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Radiological Safety Assessment of Agricultural Soil within the Bitumen Belt of Ondo State Nigeria, Using RESRAD-ONSITE and RESRAD-BIOTA Codes

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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

Exploration and exploitation of bitumen can create radiation exposure pathways that must be considered in risk management scenarios. RESRAD-ONSITE and RESRAD-BIOTA developed by the US Department of Energy (US DOE) to assess contaminated sites, were used in the present study to predict the radiation dose and excess cancer risk associated with residual radioactive materials within Ondo State Bitumen Belt for the duration of 100 years, using site-specific

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parameters. The activity concentrations of ^{40}K, ^{232}Th and ^{238}U in soil samples were determined by gamma-spectrometry and their average values were 35.85, 3.27 and 5.01 $BqKg^{-1}$ respectively. While the estimated internal doses in biota due to ^{40}K, ^{232}Th and ^{238}U were 7.54E-06, 3.03E-07 and 4.55E-08 Gy d^{-1} respectively for terrestrial animals, 6.69E-06, 3.68E-08 and 2.29E-08 Gy d^{-1} respectively for terrestrial plants, 6.49E-06, 5.88E-09 and 2.22E-08 08 Gy d^{-1} respectively for the Nigerian Dwarf Goat (NDG). The maximum total dose of 0.0229 $mSvyr^{-1}$ was obtained at Agbabu at t = 30 years for an on-site resident farmer using the RESRAD-ONSITE Code, while the minimum total dose of 0.0014 was obtained at Araromi at t = 100 years. These values were by far lower than the National Research Council's acceptable limit of 0.25 $mSvy^{-1}$. Likewise, the maximum Excess Cancer Risk (ECR) of 0.050×10^{-3} was obtained at Agbabu, while the lowest ECR value of 0.015×10^{-3} was shared by three communities: Omotosho (OMO), Akotogbo (AKG), and Ibekegbo (IKB). The observed low cancer risks in all the selected communities are of less human health concern since they are lower than the world safe value of 0.29×10^{-3}. This implies that utilization of the studied soil for farming may not cause any immediate health hazard to the inhabitant but prolonged exposure might pose radiologically induced health challenges.

Keywords: RESRAD; cancer risk; annual effective dose; bitumen; Ondo.

1. INTRODUCTION

“The exposure of human beings to natural radiation, are mainly due to natural radionuclides decay of ^{238}U (^{226}Ra) series, ^{232}Th series and ^{40}K present in the earth’s crust, in soil, air, water, building materials, the human body and food” [1]. “The soil, a major sink of environmental contaminants, comprises several organic and mineral components and acts as a repository for many environmental pollutants including naturally occurring radioactive materials (NORMS). The activity concentrations of these NORMs are low in natural form but can be enhanced and raised above background levels through human activities, hence posing a radiological risk to the public” [2].

“Gamma rays, alpha and beta particles are all forms of ionizing radiation emanating from the decay of NORMs, if present at sufficient levels, they can harm the health of humans and biota. Scientific studies conducted after the Fukushima disaster had revealed the consequences of radioactivity in living organisms, particularly in wildlife” [3].

“Bitumen exploited lands in Ondo State, Nigeria was reported to be radioactive, large chunk of coastal land had been reported to be unfit for crop production thereby worsening existing economic hardship being experienced by local farmers” [4]. “The soil and surface water are the major environmental media by which radionuclides enter the biological systems of biota” [5]. More so, these radionuclides can directly pose significant human exposure especially for local population, through major pathways such as external exposure, inhalation and ingestion depending on their concentrations. “Estimation of the public dose resulting from the residual radioactivity arising from bitumen exploration or exploitation activities is vital to ascertain the likelihood of public exposure resulting thereof and to provide public assurance that such exposure is below the recommended dose limit set by notable organizations. Previous literatures had reported the measured activity concentration of NORMs resulting from exploration or exploitation activities with values above or below the baseline limits” [6,7,8]. However, most of these works focus mainly on radiological risk to the populace while information on reclamation of contaminated environmental media were scanty.

“Good management of reclamation can mitigate and even solve the problem of radiologically contaminated environmental media, especially soil. In this context, RESRAD, a sustainability assessment tool, has been developed as an instrument to assess the sustainability of the rehabilitation of radiologically contaminated areas” [9,10]. “The RESRAD-ONSITE and RESRAD-BIOTA codes developed by the US DOE were designed to evaluate contaminated sites” [11]. They are used to derive clean-up criteria and to estimate the radiation dose and risk associated with residual radioactive materials, using site-specific parameters.

The aim of this work was to assess radiation risk from NORMs to an on-site resident farmer and biota inside a primary contaminated area within the bitumen belt of Ondo State, Nigeria. The entry parameters, namely the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K in the soil, to run RESRAD-ONSITE (Version 7.2) and RESRAD BIOTA (Version 1.8) codes were determined using a NaI-TI spectrometer. These parameters were used to calculate risks factors, such as; internal dose, external dose, total dose, excess cancer risk, sum ratio factor (SRF) and biota concentration guide (BCG). Among other things, the objective of this study is to provide baseline radiological data for environmental monitoring during exploitation of awarded bitumen blocks within the study area.

