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Assessment of Radiological Health Risks in Agricultural Soil Samples within Bitumen Belt of Ondo State, Nigeria

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

The quality of agricultural soils within the bitumen deposit areas of Ondo State, Nigeria was investigated with a view to providing valuable information on the radioactivity parameters associated with the contamination of the sites by bitumen deposit. And to provide baseline data required for future radiological impact assessment of the environment during the development of the natural resource. Naturally occurring radionuclides (^{238}U, ^{232}Th and ^{40}K) present in agricultural soil samples collected within the bitumen belt of Ondo State, Nigeria was measured using gamma spectroscopy. The radiological health risk parameters; absorbed dose rate (D), Annual Gonadal Equivalent Dose (AGED), External Hazard Index (H_{ex}), Internal Hazard Index (H_{in}) and Excess

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Lifetime Cancer Risk (ELCR) were estimated using standard analytical method. The estimated results of D ranged from 3.56 $nGyh^{-1}$ (Omotosho) to 10.55 $nGyh^{-1}$ (Igbotako) with a mean value of 5.83±2.19 $nGyh^{-1}$. While AGED ranged from 24.07 $mSvy^{-1}$ (Omotosho) to 70.72 $mSvy^{-1}$ (Igbotako) with a mean value of 40.39±14.26 $mSvy^{-1}$. Also, H_{ex} varies between 0.021 (Omotosho) to 0.063 (Igbotako) with a mean value of 0.034±0.01. Similarly, H_{in} ranged from 0.030 (Omotosho) to 0.089 (Igbotako) with a mean value of 0.047±0.02. However, the estimated ELCR were much lower than the safe limit of 0.29 x 10-3, which suggests that even though there is little radiation risk associated with exposure to natural radionuclides, using the studied soil may not immediately pose a health risk to the locals. However, prolonged exposure may result in radiologically induced health problems.

Keywords: External and internal hazard indices; ELCR; absorbed dose rate; bitumen; Ondo.

1. INTRODUCTION

Bitumen occurs naturally and is found typically on the surface and sub-surface as seepages and outcrops, or as tar sands. This implies that they occur in the earth's uppermost layer and within strata below its surface. The tar sand is a combination of clay, sand, heavy oil and water in varying proportions of 2%, 84%, 12%, and 4%, respectively [1]. Generally, bitumen is believed to have originated from fossil deposit, which represents the product of reservoir transformation of conventional oil by microorganism.

“Ondo State bitumen belt spans six of the eighteen Local Government Areas: Odigbo, Irele, Okitipupa, Ilaje, Ese-Odo and Idanre” [2]. “The exploitation sites of bitumen in Nigeria are distributed mainly along a stretch beginning at the outcrop belt Northeast of Lekki Lagoon in Ogun State and extend toward the Southeast in Ondo State” [3].

“Usually, oil exploration is known to have great impact on the environment due the presence of natural radionuclides in crude oil and bitumen” [4]. “The experience from tar sand and/or petroleum exploration and exploitation had often been the creation of oil pollution and spillages, affecting lands, crops, water and welfare of the host communities. Ordinarily, bitumen pollution occurs when there is seepage from the ground reservoir to the ground surface through cracks or faults on the ground due to changes in temperature and/or bacterial degradation” [2]. Spilling of the lower viscous bitumen through seepage on farmlands and rivers is common within Ondo State bitumen belt.

However, “the exploration and exploitation of bitumen may bring economic benefits to a country, but these activities may be destructive to the environment even at the safest and best operating practices. Such unsafe acts may include the redistribution of Naturally Occurring Radioactive Materials (NORMs) which are originally within the earth crust nonetheless brought to the surface during these processes” [5]. In addition, “contamination of soil compartments by bitumen disrupts the activities of soil microorganisms and nutrient availability to plants” [6].

“The soil, a major sink of environmental contaminants, comprises of several organic and mineral components and acts as a repository for many environmental pollutants including radionuclides. This accounts for the presence of some levels of radioactive elements which are primarily dependent on the parent rock type of the soil. The physicochemical properties of soils also influence the behavior, concentration, and distribution of radioactive materials” [7]. “Lower levels of potassium and thorium are usually associated with sedimentary rocks while higher levels are associated with igneous rocks” [8, 9].

