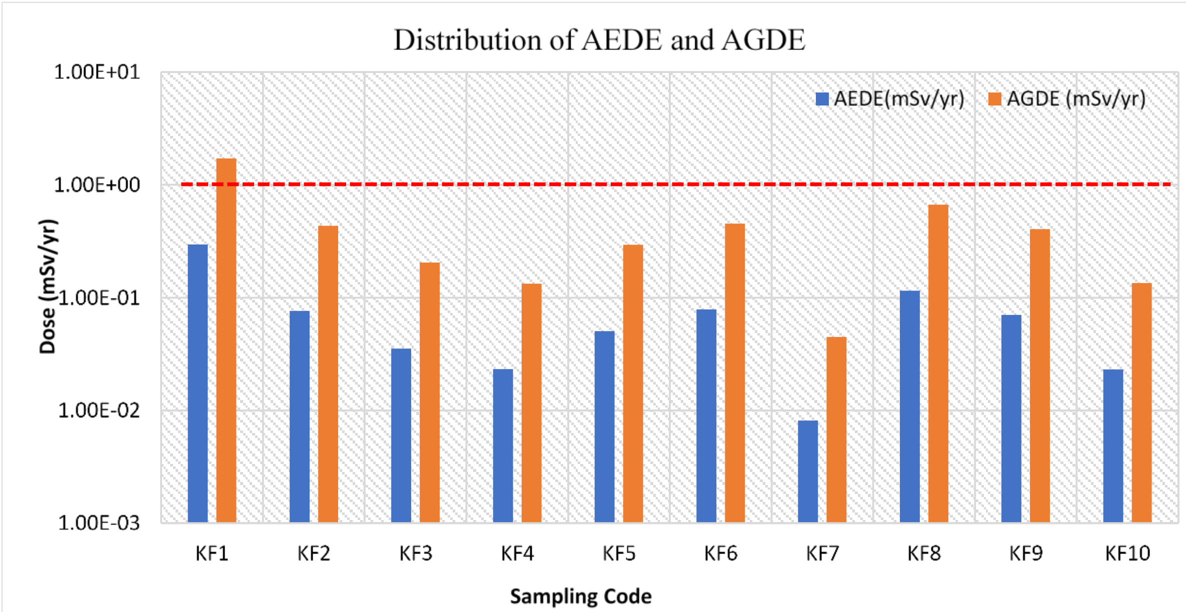


**Figure 2.** Distribution of AEDE and AGDE.

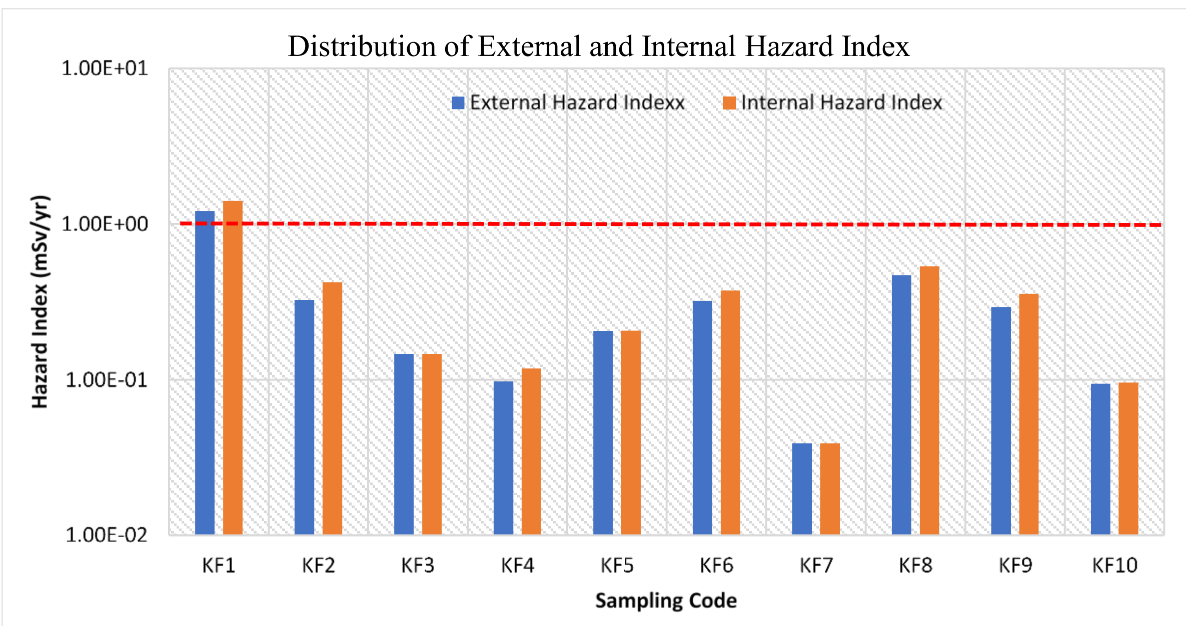


**Figure 3.** Distribution of external and internal hazard index.

**Distribution of radiological hazard analysis**

Figure 3 shows the distribution of external and internal hazard index calculated from determined activity concentration of $^{238}U$, $^{232}Th$ and $^{40}K$ obtained around the swampy agricultural soil in Keffi. The external and internal hazard index obtained from sampling point 1 (KF1) are slightly higher than the recomended dose limit when compared with other sampling points. The high external and internal hazard index in KF1 are due to the difference in geological formation of the study area which influence the distribution of $^{238}U$, $^{232}Th$ and $^{40}K$ alongside their decay