2. MATERIALS AND METHODS

2.1 Study Location

The study area occurs on the eastern margin of a coastal sedimentary basin known as the 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 postCretaceous 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 constituting another source of radioactivity due to the presence of NORMs in the bitumen.

2.2 Samples Collection

The soil samples were collected from selected farms with elevated natural radioactivity around communities with bitumen deposit. An estimated thirteen (13) soil samples were collected from a pre-determined depth of 0.5m – 1.0m [12], with the aid of hand auger across agricultural fields within the study area. The soil samples were obtained one each from Okitipupa, Iletitun, Igbotako, Omotosho, Ode-Aye, Agbabu, Ode Irele, Iyasan, Akotogbo, Loda, Ibekegbo, Igbobini and Araromi Sea-Side. The samples were sealed in a transparent polythene bag and carefully labeled to prevent sample mix-up. They were then properly marked and taken for processing and gamma spectrometry at the environmental laboratory of the Nigerian Institute of Radiation Protection and Research (NIRPR), belonging to the Nigerian Nuclear Regulatory Authority (NNRA) and situated at the University of Ibadan, Ibadan, Oyo State Nigeria.

2.3 Sample Preparation

Each soil sample was dried in a scientific setting until it reached a constant weight. Using a motorized grinder, the dry materials were ground and homogenized before being permitted to pass through a sieve with a mesh size of 200 m. 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 (Tl) 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. 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.

2.4.1 Calibration of the low background counting system

The International Atomic Energy Agency's (IAEA) standard reference materials (SRM) were used to calibrate the low background counting system's energy and efficiency. By determining the correlation between the peak point in the spectrum and the associated gamma-ray, the

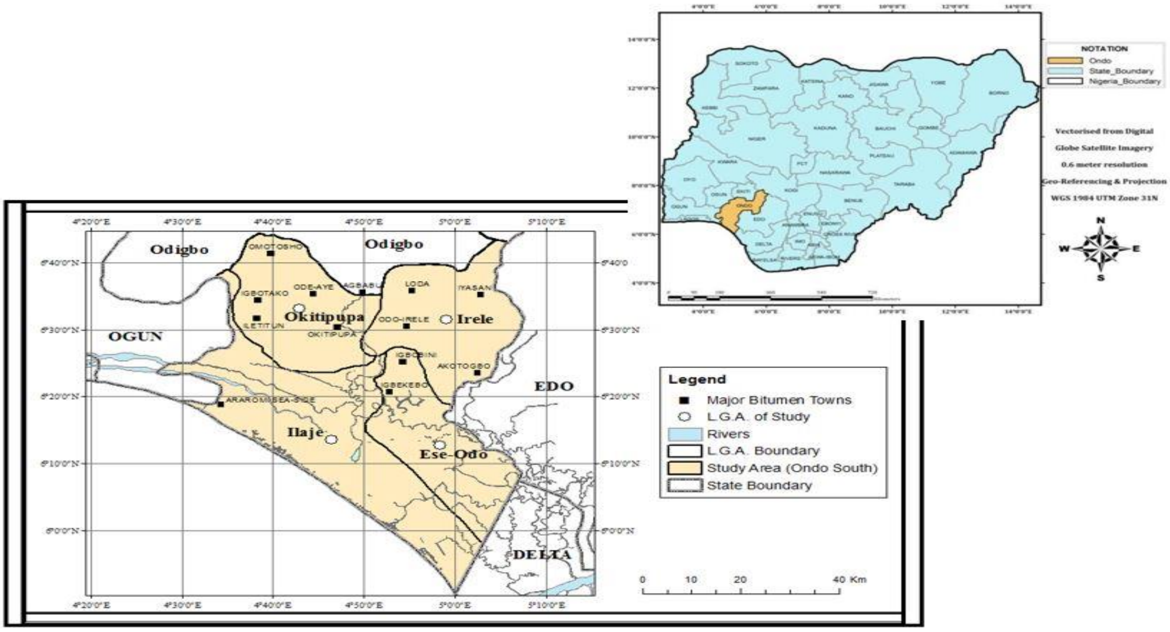

Fig. 1. Map of the study area

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 1800 seconds. 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.

3. EQUATIONS AND MODELS FOR TERRESTRIAL SYSTEMS

3.1 RESRAD-ONSITE

RESRAD-ONSITE code was developed by Argonne National Laboratory in the United States. It is a computing code that evaluates the potential exposure of an individual who works in an area contaminated with radioactive materials [13,14]. The code also allows users to specify their site's features and also to predict the total exposure dose received by an individual over a period of 1,000 years.

The likelihood of radionuclide migration and the level of radiation exposure experienced by workers and members of the public near a contaminated area are estimated using circumstances, and the main input factors affecting the total exposure dose through the different exposure pathways are thought to be site-specific. The risk of developing cancer from exposure to naturally occurring radionuclides in agricultural soil of Ondo State, Nigeria's bitumen belt, was evaluated in this study using version 7.2 of the RESRAD-ONSITE code. Table 1 contains a list of the site-specific parameters employed in the study.