Consequently, consumption of food crops grown in radionuclide contaminated soils can lead to the radiological exposure of a person [10]. More so, radionuclides in soils and other environmental matrices can directly pose significant human exposure especially for local population through various pathways, depending on their concentration. Although radionuclides exposure rate in soil is low but the effect of these radiations overtime can lead to radiological health risk, which can be estimated [11].

Anthropogenically enhanced naturally occurring radionuclides ^{238}U, ^{232}Th and ^{40}K present in soils around tar-sand deposit area of Ogun State were measured by Gbadamosi *et al*., [12]. Their report showed that the average activity concentrations of ^{238}U, ^{232}Th and ^{40}K ranges from BDL to 76.00 ± 12.00, BDL to 204.48 ± 13.02 and BDL to 755.6 ± 40.15 $Bqkg^{-1}$ respectively. While the values

obtained for their associated radiological health hazard parameters were all higher than the world's average set by the United Nations Scientific Committee on Effect of Atomic Radiation (UNSCEAR). The amount of the chance of increased lifetime cancer sustained by residents of the tar-sand deposit site, however, was calculated using the RESRAD computer code, and it was found to be 2.3 103. As a result of the numerous exposure paths, the tar-sand soil samples were thought to offer a serious radiological risk and cancer risk to people.

Isinkaye *et al*., [4] evaluated "radiological hazards due to natural radioactivity in bituminous soils from tar-sand belt of Southwest Nigeria using HpGe Detector. They concluded that the activity contents of soil and viscous bitumen from the tar-sand belt are lower than those in soils of non-bituminous area". Meanwhile, Fasasi *et al*., [1] studied "natural radioactivity of the tar-sand deposits areas of Ondo State, Southwestern Nigeria and their report revealed that the measured activity in the bituminous sand layer is so low that it can be said to be non-radioactive. However, the result of the Energy Dispersive X-Ray Fluorescence (EDXRF) supports the presence of radioelements in the overburden".

It is of concern that there might be a high level of radionuclides presence in the tar-sand deposit and bitumen contaminated agricultural soil within the study area, and future exploration or exploitation can elevate this level hence pose negative radiological impact on the environment and the population. It might expose individuals to both stochastic and deterministic effects through various pathways due to the ionizing radiation emitted by these radionuclides. These effects include; sterility, tumor necrosis and cancer.

However, the renewed interest in the exploration and exploitation of the vast bituminous sand deposit of Nigeria, the suspected radiological health risk and recent reported cases of possible high levels of radioactive materials in some bituminous nodules in Czech Republic [13] and in northern Saskatchewan, Canada [14] account for the need to quantify the presence and level of radionuclides in agricultural soil within the Ondo State bitumen belt.

2. MATERIALS AND METHODS

2.1 Study Location

The study area is located on the eastern margin of a coastal sedimentary Benin basin which lies on the onshore regions of Eastern Dahomey between the coordinates; longitude 6^{o} 15' 0'' N & 6^{o} 45' 0'' N and latitude 4^{o} 30' 0'' E & 5^{o} 10' 0''E (Fig. 1). It is the most noted area of bitumen activities in Nigeria, and falls within the tropical rainforest region with two distinct climatic seasons, which are; dry season from November to April and wet (rainy) season from May to October. The sedimentary rocks are mainly of the post Cretaceous sediments and the Cretaceous Abeokuta Formation. Although exploitation of the bitumen is yet to commence, seepages of the naturally occurring bitumen within the shallow subsurface contaminates soils, farmlands and rivers within the study area, hence constitute another source of radioactivity due to the presence of naturally occurring radioactive materials in the bitumen. The soil samples were collected one each from Okitipupa, Iletitun, Igbotako, Omotosho, Ode-Aye, Agbabu, Ode Irele, Iyasan, Akotogbo, Loda, Ibekegbo, Igbobini and Araromi Sea-Side.

2.2 Samples Collection

Using a hand auger, thirteen (13) soil samples were taken across agricultural areas in the research area from a depth of 0.5 m to 1.0 m [15]. To avoid sample confusion, the samples were labeled precisely and placed in a clear polythene bag. Following proper marking, they were delivered to the University of Ibadan's Nigerian Institute of Radiation Protection and Research (NIRPR), Ibadan, Oyo State, Nigeria, for processing and analysis.

