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Assessment of Radiological Risk in Flooded Soil Samples of Kudenda, Kaduna State Nigeria.

M. Bashir[1], I G E Ibeanu[2] , Y I Zakari[1] and U Sadiq[1]
[1]*Department of physics, Ahmadu Bello University Zaria, Kaduna state. Nigeria*
[2]*Centre for energy research and training (CERT) Zaria, Kaduna state. Nigeria.*

ABSTRAST :*Assessment of radiological risk was conducted in the flooded soil of kudenda area (latitude 10.480^0N and 10.481^0 N and longitude 7.394^0E and 7.395^0E) in Kaduna state, Nigeria. The activity concentrations of naturally occurring radioactive materials in the ^{238}U (^{226}Ra) and ^{232}Th decay chains and from ^{40}K were determined by means of a gamma-ray spectrometry system using Sodium Iodide (NaI(Tl)) detector in a low background configuration. The ranges of activity concentrations of ^{238}U, ^{232}Th and ^{40}K were found to be 8.1±3.6 ↔ 45±4.4, 38±1.3 ↔149.6±3.9 and 400.5±3.9 ↔ 873.7±11.6Bqkg^{-1}, respectively. The results of this current study have been compared with the world mean values of 35, 30 and 400 Bq.kg^{-1}, respectively, specified by the UNSCEAR (2000).Concerning radiological risk to human health, the absorbed gamma dose rate (D) in air at 1 metre above the ground surface was estimated to lie in the range 47.4±2.2 to 141.2±4.4nGy.h^{-1}; the outdoor annual effective dose equivalent (AEDE) was evaluated to vary from 0.06±0.003 to 0.17±0.005mSv.y^{-1}, with the arithmetic mean value of 0.11±0.004mSv.y^{-1},which is higher than the worldwide effective dose of 0.07mSv.y^{-1}. Also, the values of the Raeq and the Hex for all soil samples in the present work are lower than the accepted safety limit value of 370 Bq.kg^{-1} and below the limit of unity, respectively. The results indicate that the radiation hazard from primordial radionuclides in all soil samples from the area studied in this current work is not significant.*

KEYWORDS: *radionuclides, Absorbed dose rate, AEDE, Ra_{eq}, H_{ex}, gamma spectrometry, NaI(Tl)*

I. INTRODUCTION

Human beings have always been exposed to natural radiation from within and outside earth. The natural radioactivity in soil comes from ^{238}U and ^{234}Th series and ^{40}K. The radiological implication of these radionuclides is due to gamma exposure of the body and irradiation of the lung from inhalation of radon and its daughters. Therefore, the assessment of gamma radiation dose from natural sources is of particular importance as natural radiation is the largest contributor to the external dose of world population [1]. External gamma dose estimation due to the terrestrial sources is essential as these doses vary depending upon to concentrations of natural radionuclides, ^{238}U, ^{234}Th their daughter and ^{40}K, present in the soils and rocks which further depends upon the local geology of each region in the world [2-3]. Many studies have been carried out worldwide in order to determine the risks and effects of long term, low level and natural radiation exposure [4]. The international Basic Safety Standard (BSS) for protection against ionizing radiation and the safety of radiation sources [26] specify the basic requirement for the protection of health and the environment from ionizing radiation. These are based on the latest recommendation of the International Commission on Radiological Protection on the regulation of practices and intervention [27], the BSS is applied to both natural and artificial sources of radiation in the environment and the consequences on living and non-living species.The aim of this study is to determine the radiological risk associated with Naturally Occurring Radioactive Materials (NORM) at Kudenda area of Kaduna state, Nigeria.

II. MATERIALS AND METHOD

The study area is 60m^2 of the Kudenda area of Kaduna state, Nigeria where the flooding of river Kaduna occurred in 2012. The area is bounded by latitude 10.480^0N, 10.481^0 N and longitude 7.394^0E, 7.395^0E. The chosen site 60m^2 is divided into 9grid points (mesh) of 20m^2 each labeled A-I with A-C, D-F and G-I parallel to the bank of river but separated by 20m from each other and A-G, B-H and C-I perpendicular to the river bank and 60m away. In-situ gamma dose rate measurements were taken and samples collected at the middle of each grid from depths of 0-<5, 5-<25, 25-<50 and 50-100cm using hand auger. After removal of stones and vegetable matter, each soil sample was packed into its own secure water-tight bag to prevent cross contamination.