3.1.1 Rate of radionuclide release from the contaminated zone

A nuclide dependent, first-order leach rate constant, which is defined as the percentage of the available radionuclide *i* that leaches out per unit of time, was used to determine the release-rate of radionuclides from the contaminated zone. Equation 1 represents the radionuclide release [15].

$$\frac{R_i(t)}{d_t} = L_i \times \rho_b \times A \times T \times C_i \quad (1)$$

Where; Li = leach rate for radionuclide *i* (yr^{-1}), ρ_b = bulk density of the contaminated zone (kg/m^3), A = area of the contaminated zone (m^2), T= thickness of the contaminated zone (m), and C_i = average concentration of the i^{th} principal radionuclide in the contaminated zone available for leaching rate.

Time independent radionuclide leach rate constant is a first-order leach rate constant utilized in RESRAD. It is calculated using equation 2 [15] and is based on the soil residence time for the initial thickness of the contaminated zone.

$$L_i = \frac{I}{V_{wc}\ x\ T_o\ x\ R_f} = \frac{[1-K_e]\ x\ \{P_r\ x\ (1-K_r)+I_r\}}{V_{wc}\ x\ T_o\ x\ R_f} \qquad (2)$$

Where; I is equal to the infiltration rate (m/yr), V_{wc} is volumetric water content of the contaminated zone defined as the product of the saturated water content of the contaminated zone V_{wc}^{s} and the saturation ratio of the contaminated zone R_s. The saturated water content V_{wc}^{s} is defined as the water content when the soil material is saturated. Hence, the saturated water content of the contaminated zone V_{wc}^{s} is equals to the total porosity P_t of the soil material. T_0 is the initial thickness of the contaminated zone (m), R_f is retardation factor in the contaminated zone for i-radionuclide, K_e is evapotranspiration coefficient, K_r is runoff coefficient (dependent on the environmental setting and the slope of the contaminated zone), P_r is precipitation rate (annual rainfall), and I_r is irrigation rate (m/yr).

When the medium is saturated, then the saturation ratio of the contaminated zone R_s equals unity. Under unsaturated infiltration conditions, the saturation ratio is a function of the infiltration rate, the saturated hydraulic conductivity, and the texture of the soil. The saturation ratio can be estimated by using equation 3 [16].

$$R_s = \left[\frac{I}{H_c^s}\right]^{\frac{1}{2b+3}} \qquad (3)$$

Where; H_c^s is equal to the saturated hydraulic conductivity (m/yr), b is soil-specific exponential parameter. The retardation factor for radionuclide i, R_s is the ratio of the average pore water velocity to the radionuclide transport velocity. Assuming that the adsorption-desorption process can be represented with a linear isotherm; the retardation factor can be calculated with the formula presented in equation 4 [17,18].

$$R_{fi} = 1 + \frac{\rho_b K_{di}}{V_{wc}} = 1 + \frac{\rho_b K_{di}}{P_t R_s} \qquad (4)$$

Where; K_{di} is equal to the distribution coefficient for the i^{th} principal radionuclide (cm^3/g).

It is a known fact that a radionuclide's leach rate depends on its K_{di} value, which establishes the radionuclide's relative transport speed to water in the pore space. The capacity of the liquid phase in soil is determined by the water infiltration rate, as well as by soil characteristics like bulk density, porosity, saturated hydraulic conductivity, the b-parameter, and the degree of contamination, which is indicated by the thickness, area, and radionuclide concentration of the contaminated zone.

3.1.2 Hydrogeological and hydro geochemical properties

The parameters of the zone underneath the polluted zone are considered to be the same as those of the saturated stratum in terms of hydrogeology and hydro geochemistry. The RESRAD code allows up to five horizontal strata below the contaminated zone, that is, n is ≤ 5. If n = 0, the contaminated zone extends down to the aquifer. The distance from the ground surface to the water table D_{wr} , at time t is evaluated using equation 5 [15].

$$D_{wr}\ (t) = C_d + T + \sum_{n=1}^{n+1} \triangle Z_M \qquad (5)$$

Where; C_d is equal to the cover depth (m), and T is the thickness of contaminated zone (m).

3.2 RESRAD-BIOTA

The RESRAD-BIOTA code is a tool for implementing a graded approach to biota dose evaluation. The code was principally sponsored and developed by the U.S. Department of Energy (DOE), with support from the U.S. Environmental Protection Agency (EPA) and the U.S. Nuclear Regulatory Commission (NRC), through the informal interagency Ecological Radiological Work Group (ECORAD-WG). The work group was led by DOE and coordinated under the oversight of the Interagency Steering Committee on Radiation Standards (ISCORS).