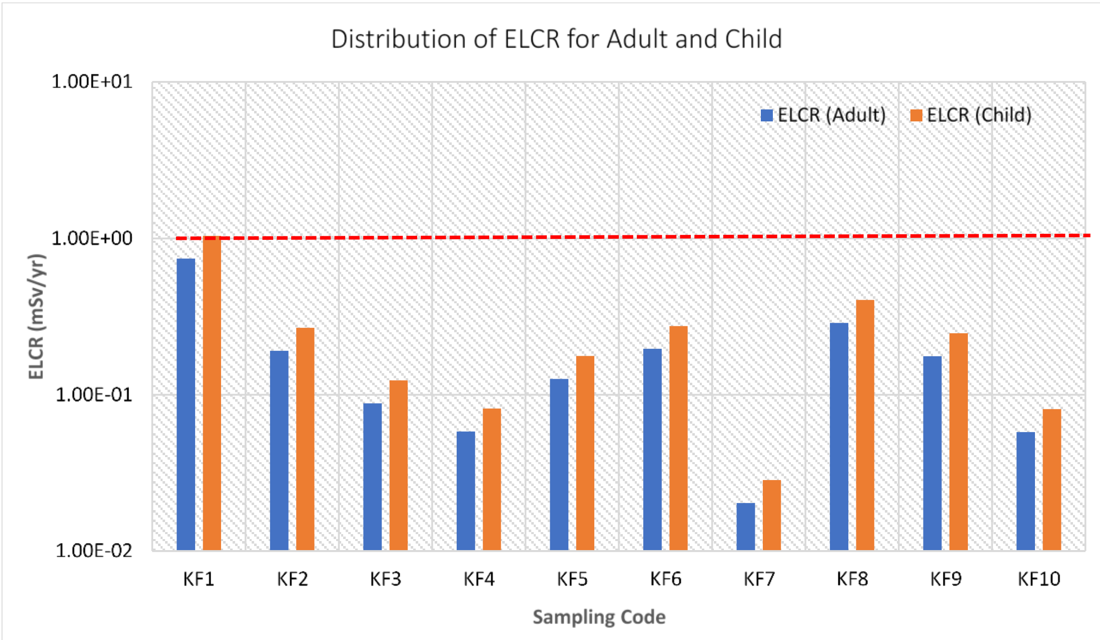


**Figure 4.** Distribution of excess life cancer risk for adult and child.

**Table 6.** Comparison of activity concentration.

| Country | $^{238}$U(Bq/kg) | $^{232}$Th (Bq/kg) | $^{40}$K (Bq/kg) | Reference |
|---|---|---|---|---|
| Nigeria (Keffi) | 26.73±4.64 | 9.77±2.57 | 1115.52±67.43 | Present Study |
| Nigeria (Adamawa) | 107.596±11.2 | 84.856±6.23 | 475.343±12.3 | Yusuf *et al.*, 2022 |
| Senegal | 4082±41.0 | 1060±38 | 3568±12.3 | Fall *et al.*, 2023 |
| Nigeria (Mayo Belwa) | 74.59 | 104.41 | 950 | Oduh *et al.*, 2022 |
| Iraq | 11.05 | 23.93 | 226.60 | Hamoo *et al.*, 2022 |
| Nigeria (Ogun) | 29.68±1.54 | 17.61±1.06 | 175.50±2.73 | Odeleye *et al.*, 2022 |
| Kuwait | 16.99±0.02 | 12.70±0.17 | 333.20±7.59 | Bajoga *et al.*, 2019 |
| Egypt | 660±63 | - | 556±86 | Abdelbary *et al.*, 2019 |
| Nigeria (Adamawa) | 106.32 | 84.34 | 466.14 | Dauda *et al.*, 2022 |
| Iraq | 19.80±0.948 | 13.65±1.021 | 231.7±8.89 | Najam *et al.*, 2022 |
| World Average | 32 | 45 | 420 | UNSCEAR, 2000 |

products around the swampy agricultural soil in Keffi. From all the ten sampling points considered in this study, internal hazard index tends to be higher than the external hazard index due to gaseous decay of $^{238}$U and $^{232}$Th resulting to emission of carcinogenic radon and thoron which constitute an important route of internal exposure, and are harmful when inhaled.

Figure 4 shows the distribution of excess life cancer risk for both adult and child obtained from the determined activity concentration of $^{238}$U, $^{232}$Th and $^{40}$K obtained around the swampy agricultural soil from ten (10) sampling points in Keffi. The ELCR obtained from sampling point 1 (KF1) is higher for child than adult due to sensitivity of tissue to radiation, which implies that the growing tissue (typically for child) tends to be more sensitive than the matured tissue (typically for adult). From all the ten sampling points considered in this study, the ELCR for the child is higher than that of the adult.

## Comparison of activity concentration

The activity concentration of $^{238}$U, $^{232}$Th and $^{40}$K obtained from the present study was compared with the activity concentration from previous studies within Nigeria and across some selected countries as presented in Table 6. Table 6 shows the comparison of activity concentration (AC) of $^{238}$U, $^{232}$Th and $^{40}$K obtained from swampy agricultural soil