2.3 Sample Preparation

Each soil sample was dried under the laboratory condition until constant weight was achieved. The dried samples were pulverized and homogenized using a motorized grinder and allowed to pass through a sieve of 200 µm mesh size. The homogenized soil samples were then dried in a temperature-controlled oven at 105^{0}C for about 24 hours in order to eliminate organic matter content of the soil samples. They were then placed in Marinelli beakers (size 500ml each) and sealed accordingly to maintain their in-situ characteristics. The weights of the sealed samples were recorded using electronic weighing balance and then kept for twenty-eight (28) days in order to achieve radioactive secular equilibrium between parent radionuclides and their respective daughters.

2.4 Gamma Spectrometry

A scintillation detector made of sodium iodide (NaI-TI) was used to measure the radioactivity.

Lead shield Canberra 76 x 76 mm NaI (TI) crystal, model number 802 series, is the detector. It is a compatible sealed assembly that includes a photomultiplier tube, a high-resolution NaI (Tl) crystal, and a preamplifier base that feeds amplified electrical pulses into analyzer systems. The photomultiplier tube detects the tiny visible light photons produced in the crystal. The detector system was calibrated before carrying out actual measurement of the soil samples. In order to commence counting, three gamma standard sources Cs-137, Am-241 and Co-60 were placed into 6cm lead shield of the detector chamber. This set up is aimed to minimize the effects of background and scattered radiation. By determining the correlation between the peak point in the spectrum and the associated gamma-ray, the energy calibration was completed. Each pulse produced by a photomultiplier tube, as seen on the display output and the associated channel, has a height that is directly proportional to the original gamma energy that caused the pulse. The calibration was done using gamma emitter sources of known energies, these are Cs-137 and Co-60 source that emits gamma rays with energies of 662 keV, 1332 keV and 1173 keV, and Am-241 which is an alpha emitter but also emits some gamma rays with energies 26.3 keV and 59.6keV. The gamma emitter sources were exposed to the NaI (TI) detector and gamma spectrum was acquired. These were done with the amplifier gain that gives 72% energy resolution for the 662 keV of Cs-137 and counted for 30 minutes. The net area corresponding to the photopeak's in the energy spectrum was computed by subtracting count from the background source from the total area of the photopeak's. The identification of individual radionuclides was performed using their gamma ray energies and the quantitative analyses of radionuclides were performed using gamma ray spectrum analysis software, Genie 2000.

3. RADIOLOGICAL HEALTH RISK PARAMETERS

The radiological health risks indices are standard parameters used in radiation studies to asses and estimate the effects of radiation exposure on the health of people and the environment. These indices are useful in estimating the radiological effects of samples that contains radionuclides (^{238}U, ^{232}Th and ^{40}K). Some radiation health risks parameters associated with the studied soil samples are discussed below:

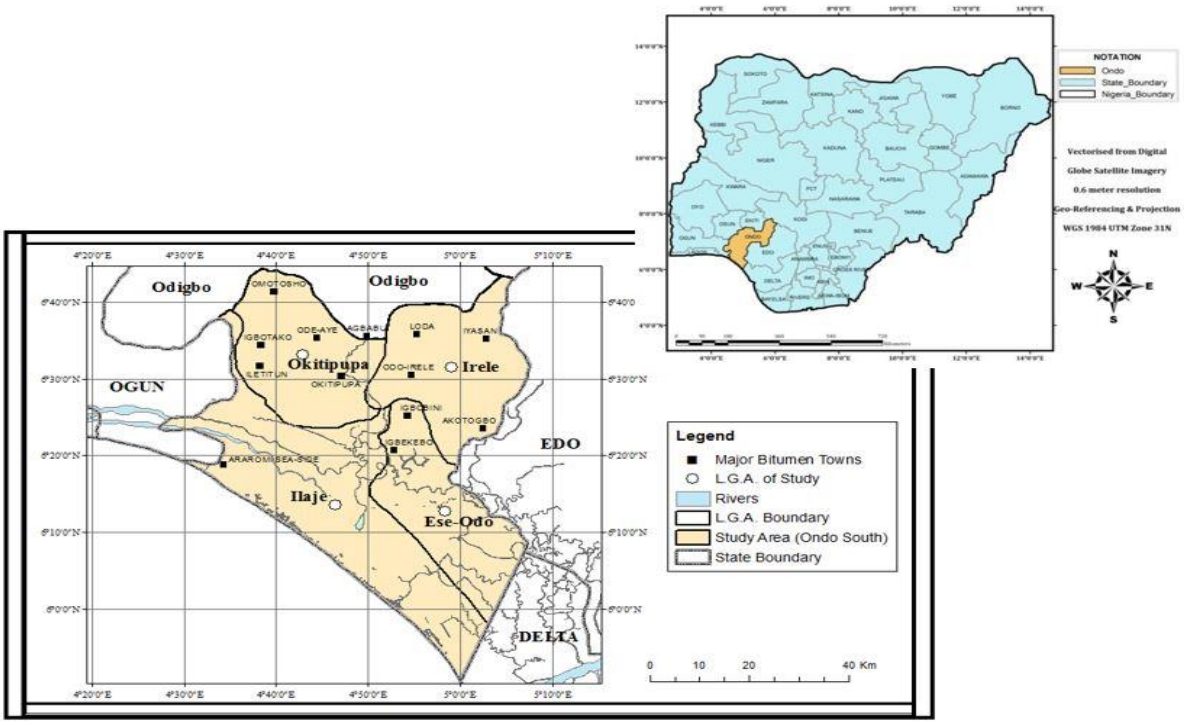

Fig. 1. Map of the study area

3.1 Radium Equivalent Activity Index (Ra_{eq})

The radium equivalent is an index used to describe the gamma output from different mixtures of Uranium (i.e ^{226}Ra), ^{232}Th and ^{40}K in a material. From the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K, the radium equivalent concentration was calculated using the equation below [16].

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad (1)$$

Where A_{Ra}, A_{Th} and A_K are the activity concentrations of 238U, 232Th and 40K (Bq/kg), respectively. An assumption was made in defining radium equivalent activity, that 370 Bq/kg of 226Ra, 259Bq/kg of 232Th and 4810 Bq/kg of 40K yields the same gamma dose rate [17].

3.2 Absorbed Dose Rate (D)

If a radionuclide activity concentration is known then its exposure dose rate in air at 1m above the ground can be calculated using equation 2 [18].

$$D = 0.429A_{Ra} + 0.666A_{Th} + 0.042A_K \quad (2)$$

Where D is the dose rate in nGyh-1 whileA_{Ra}, A_{Th} and A_k are the specific activity concentrations in Bq kg^{-1} of ^{238}U, ^{232}Th and ^{40}K respectively in the soil sample and 0.429, 0.666 and 0.042 (nGyh-^{1} per Bq kg^{-1}) are the concentration-to-dose conversion factors.

The absorbed dose values are often converted to effective dose equivalent from which the excess life cancer risk is calculated, since the absorbed dose rate itself does not show possible biological effects.

3.3 External Hazard Index (H_{ex})

The concept of external hazard index (H_{ex}) was used to assess the potential health risk associated with humans and gamma radiation emitted by radionuclides. The index was estimated using equation 3 [19, 20, 21].

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

Where A_{Ra}, A_{Th} and A_K are the average activity concentrations of 226Ra, 232Th and 40K, respectively in Bq/kg as earlier defined. The value of this index must be less than unity for the radiation hazard to be insignificant. The maximum value of H_{ex} equal to unity corresponds to the upper limit of Ra_{eq} (i.e 370 Bq/Kg) [21].

3.4 Internal Hazard Index (H_{in})

Radon and its short-lived products are radiologically hazardous when inhaled. Internal exposure to radon and its daughter products is very hazardous and can lead to respiratory diseases like asthma and cancer. The internal hazard index (H_{in}) can be used to determine the internal exposure of living cell to radon and its products [10]. These indices were determined using equation 4 [19, 20, 21].

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

Where A_{Ra}, A_{Th} and A_K, are the average activity concentrations of 226Ra, 232Th and 40K, respectively in Bq/kg. H_{in} should be less than unity for the radiation hazard to be insignificant.