A full range of biota dose evaluation capabilities, ranging from broad screening techniques to thorough receptor-specific dose calculation, are offered by the RESRAD-BIOTA code. The code was created to support the anticipated needs of the DOE and other agencies while also being consistent with and serving as a tool for implementing the DOE's "Graded Approach for

Evaluating Radiation Doses to Aquatic, Sediment and Terrestrial Biota". Radiation exposure is thought to be caused through contaminated soil, water, and sediment, which then causes contamination of the air and various food sources.

For the purpose of creating default exposure parameter values, a variety of organisms were assessed. For a terrestrial system, these reference living things were divided into terrestrial animals and plants, and for an aquatic system, into aquatic animals and riparian animals. If the user enters the appropriate exposure parameters for the target organisms, RESRAD-BIOTA is capable of analyzing radiation exposures for those particular organisms. RESRAD-BIOTA version 1.8 offers 8 pre-configured geometries for the terrestrial environment at level 3 (step 3b of the US DOE graded method), since it is possible to change the organism's mass, Geometry 6 was used in this work to imitate terrestrial animals that are specific to the location under study.

3.2.1 Soil Biota Concentration Guides (BCGs) for terrestrial plants

The Biota Concentration Guide (BCG) is the maximum radionuclide concentration that can exist in soil, sediment, or water without exceeding the dose rate thresholds necessary to protect populations of aquatic and terrestrial biota [19]. Equation 6 represents the process used to determine the BCGs for terrestrial plants exposed to a single nuclide in contaminated soil [3].

$$BCG_{Soil,\ terrestrial\ plant,\ i} = \frac{365.25\ x\ DL_{tp}}{CF_{tp}\ x\ [(B_{iv,tp,i}\ x\ DCF_{int,i}) + DCG_{ext,i,sol}]} \quad (6)$$

Where, $BCG_{Soil,terrestrial\ plant,\ i}$ (B q/k g) is the nuclide concentration *i* in the soil; $B_{iv,tp,i}$ is the concentration factor of the fresh mass of the land plant with respect to the soil; CF_{tp} is the correction factor for area or time; DL_{tp} (0.01 Gy d^{-1}) is the dose limit recommended for terrestrial plants; $DCF_{ext,soil,i}$ (Gy.kg/y.Bq) is the dose conversion; $DCF_{int,}$ (Gy.kg/y.Bq) is the dose conversion factor.

3.2.2 Soil Biota Concentration Guides (BCGs) for terrestrial animals

The method used to derive the terrestrial animal BCGs for exposure to a single nuclide in contaminated soil is expressed in equation 7 [3].

$$BCG_{Soil,\ terrestrial\ animal,\ i} = \frac{365.25\ x\ DL_{ta}}{CF_{ta}\ x\ [(B_{iv,ta,i}\ x\ DCF_{int,i}) + DCG_{ext,i,sol}]} \quad (7)$$

Where, DL_{ta} (0.01 Gyd^{-1}) is the dose limit recommended for terrestrial animals; $BCG_{soil,ta,i}$ (Bq/kg) is the concentration of nuclide *i* in the soil; $B_{iv,ta,i}$ is the concentration factor of the fresh mass of land animals in relation to the soil.

3.2.3 Sum Ratio Factor (SRF)

The SFR is the value of the absorbed dose rate in biota relative to the total dose limit in biota. DOE reports show that the absorbed dose limits in biota are 10 m Gy d^{-1} for aquatic animals and terrestrial plants and 1 m Gy d^{-1} for terrestrial and riparian animals [19]. The following relationship gives the expression of SFR [3].

$$SRF = \frac{dose\ in\ biota}{dose\ limit} \quad (8)$$

Where the dose to biota is measured in Gyd^{-1}, and the dose rate limit value is based on international standard DOE reports (Gy d^{-1}).

3.3 Annual Effective Dose

The annual effective dose equivalent (AED) received by an adult in both indoor and outdoor settings from the absorbed dose rate in the air can be calculated using the concentrations of terrestrial gamma radiation from ^{238}U, ^{232}Th, and ^{40}K in the environmental matrix, using their respective average conversion coefficients and occupancy factor. While the occupancy factors were estimated based on the social habits of a typical resident farmer in Nigeria, they were assumed to be 0.3 and 0.5 for indoor and outdoor situations, respectively [20]. The conversion factor value was estimated to be 0.7$SvGy^{-1}$ for gamma ray exposure in the environment in both indoor and outdoor situations [21].

According to Ajetunmobi et al., [22], equation 9 was therefore utilized to estimate the AED in an outdoor setting. This index gauges the likelihood that exposed irradiated people may have stochastic and deterministic consequences [23]. For each sampling area, the annual total dose from the RESRAD-ONSITE code was also estimated.

$$H_e\ \text{(Outdoor)} = D \times T \times F_o \times 10^{-6} \quad (9)$$

Where H_e is the annual effective dose rate in $mSvy^{-1}$, D is the value of the absorbed dose rate in air at 1m above the ground (in $nGyh^{-1}$) calculated from equation 10 [24], T is the occupancy time ($T = f \times 24 \times 365.25$ h $year^{-1}$), f is the occupancy factor with value of 0.5 because the farmers spend 12 h out of 24 h outdoor, and F_o is the conversion factor with a value of 0.7 $SvGy^{-1}$.