2.2 Sample preparation and Analysis

Samples were left open in the laboratory for a minimum of 24hours to dry under ambient temperature. The dried samples were pulverized into a fine powder and passed through a standard mesh (500µm). The samples were homogenized and filled into 25g plastic containers which were then hermetically sealed with the aid of PVC tape to prevent the escape of airborne ^{222}Rn and ^{220}Rn from the samples. All samples were weighed and stored for a minimum of 24days prior to measurement in order to attain radioactive secular equilibrium between ^{226}Ra and ^{228}Ac and their short-lived progeny (>7 half-lives of ^{222}Rn and ^{220}Rn). The samples were then counted for 29,000sec in a low-level gamma counting spectrometer comprising a 7.6cm x 7.6cm NaI (Tl) detector which is coupled to multichannel analyzer (MCA) through a preamplifier base. The spectral and live times of the NORMs were acquired using MAESTRO software.

2.3Theoretical Calculations

2.3.1 Absorbed Dose Rate in Air (*D*)

In order to assess any radiological hazard, the exposure to radiation arising from radionuclides present in soil can be determined in terms of many parameters. A direct connection between radioactivity concentrations of natural radionuclides and their exposure is known as the absorbed dose rate in the air at 1 metre above the ground surface. The mean activity concentrations of ^{226}Ra (^{238}U), ^{232}Th, and ^{40}K (Bq.kg^{-1}) in the soil samples are used to calculate the absorbed dose rate given by the following formula [5, 6, 7-11]:

$$D(\mathrm{nGyh^{-1}}) = 0.462A_{Ra} + 0.604A_{Th} + 0.0417A_K \qquad (1)$$

where *D* is the absorbed dose rate in nGy.h^{-1}, ARa, ATh and AK are the activity concentration of ^{226}Ra (^{238}U),^{232}Th and ^{40}K, respectively. The dose coefficients in units of nGy.h^{-1} per Bq.kg^{-1} were taken from the UNSCEAR (2000) report [12].

2.3.2 Annual Effective Dose Equivalent (*AEDE*)

The absorbed dose rate in air at 1 metre above the ground surface does not directly provide the radiological risk to which an individual is exposed [13]. The absorbed dose can be considered in terms of the annual effective dose equivalent from outdoor terrestrial gamma radiation which is converted from the absorbed dose by taking into account two factors, namely the conversion coefficient from absorbed dose in air to effective dose and the outdoor occupancy factor. The annual effective dose equivalent can be estimated using the following formula [7-11,12]:

$$AEDE(\mu\mathrm{Sv.y^{-1}}) = D(\mathrm{nGy.h^{-1}}) \times 8760\mathrm{h} \times 0.2 \times 0.7\mathrm{Sv.Gy^{-1}} \times 10^{-3} \qquad (2)$$

The values of those parameters used in the UNSCEAR report (2000) are 0.7 Sv.Gy^{-1} for the conversion coefficient from absorbed dose in air to effective dose received by adults and 0.2 for the outdoor occupancy factor [12].

2.3.3 Radium Equivalent Activity (*Raeq*)

Due to a non uniform distribution of natural radionuclides in the soil samples, the actual activity level of ^{226}Ra, ^{232}Th and ^{40}K in the samples can be evaluated by means of a common radiological index named the radium equivalent activity (Raeq) [14]. It is the most widely used index to assess the radiation hazards and can be calculated using Equation (3) given by Beretka and Mathew [14]. This estimates that 370 Bq.kg^{-1} of ^{226}Ra, 259 Bq.kg^{-1} of ^{232}Th and 4810 Bq.kg^{-1} of ^{40}K produce the same gamma-ray dose rate [8-11,15-17,].

$$Ra_{eq}(\mathrm{Bq.kg^{-1}}) = A_{Ra} + 1.43A_{Th} + 0.077A_K \qquad (3)$$

where ARa, ATh and AK are the activity concentration of ^{226}Ra,^{232}Th and ^{40}K in Bq.kg^{-1}, respectively. The permissible maximum value of the radium equivalent activity is 370 Bq.kg^{-1} [12, 18] which corresponds to an effective dose of 1 mSv for the general public [10].