3.5 Annual Effective Dose Equivalent

The concentrations of terrestrial gamma radiation from 238U, 232Th and40K in environmental matrix can be used to deduce the annual effective dose equivalent (AEDE) received by an adult in both indoor and outdoor situations from absorbed dose rate in the air, using their respective average conversion coefficients and occupancy factor. The conversion factor value was estimated to be 0.7SvGy-1 for gamma ray exposure in the environment in both indoor and outdoor situations [22], while the occupancy factor was 0.2 for outdoor considering that people on regular basis spent 20% of their time outdoors. For indoor measurement, the occupancy factor for building materials was estimated to be approximately 0.8. Hence to estimate the Annual Effective Dose Equivalent (AEDE), equations 5 and 6 can be used for outdoor and indoor situations respectively.

$$AEDE(Outdoor)\left(\frac{\mu Sv}{y}\right) = D_{air}\left(\frac{nGy}{h}\right) x\ 8760\left(\frac{h}{y}\right) x\ 0.2\ X\ 0.7\left(\frac{Sv}{Gy}\right) x10^{-3} \quad (5)$$

$$AEDE(Indoor)\left(\frac{\mu Sv}{y}\right) = D_{air}\left(\frac{nGy}{h}\right) x\ 8760\left(\frac{h}{y}\right) X\ 0.8\ x\ 0.7\left(\frac{Sv}{Gy}\right) x10^{-3} \quad (6)$$

The world AEDE for both indoor and outdoor terrestrial gamma radiation is 0.460mSvy^{-1}. This index measures the risk of stochastic and deterministic effects in the irradiated individuals exposed [23].

3.6 Annual Gonadal Equivalent Dose (AGED)

Gonads, bone marrow and the bone surface cells are the most sensitive parts of human body to radiation, hence are regarded as organs of interest according to UNSCEAR [24]. It had been known that an increase in AGED will affect the bone marrow and destroy the red blood cells which are then replaced by white blood cells. This situation results in a health condition known as blood cancer (leukemia). AGED for members of the public can be calculated with given activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) using the relationship below [25]:

$$AGED\left(\frac{mSv}{y}\right) = 3.09A_{Ra} + 4.18A_{Th} + 0.314A_{K} \quad (7)$$

Where, A_{Ra}, A_{Th} and A_K represent the radioactivity concentration of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/Kg) in soil samples respectively.

3.7 Excess Lifetime Cancer Risk (ELCR)

The ELCR value describes the number of cancers expected in a given number of people on exposure to a carcinogen at a given dose. It is associated with the probability of developing cancer over a lifetime at a given exposure level. An increase in the ELCR causes a proportionate increase in the rate at which an individual can get cancer of the breast, prostate or even blood. Excess Lifetime Cancer Risk (ELCR) is given according to Taskin *et al*., [26] as:

$$ELCR = AEDE\ x\ Average\ Duration\ of\ Life\ (DL)\ x\ Risk\ Factor\ (RF) \quad (8)$$

Where; AEDE is the Annual Effective Dose Equivalent, DL is the average duration of life / life expectancy (estimated as 70 years), and RF is the Risk Factor (Sv^{-1}), i.e., fatal cancer risk per Sievert. For stochastic effects, International Commission on Radiological Protection (ICRP) uses RF as 0.05 Sv^{-1} for public [26], with the UNSCEAR standard for ELCR being 0.29 X 10^{-3}. Substituting the values of DL and RF in equation 8 gives equation 9 for ELCR.