$$D = 0.429A_{Ra} + 0.666A_{Th} + 0.042A_K \quad (10)$$

4. INPUT PARAMETERS AND SCENARIO DESCRIPTION

4.1 Activity Concentrations of Soil Samples

Helsel et al., [25] and Ewuzie et al., [26] provided a description of the sufficiency, trustworthiness, and representation of environmental data. The peak area for each energy in the spectrum of gamma spectroscopy was used to compute the activity concentrations in each sample using equation 11 [27]. Samples were measured for a duration of 29000 seconds per one. The results acquired were translated to conventional units using appropriate conversion factors [28,29].

$$A = \frac{C_{net}}{\gamma \ x \ \varepsilon(E_\gamma) \ x \ m} \quad (11)$$

Where, A is the activity in Bq/kg, C_{net} represent net peak counts for a given energy line, γ represent the emission of specific energy, $\varepsilon(E\gamma)$ is the absolute photo-peak efficiency of the detector, while m is the mass of the sample (in Kg).

4.2 Selection of Parameters for use in the RESRAD-ONSITE Code

According to Yu et al., [30], the exposure scenario used for this study represents typical chronic exposure settings for a farmer who is a permanent resident. To effectively estimate the exposure scenario, a number of elements, including soil activity concentrations, hydrological and geological traits, resident lifestyle choices, and others, were specified. We expected that the farmer would spend 50% of his time outside and 30% indoors [20]. The dose constraint was set at 0.25 mSv/yr [31], and because of secular equilibrium, the progeny's concentrations were identical to the primordial radionuclides.

For dosage assessments, the default values taken from the literature and site-specific parameters were employed [32], as given in Table 1. The Federal Guidance Report (FGR) 11 & 12 for internal and external dose conversion libraries, as well as the FGR 13 library for health risk, served as the foundation for the radionuclide transition based on the International Commission on Radiological Protection-38 library (ICRP 2008). Consideration was given to parent and daughter radionuclides with cut-off half-lives of at least 180 days.

The soil in the study area was classified to be loamy [33], hence the distribution coefficients (k_d) of the three zones (contaminated, saturated and unsaturated) were set at 15 cm^3 /g, 3300 cm^3 /g and 55 cm^3 /g for ^{238}U, ^{232}Th and ^{40}K respectively [15], and were used to evaluate the transport mechanism to the water table. However, "the storage times before use" were changed to 7 days for leafy vegetables and water, 3 days for milk, meat, and fish, and 90 days for livestock feed due to the lack of electricity in the majority of Nigeria's rural areas [20].

4.3 Selection of Parameters for use in RESRAD-BIOTA Code

For all computations, the pathways external gamma, inhalation, plant, meat, milk, and soil ingestion were all set to be active. The calculations were done at 1, 3, 10, 30, and 100 years to ensure that there was appropriate radiation protection. Parent and daughter radionuclides with cut-off half-lives of at least 180 days were taken into consideration.

In this work a three-system organism was employed, Nigerian Dwarf Goat (NDG) was selected and modelled along-side terrestrial plant and terrestrial animal. Defaults values were used in the calculation of the Bio-accumulation Factor (BIV) while modelling terrestrial plants and terrestrial animals. However, in modelling the selected NDG, some organism-specific parameters as shown in Table 2 were selected and used as allometric parameters, while geometry six (6) was also selected. Meanwhile, dose calculation was based on dose conversion factors [39,19]. Radiological parameters estimated using the RESRAD-BIOTA code includes; Bio-Concentration Guide, Sum Ratio Factor, Internal Dose, External Dose, and Total Dose.

Table 1. Basic defaults and site-specific input values used in RESRAD-ONSITE computation

S/N	Parameters	Site specific data	Default data	Reference
1.	Area of contaminated zone	-	10, 000 m^2	
2.	Thickness of contaminated zone	-	0.15 m	
3.	Density of contaminated zone	1.44 g/m^3	-	[34]
4.	Cover depth	0	-	-
5.	Length parallel to aquifer flow	-	100	-
6.	Contaminated erosion rate	-	0.001 m/yr.	-
7.	Contaminated zone total porosity	0.43	-	[35]
8.	Contaminated zone b- parameter	-	5.3	
9.	Evapotranspiration coefficient	-	0.5	-
10.	Wind speed	4.1 m/s	-	[36]
11.	Precipitation rate	1 m/yr	-	[37]
12.	Irrigation rate	-	0.2 m/yr	
13.	Hydraulic conductivity	1090 m/yr	-	[35]
14.	Runoff coefficient	0.65	-	[35]
15.	Density of saturated zone	-	1.5 g/cm^3	-
16.	Saturated zone total porosity	-	0.4	-
17.	Saturated zone effective porosity	-	0.2	-
19.	Saturated hydraulic gradient	-	0.02	-
20.	Saturated zone b- parameter	-	5.3	-
21.	Water table drop rate	-	0.001 m/yr	-
22.	Well pump intake depth	10 m	-	[38]
24.	Exposure duration	-	30 yrs.	-
25.	Indoor time factor	0.3	-	[20]
26.	Outdoor time factor	0.5	-	
27.	Fruits and grains consumption rate	-	160 kg/yr	-
28.	Leafy vegetable consumption rate	-	14 kg/yr.	-
29.	Soil ingestion rate	37 g/yr	-	[34]
30.	Drinking water intake	730 liters/yr	-	[20]
31.	Inhalation Rate	8059.2 m^3 /year	-	[34]
32.	Contaminated fraction of plant food	-	0.5	-
33.	Contaminated fraction of Milk	-	1.0	-
34.	Contaminated fraction of Meat	-	1.0	-
35.	Contaminated fraction of plant Aquatic Food	-	0.5	-
36.	Soil specific exponential b parameter	4.9	-	[35]