2.3.4 External Hazard Index (*Hex*)

To limit the radiation exposure attributable to natural radionuclides in the samples to the permissible dose equivalent limit of 1 mSv.y^{-1}, the external hazard index based on a criterion have been introduced using a model proposed by Krieger (1981) [19] which is given by [9-11, 15, 16,]

$$H_{ex} = \left(\frac{A_{Ra}}{370}\right) + \left(\frac{A_{Th}}{259}\right) + \left(\frac{A_K}{4810}\right) \leq 1 \qquad (4)$$

In order to keep the radiation hazard insignificant, the value of external hazard index must not exceed the limit of unity. The maximum value of Hex equal to unity corresponds to the upper limit of radium equivalent activity 370 $Bq.kg^{-1}$ [9,16, 20].

III. RESULT AND DISCUSSION

Fig.1(a-c) are the plot of the activity concentration of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K of each sampled grid points A-I with depths. From the fig(4.4(a-c)), it can be seen that the highest activity concentrations of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K were found to be 45±4.4 (grid point H), 149.6±3.9 (grid point C) and 873.7±11.6$Bqkg^{-1}$ (grid point A), respectively, at depth 50-100cm. conversely, the lowest activity concentrations of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K were found to be 8.1±3.6 (grid point I), 38±1.3 grid point A) and 400.5±3.9$Bqkg^{-1}$ (grid point H), respectively at depth 0-<5cm. from fig 4.4, it is apparent that ^{40}K exhibited the highest activity concentrations for all measured radionuclides in all of the soil samples measured. It can also be observed from fig. 1(a-c) that the activity concentrations increased with increase in depths (0-100cm).

The results of the current study have been compared with the world mean activity concentrations in soil, as shown in table 1. According to the UNSCEAR report 2000, the worldwide activity concentrations of ^{226}Ra (^{238}U), ^{232}Th, ^{40}K were reported to be 17-60, 11-64 and 140-850Bq/kg with the mean concentrations of 35, 30 and 400$Bqkg^{-1}$, respectively. The obtained results show that the activity concentrations of ^{226}Ra (^{238}U) in all the soil samples range from 8.1±3.6 to 45±4.4 and fall within the worldwide range. The mean activity of ^{226}Ra (^{238}U) of samples at 50-100cm depth show slightly higher value than the worldwide mean concentration. However, the overall mean activity concentration of ^{226}Ra (^{238}U) (22.8±4.1 $Bqkg^{-1}$) is comparable to the mean activity worldwide concentration. The ranges of the activity concentrations of ^{232}Th and ^{40}K vary from 38±1.3 to 149.6±3.9 and 400.5±3.9 to 873.7±11.6$Bqkg^{-1}$, respectively. The activity concentrations of ^{232}Th and ^{40}K are above the upper range due to the high concentration values found in some soil samples. The overall means of the activity concentrations of ^{232}Th and ^{40}K are 87.7±2.3 and 586.4±8.5$Bqkg^{-1}$, respectively, which were above the worldwide mean activity concentration. The higher concentrations of ^{238}U, ^{232}Th and ^{40}K in some soil samples may be influenced in part by a result of variation in geological structure and/or industrial waste released into the river and deposited at the riverbank due to flood activity.