$$ELCR = AEDE\ x\ 70\ x\ 0.05 \quad (9)$$

4. RESULTS AND DISCUSSION

In this study, the activity concentrations of naturally occurring radionuclide 40K, 232Th and 238U in agricultural soil samples were measured using gamma ray spectroscopy method and the result presented in Table 1. These values were used in the assessment of radiological health risks in agricultural soil samples within the bitumen belt of Ondo state, Nigeria. The activity concentration of 40K ranges from 8.73Bqkg-1 (Omotosho) to 93.83 Bqkg-1 (Araromi Sea-Side) with mean value of 35.85 ± 23.75 Bqkg-$_1$. The activity concentrations of 238U in the soil samples have its lowest value as 2.81 Bqkg-1(Okitipupa) and highest value as 9.55Bqkg-1 (Igbotako), with a mean value of 5.01 ± 2.08 Bqkg-1. While the activity concentration of ^{232}Th ranges from 0.35 Bqkg-1 (Araromi Sea-Side) to 10.49 Bqkg-1 (Agbabu) with a mean value of 3.37 ± 2.98 Bqkg-1. The activity concentrations of ^{40}K, 232Th and 238U obtained in this work were found to fall within the range of that obtained by Gbadamosi *et al*., [12] in soils around tar-sand deposit area of Ogun state, Nigeria, but lower than that obtained by Olawale *et al*; [27] at Gbeleju-Loda and Ode-Irele in Ondo State Nigeria.

The values of activity concentrations from the current study were compared with similar work on soil samples investigated from other countries by Alharbi [28]. The mean activity concentration value of ^{238}U was lower than reported values for soil of Turkey (55.42 Bqkg^{-1}), Jordan (57.7 Bqkg^{-1}), Bangladesh (30.93 Bqkg^{-1}), Najaf-Iraq (77.33 Bqkg^{-1}) and Northern India (56.02 Bqkg^{-1}). It was also found that the mean value of the activity concentration of ^{232}Th was lower than reported values for soil of Turkey (22.86 Bqkg^{-1}), Najaf-Iraq (9.36 Bqkg-1), Baghdad Iraq (21.74 Bqkg^{-1}), Yemen (36.26 Bqkg^{-1}), Jordan (18.1 Bqkg^{-1}), Iran (43.4 Bqkg^{-1}) and Saudi-Arabia (12.3 Bqkg^{-1}) while the activity concentration of ^{40}K in soil samples of the present study area was lower than reported values for soil of Saudi-Arabia (535.0 Bqkg^{-1}), Iran (555.1 Bqkg^{-1}) and Bangladesh (467.8 Bqkg^{-1}).

Table 1. Specific activity concentration of radionuclides in soil samples within the study area

Sample Location	Sample Code	Activity Concentration (Bq/Kg)		
		^{40}K	^{238}U	^{232}Th
Oktipupa	OKT	37.65	2.81	2.53
Iletitun	ILT	58.91	4.83	1.80
Omotosho	OMO	8.73	3.21	2.73
Igbotako	IGTK	13.7	9.55	8.83
Ode-Aye	AYE	47.59	8.20	2.83
Ode-Irele	ODIR	45.73	3.22	2.89
Iyasan	IYS	39.9	3.98	1.20
Akotogbo	AKTG	17.52	4.55	2.00
Loda	LOD	23.63	6.96	3.62
Agbabu	AGB	13.9	4.77	10.49
Igbekebo	IKB	46.72	5.73	1.42
Igbobini	IGBN	18.23	4.01	1.79
Araromi Sea-Side	ARR-SS	93.83	3.28	0.35
Mean		35.85 ± 23.75	5.01 ± 2.08	3.37 ± 2.98

Table 2. Estimated radiological health risk parameters

Sample Location	D (nGyh-1)	R_{eq} (Bq/Kg)	AEDE (mSvy-1)	AGED (mSvy-1)	ELCR (x 10^{-3})	H_{in}	H_{ex}
Okitipupa	4.47	9.327	0.006	31.08	0.019	0.033	0.025
Iletitun	5.75	11.940	0.007	40.95	0.025	0.045	0.032
Omotosho	3.56	7.786	0.004	24.07	0.015	0.030	0.021
Igbotako	10.55	23.232	0.013	70.72	0.045	0.089	0.063
Ode-Aye	7.40	15.911	0.009	52.11	0.032	0.065	0.043
Ode-Irele	5.23	10.874	0.006	36.39	0.022	0.038	0.029
Iyasan	4.18	8.768	0.005	29.84	0.018	0.034	0.024
Akotogbo	4.02	8.759	0.005	27.92	0.017	0.036	0.024
Loda	6.39	13.956	0.008	44.06	0.027	0.057	0.038
Agbabu	9.62	20.841	0.012	62.95	0.041	0.069	0.056
Igbekebo	5.37	11.358	0.007	38.31	0.023	0.046	0.031
Igbobini	3.68	7.97	0.005	25.60	0.016	0.032	0.022
Araromi Sea-Side	5.58	11.01	0.007	41.06	0.024	0.039	0.030
Mean	5.83±2.19	12.44 ±4.88	0.007±0.00	40.39±14.26	0.025±0.00	0.047±0.02	0.033±0.01
World Average	84.00	370	1.00	300.0	0.29	1.00	1.00