The US DOE dose rate limits (criteria) for terrestrial plants and terrestrial animals are reported as 0.01 and 0.001, respectively [3], in the RESRAD computation. Higley et al., [39] also provided descriptions of the formulas for external and internal doses. The concentrations of the progeny were equal to those of the primordial radionuclides due to secular equilibrium, and it should be noted that the average values of the activity concentrations were employed as input values in the RESRAD programs.

5. RESULTS AND DISCUSSION

5.1 Sum Total Dose for ONSITE R Esidents

Table 3 displays the activity concentrations of the primordial radionuclides ^{40}K, ^{232}Th, and ^{238}U as well as the total doses from all releases (external gamma radiation, inhalation of dust, and unintentional ingestion of soil, plants, milk, and meat) as a result of primary contamination for onsite resident farmer. The safety of the sites

Table 2. Basic defaults and organism-specific parameters used in RESRAD-BIOTA computation

S/N	Parameters	Organism Specific Data	Default Data	Description and/or Reference
1.	Life Span (yrs)	20	-	Maximum (https://goatowner.com/how-long-do-nigerian-dwarf-goats-live) Last Retrieved on 2nd June, 2023
2.	Mass (Kg)	34	-	Adult (https://www.betterhensandgardens.com/feeding-nigerian-dwarf-dairy-goats/) Last Retrieved on 2nd June, 2023
3.	Ratio of Active to Basal Metabolic Rate	-	2	-
4.	Calorific Value of food (kcal/g)	2430	-	Typical Nutrient Content of Hays (https://strayhounds.com/2018/04/05/finding-the-good-stuff-or-what-type-of-hay-to-feed-your-horse/) Last Retrieved on 9th June, 2023
5.	Fraction of Energy ingested that is assimilated and oxidized	-	0.44	-
5.	Mass Loading Factor (g/m^3)	-	0.0001	-
6.	Fraction of Soil in Diet	-	0.1	-
7.	Food Intake Rate (g/d)	2267.96	-	Adult NDG (https://www.betterhensandgardens.com/feeding-nigerian-dwarf-dairy-goats/) Last Retrieved on 12th June, 2023
8.	Sediment/Soil ingestion Rate (g/d)		71.1	-
9.	Water Ingestion Rate (L/d)	6	-	Adult NDG (https://farminly.com/nigerian-dwarf-goats eat/#Do%20Nigerian%20Dwarf%20Goats%20Eat%20Weeds?) Last Retrieved on 12th June, 2023
10.	Cut-Off Half-Live (days)	-	180	-

was determined by taking into account the total dose (mSvy^{-1}) received at the time t = 01, 03, 10, 30, and 100 years. The minimum total dose of 0.0014 mSvy^{-1} was attained in Araromi at t = 100 years, whereas the maximum total dose of 0.0229 mSvy^{-1} was attained in Agbagbu at t = 30 years. The National Research Council's acceptable limit of 0.25 mSvy^{-1} was exceeded by none of the predicted dosage values [31].

Similar to this, radiological models were employed to calculate the annual effective dose (AED) and Excess Cancer Risk (ECR) as a result of radionuclides found in agricultural soil samples taken from the study area. The outcomes were contrasted with the same risk parameters predicted using the RESRAD-ONSITE Code and shown in Table 4. The results demonstrate that the determined risk parameters were identical in both scenarios. This attests to the RESRAD Code's reliability.

However, changes in excess cancer risks (ECRs) during a 100-year period were seen in the study area. The lowest ECR value of 0.015 x 10^{-3} is shared by three communities; Omotosho (OMO), Akotogbo (AKG), and Ibekegbo (IKB), while Agbabu (AGB) has the highest ECR value of 0.050 x 10^{-3}. All the ECR values were lower than the world safe limit of 0.29 x 10^{-3} and by far lower than the values of 2.3 × 10^{-3} obtained by Gbadamosi et al., [40] in soils around tar-sand