samples from Keffi LGA with those obtained from other literature. The AC of $^{238}U$ and $^{232}Th$ obtained from the present study are lower than the recommended standard values of 32 Bq/kg and 45 Bq/kg while that of $^{40}K$ is higher than the world standard value of 420 Bq/kg as reported by UNSCEAR. The AC of $^{238}U$, $^{232}Th$ and $^{40}K$ reported by Fall *et al. (*2023) from Senegal are higher than those reported in the present study. The AC of $^{238}U$ and $^{40}K$ reported by Najam *et al. (*2022) from Iraq and Bajoga *et al.* (2019) from Kuwait are all lower than those reported from the present study and lower than the recommended world average as reported by UNSCEAR. The AC of $^{232}Th$ obtained from the present study is lower than those reported by Najam *et al. (*2022) from Iraq and Bajoga *et al.,* (2019) from Kuwait as well as the world average. The values of $^{238}U$, $^{232}Th$ and $^{40}K$ reported by Ignatuis *et al*. (2022) and Dauda *et al*. (2022) from Adamawa are all higher than the standard recommended values as reported by UNSCEAR.

## Conclusion

Radiological dose assessment was evaluated for absorbed dose rate, annual effective dose equivalent and annual gonadal dose equivalent while radiological hazard assessment was evaluated for radium equivalent activity, external and internal hazard index, gamma index, activity utilization index as well as excess life cancer risk using the determined AC of $^{238}U$, $^{232}Th$ and $^{40}K$ obtained from swampy agricultural soil samples from Keffi LGA. All the parameters evaluated are lower than the standard recommended limits except for ELCR. The implication of the high value of ELCR is that resident dwelling around the study have high chance of developing cancer over a life time. The ICRP suggested dose limits intended to act as a parameter by limiting deterministic effects while minimizing stochastic effects. The competent authority must take action to protect the public if the dose is above 1 *mSv/yr*. Hence periodic radiological dose and hazard analysis is recommended. This is to ensure that exposure is kept as low as reasonably achievable in accordance with the ALARA principle of limiting radiation dose and the release of radioactive materials into the environment due to human activities, resulting to increase in the radiation level to the environment.

## CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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