All the radiological health risk parameters calculated from the activity concentrations in this work are presented in Table 2. The values of radium equivalent calculated ranged from 7.786 to 23.232 (Bq/Kg) with a mean value of 12.44 ±4.88 (Bq/Kg), which are by far lower than the world average value of 370 (Bq/Kg) [10].

The calculated external hazard index (H_{ex}) varies between 0.021 (Omotosho) to 0.063 (Igbotako) with a mean value of 0.034±0.01. Similarly, the internal hazard index (H_{in}) ranged between 0.030 (Omotosho) to 0.089 (Igbotako) with a mean value of 0.047 ± 0.02. All the soil samples had both their external (H_{ex}) and internal (H_{in}) hazard indices to be less than the safe limit (i.e less than 1).

The absorbed dose rate (D) ranged from 3.56 nGy^{-1} (Omotosho) to 10.55 nGy^{-1} (Igbotako) with a mean value of 5.83±2.19 nGy^{-1} which is lower than that obtained by Ademola and Ademonehin

[29] in soil samples around a bituminous deposit in Ondo State, Nigeria, by Lu *et al*., [30] in soil around Baqiao coal-fired power plant in China, by Alias *et al*., [23] in forest, flat and slope areas of an oil palm plantation located at Jengka, Pahang, Malaysia.