Table 3. Activity concentration and sum total dose results RESRAD-ONSITE

Sample Locations	Activity Concentration of Soil $BqKg^{-1}$			Sum Total Dose ($mSvy^{-1}$)				
	^{40}K	^{238}U	^{232}Th	t = 1 (yr)	t = 3 (yrs)	t = 10 (yrs)	t = 30 (yrs)	t = 100 (yrs)
Okitipupa	37.65	2.81	2.53	0.0084	0.0089	0.0099	0.0086	0.0034
Iletitun	58.91	4.83	1.80	0.0125	0.0125	0.0122	0.0096	0.0028
Omotosho	8.73	3.21	2.73	0.0129	0.0129	0.0126	0.0094	0.0029
Igbotako	13.70	9.55	8.83	0.0056	0.0089	0.0165	0.0194	0.0107
Ode-Aye	47.59	8.20	2.83	0.0112	0.0111	0.0132	0.0101	0.0044
Ode-Irele	45.73	3.22	2.89	0.0112	0.1070	0.0119	0.0101	0.0039
Iyasan	39.90	3.98	1.20	0.0085	0.0085	0.0087	0.0061	0.0018
Akotogbo	17.52	4.55	2.00	0.0043	0.0048	0.0048	0.0063	0.0026
Loda	23.63	6.96	3.62	0.0061	0.0070	0.0096	0.0095	0.0046
Agbagbu	13.90	4.77	10.49	0.0061	0.0088	0.0191	0.0229	0.0127
Ibekegbo	46.72	5.73	1.42	0.0104	0.0100	0.0096	0.0071	0.0022
Igbobini	18.23	4.01	1.79	0.0048	0.0044	0.0058	0.0056	0.0023
Araromi	93.83	3.28	0.35	0.1899	0.0181	0.0153	0.0092	0.0014
Mean Value	35.85	5.01	3.27	0.0225	0.0171	0.0115	0.0103	0.0043

Table 4. Comparison of risk parameters estimated using RESRAD-ONSITE code and radiological model

Sample Locations	D ($nGyh^{-1}$)	AED (1yr)		EXCESS CANCER RISK (x 10^{-3})	
		Radiological Model (Ajetunmobi, 2019)	RESRAD ONSITE	Radiological Model (Taskin et al., 2009)	RESRAD ONSITE (x 10^{-3})
OKT	4.47	0.01	0.01	0.019	0.026
ILT	5.75	0.02	0.01	0.025	0.033
OMO	3.56	0.01	0.01	0.015	0.015
IGT	10.55	0.03	0.01	0.045	0.046
AYE	7.40	0.02	0.01	0.032	0.033
ODIR	5.23	0.02	0.01	0.022	0.031
IYS	4.18	0.01	0.01	0.018	0.024
AKG	4.02	0.01	0.01	0.017	0.015
LOD	6.39	0.02	0.01	0.027	0.025
AGB	9.62	0.03	0.01	0.041	0.050
IKB	5.37	0.02	0.01	0.023	0.026
IGBN	3.68	0.01	0.01	0.016	0.015
ARAROMI	5.58	0.02	0.19	0.024	0.043

deposit area of Ogun State, 1.356 × 10^{-3} by Gondji et al., [3] in soil around Cobalt-Nickel Bearing Areas of Lomié Eastern Cameroon and 3.46 x 10^{-3} by Njinga and Tshivhase, [15] around Tudor Shaft Mine Tailing Site, Krugersdorp, South Africa.

RESRAD-BIOTA Code (version 1.8) calculation results as shown in Table 5, revealed that the Bio-Concentration Guide (BCG) levels in the agricultural soil samples ranged from 4.56E+03 Bq kg^{-1} to 5.10E+04 Bq kg^{-1} for ^{40}K; 1.08E+04 Bq kg^{-1} to 8.75E+05 Bq kg^{-1} for ^{232}Th; and 4.61E+04 Bq kg^{-1} to 5.82E+05 Bq kg^{-1} for ^{238}U. These BCG values represent the limits of radionuclide concentrations in an environmental medium that will not result in exceeding the standard recommended doses for biota. The Sum Ratio Factors (SRFs) of ^{40}K, ^{232}Th, and ^{238}U in the soil samples show that the values of ^{40}K were 7.87E-03 for terrestrial animals, 6.54E-03 for NDG and 7.02E-04 for terrestrial plants. For the case of ^{232}Th, the values were 3.03E-04 for terrestrial animals, 5.88E-06 for NDG and 3.74E-06 for terrestrial plants while for ^{238}U, the values were 1.09E-04 for terrestrial animals, 2.35E-05 for NDG and 8.60E-06 for terrestrial plants. The total sum ratio factors (SRFs) for the different radionuclides met the requirement that this factor be less or equal to 1 [11]. Fig. 2a shows the variation of SRF in biota due to soil media in the study area.