Assessment of Radiological Hazard

One of the main objectives of the radioactivity measurement in environmental sample is not simply to determine the activity concentrations of ^{238}U, ^{232}Th and ^{40}K but also to estimate the radiation exposure dose and to assess the biological effects on humans. The assessment of radiological risk can be considered in various terms. In the current study four related quantities were deduced, these being: (i) the absorbed dose rate (*D*) in air at 1 metre above the ground surface; (ii) the annual effective dose equivalent (*AEDE*) from outdoor terrestrial gamma radiation; (iii) the radium equivalent activity (*Raeq*); and (iv) the external hazard index (*Hex*). These radiological parameters can be calculated from the measured activity concentrations of three main primordial radionuclides in soil samples, using the relations described in Section 2.3. The values of these radiological hazard parameters as deduced in the current work are listed in Table 2.From Table 2, the estimated absorbed dose rates based on soil radioactivity range from 47.4±2.2 to 141.2±4.4$nGy.h^{-1}$ with a mean value and standard deviation of 85.3±4.3$nGy.h^{-1}$. As can be seen in Figure 4.4, ^{40}K is the main contributor to the absorbed dose rate in most of the soil samples measured in the current work. Compared with the worldwide values, the average mean value of absorbed dose rate from all the samples in this current study are higher than the worldwide mean value. It can also be observed that the absorbed dose rate values of the in-situ are higher than those of the computed (table 2) which could be attributed to effect of cosmic radiation on the in-situ measurement.

The absorbed dose rate in air at 1 metre above the ground surface does not directly provide the radiological risk to which an individual is exposed [13 and 21]. The annual effective dose equivalent from outdoor terrestrial gamma radiation was estimated by taking into account the conversion coefficients from absorbed dose in air to effective dose and the outdoor occupancy factor. The effective dose for the different locations of soil samples in this study varied from 0.06±0.003 to 0.17±0.005$mSv.y^{-1}$, with the arithmetic mean value and standard deviation of 0.11±0.004$mSv.y^{-1}$ but when been compared with the worldwide effective dose of 0.07$mSv.y^{-1}$ [12] the current study results are higher. The acceptable annual effective dose for members of the public without constraint should be 1.0$mSvyr^{-1}$ for safety purposes [23, 24]. However under radiological constraints for an adequate protection of potential users of 0.5mSv/y as recommended by EC report [25] in which all the values obtained in the current work were comparable to that.

The radiation hazard parameters in terms of the radium equivalent activity (*Raeq*) and the external hazard index (*Hex*) were also evaluated. The Radium equivalent activity (*Raeq*) is a single quantity which compares the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in soil samples in order to obtain a total activity concentration. The results for the calculated *Raeq* from the current work are given in table 2. The values of *Raeq* range from 100.7±4.9 to 314.2±9.9Bq.kg^{-1} with an overall arithmetic mean and standard deviation of 187.2.4±14.4 Bq.kg^{-1}. It can be seen that the *Raeq* values for all soil samples in the present work are lower than the accepted safety limit value of 370 Bq.kg^{-1} as recommended by the Organisation for Economic Cooperation and Development (OECD) [1,11, 22,]. Therefore the use of these soils as raw materials for building does not constitute a health hazard of radiation. As listed in Table 4.4, the calculated values of the external hazard index for all soil samples studied vary from 0.27±0.01 to 0.85±0.03 and the average value were found to be 0.51±0.02. Results show that the *Hex* values for all soil samples are below the limit of unity, meaning that the radiation dose is above the permissible limit of 1 mSv.y^{-1} recommended by [24].

IV. CONCLUSION

The calculated average activity concentration value for ^{226}Ra (^{238}U) lies within the world's average range but for ^{232}Th and ^{40}K the calculated activity values were on the higher side of the worldwide ranges. The higher activity concentrations of ^{232}Th and ^{40}K may be influenced in part by a result of variation in geological structure and/or industrial waste released into the river and deposited at the riverbank due to flood activity. The calculated results of the average mean value of absorbed dose rate from all the samples are higher than the worldwide mean value. It can also be observed that the absorbed dose rate values of the in-situ are higher than those of the computed (table 2) which could be attributed to effect of cosmic radiation on the in-situ measurement. The annual effective doses due to natural radioactivity of the soil samples were lower than the average world recommended value of 1.0mSvy^{-1}. Also the mean of Raeq activity value and external health hazard index values were found to be lower than recommended safe limit values. It can be concluded that the radiological health risks to the people living in the areas studied in this current work is not significant.