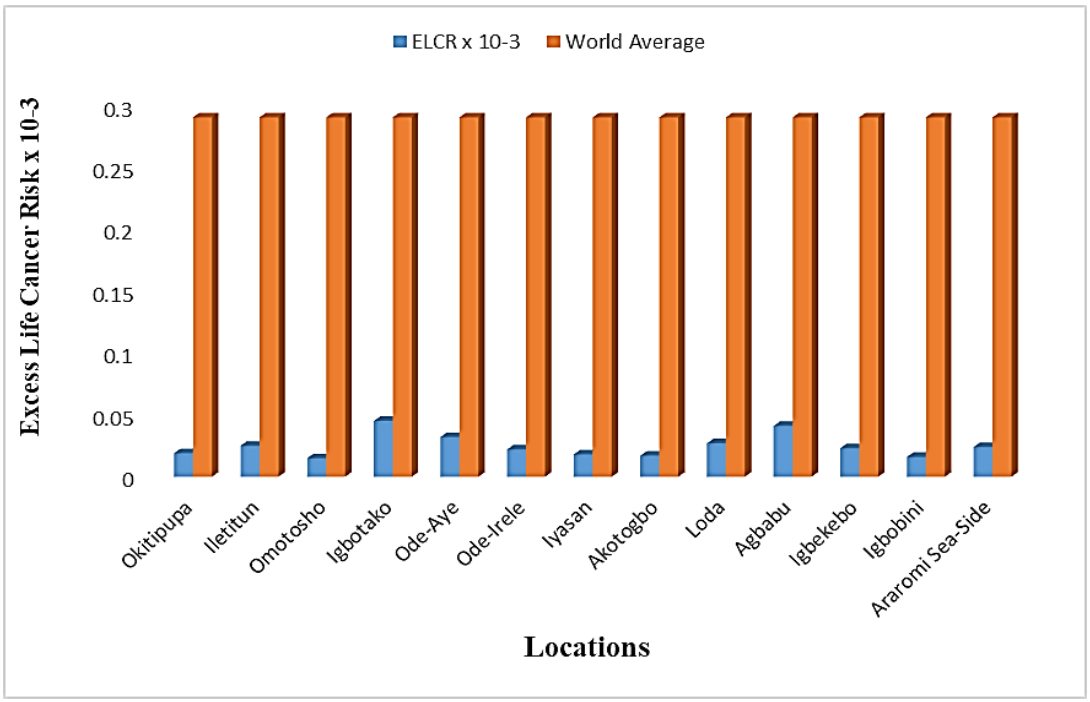

Fig. 2. Comparison of ELCR with the World average

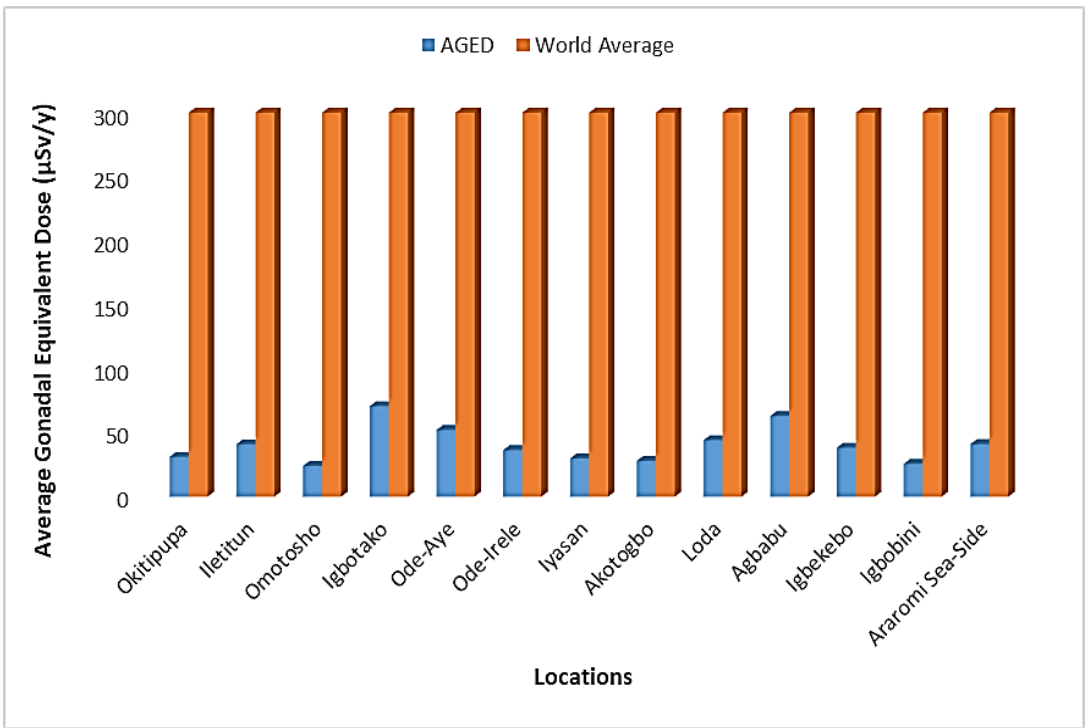

Fig. 3. Comparison of AGED with the World average

The estimated excess life cancer risk (ELCR) as presented in Fig. 2, varied from 0.015 x 10^{-3} (Omotosho) to 0.045 x 10^{-3} (Igbotako) with a mean value of 0.025 x 10^{-3}. The ELCR mean value was also found to be far lower than the safe limit of 0.29 x 10^{-3}. In fact, these values can be said to be near zero, an indication that the study area may be safe for a very long time, however inhabitants might likely develop cancer over time. Similarly Annual Gonadal Equivalent Dose (AGED) estimated in the current study ranged from 24.07 $mSvy^{-1}$ (Omotosho) to 70.72 $mSvy^{-1}$ (Igbotako) with a mean value of 40.39 ± 14.26 $mSvy^{-1}$. The values obtained for AGED in the samples were lower than the recommended safe limit of 300 $mSvy^{-1}$ as seen in Fig. 3. This implies that the gonadal values may pose no threat to the bone marrow and the bone surface cells of residents in the study area.

5. CONCLUSION

In the bitumen belt of Ondo State, Nigeria, agricultural soil samples were evaluated for their radiological health risks. The mean air absorbed dose and annual effective dose equivalent were found to be lower than the UNSCEAR standard levels when the findings were analyzed. Both external and internal radiation hazard indices were less than 1, while the calculated values of annual gonadal equivalent dose and excess life cancer risk were less than the recommended safe limits of 300mSvy-1 and 0.29x10-3 respectively. The result showed that the bitumen belt area of Ondo State, Nigeria has low level of radionuclide content hence no immediate radiological risk to the population.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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