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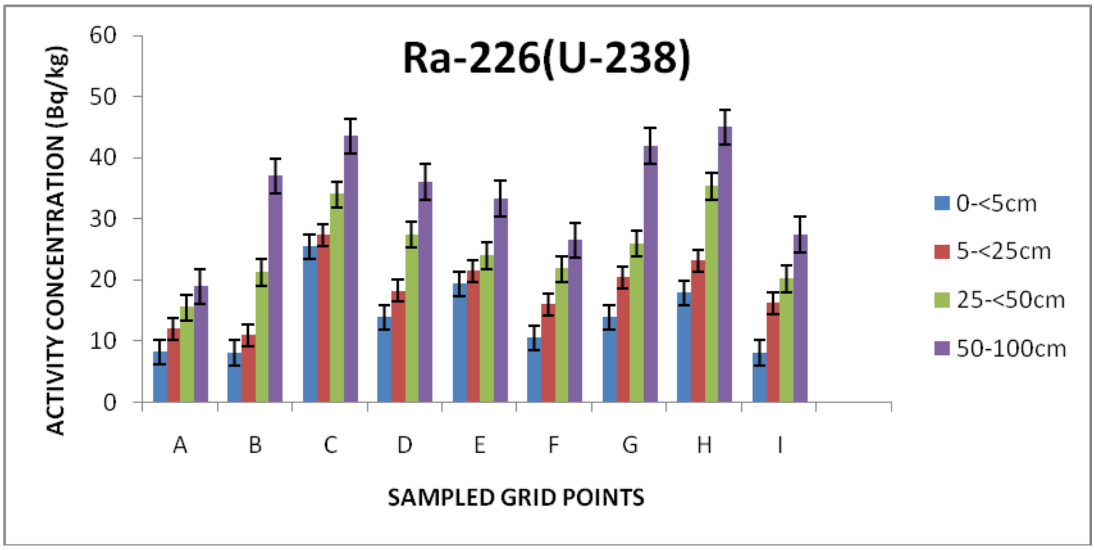
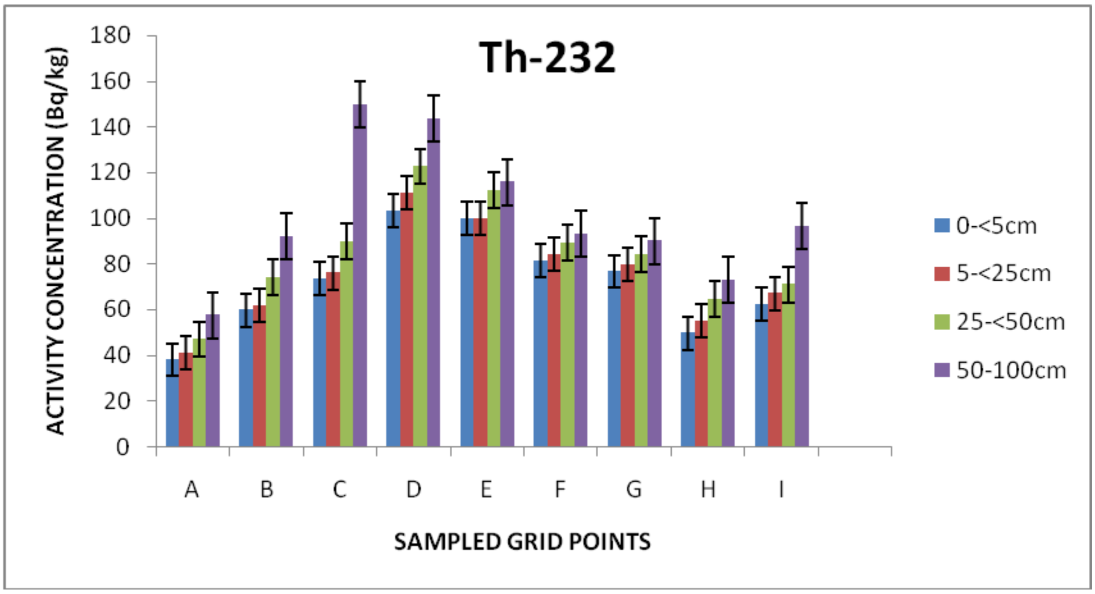
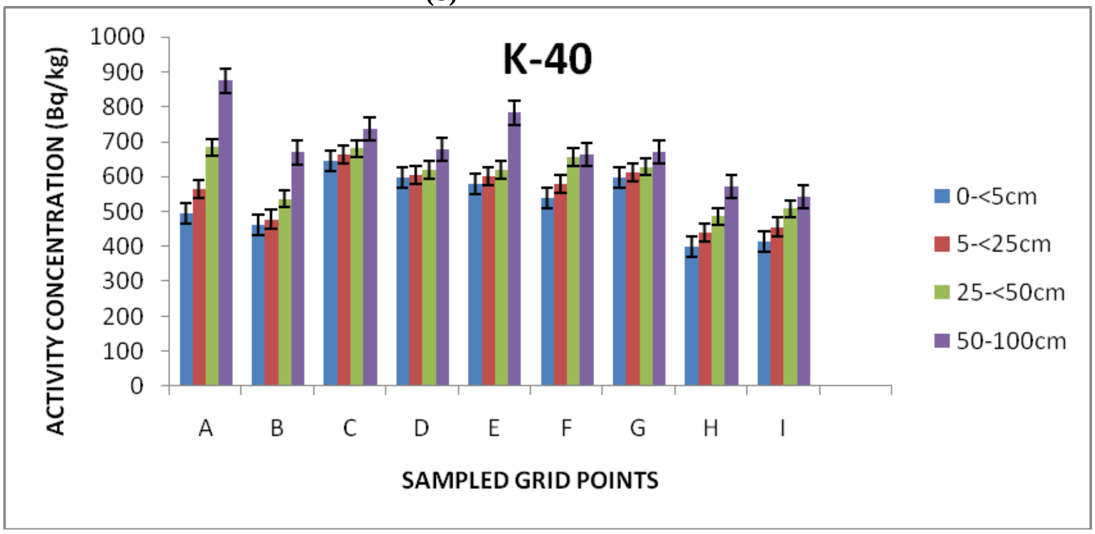


(a)



(b)



(c)

Fig.1(a-c): plot of activity concentration of ^{226}Ra (^{238}U) ^{232}Th and ^{40}K, for the sampled grid points with depth

Table 1: Comparison between the average mean activity concentrations of ^{226}Ra (^{238}U), ^{232}Th and ^{40}K in the gridded sampled depths with the mean value for the worldwide.

SAMPLED DEPTHS (cm)	ACTIVITY CONCENTRATION (Bq/kg)		
	^{226}Ra (^{238}U)	**^{232}Th**	**^{40}K**
0-<5	13.9±4.1	71.7±2.1	525.4±8.3
5-<25	18.4±2.9	92.3±2.2	555.3±7.3
25-<50	24.6±4.6	85.4±2.1	577.2±8.7
50-100	34.4±4.6	101.3±2.6	687.6±9.5
Total	**22.8±4.1**	**87.7±2.3**	**586.4±8.5**
Worldwide Range mean	 **17-60** **35**	 **11-64** **30**	 **140-850** **400**

Table 2: Comparison between mean absorbed dose rate (*D*), annual effective dose equivalent (*AEDE*), radium equivalent activity (*Raeq*) and external hazard index (*Hex*) obtained from all the soil samples with that of worldwide.

	Computed		**In-Situ**		***Raeq***	***Hex***
	D (nGy.h^{-1})	**AEDE** (mSv.y^{-1})	***D*** (nGy.h^{-1})	**AEDE** (mSv.y^{-1})	**(Bq.kg^{-1})**	
Min.	47.4±2.2	0.06±0.003	90	0.11	100.7±4.9	0.27±0.01
Max.	141.2±4.4	0.17±0.005	300	0.37	314.2±9.9	0.85±0.03
Mean+S.D	85.3±4.3	0.11±0.004	162.5	0.20	187.2±7.8	0.51±0.02
Worldwide Mean	**57**	**0.07**	**57**	**0.20**	**<370**	**<1**

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