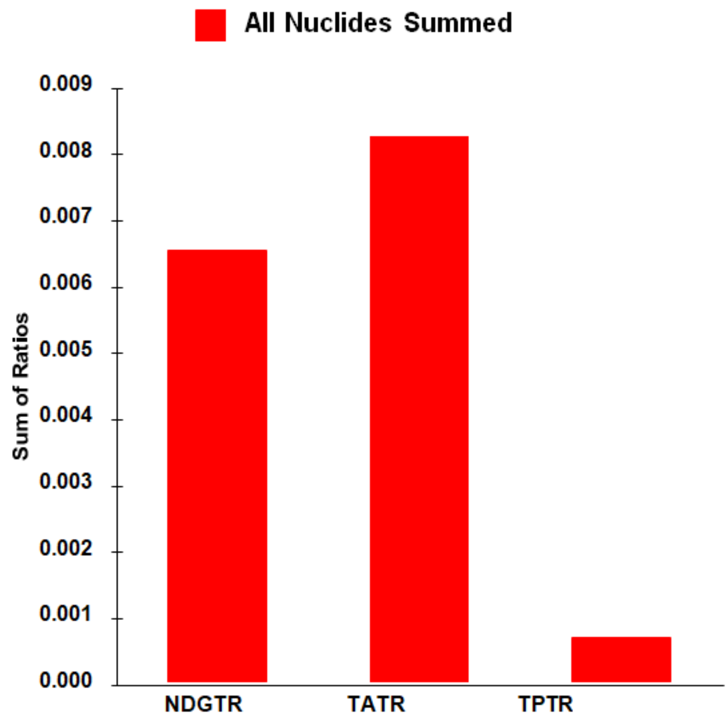

Fig. 2(a) Sum Ratio Factor (SRF) in biota

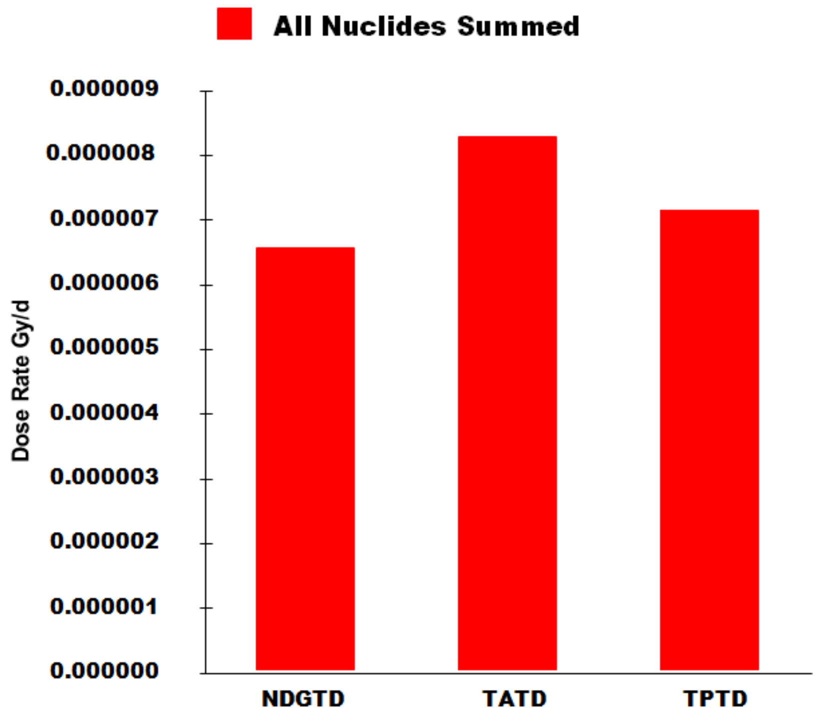

Fig. 2(b). Total dose rate in biota

Table 5. Biota Concentration Guide (BCG), Sum Ratio Factor (SRF), internal dose, external dose, and total dose of ^{238}U, ^{232}Th, and ^{40}K by Soil (Bq kg^{-1}) media

Risk Parameter	Radionuclides	Terrestrial Animal	Terrestrial Plant	Nigerian Dwarf Goat (NDG)
Sum Ratio Factor $\left(\frac{dose\ in\ biota}{dose\ limit}\right)$	^{40}K	7.87E-03	7.02E-04	6.54E-03
	^{232}Th	3.03E-04	3.74E-06	5.88E-06
	^{238}U	1.09E-04	8.60E-06	2.35E-05
Biota Concentration Guide (BCG) (Bq kg^{-1})	^{40}K	4.56E+03	5.10E+04	5.49E+03
	^{232}Th	1.08E+04	8.75E+05	5.56E+05
	^{238}U	4.61E+04	5.82E+05	2.13E+05
External Dose (Gy d^{-1})	^{40}K	3.34E-07	3.34E-07	4.78E-08
	^{232}Th	5.47E-10	5.47E-10	4.28E-12
	^{238}U	6.31E-08	6.31E-08	1.29E-09
Internal Dose (Gy d^{-1})	^{40}K	7.54E-06	6.69E-06	6.49E-06
	^{232}Th	3.03E-07	3.68E-08	5.88E-09
	^{238}U	4.55E-08	2.29E-08	2.22E-08
Total Dose (Gy d^{-1})	^{40}K	7.87E-06	7.02E-06	6.54E-06
	^{232}Th	3.03E-07	3.74E-08	5.88E-09
	^{238}U	1.09E-07	8.60E-08	2.35E-08
Overall Total Dose (Gy d^{-1})		8.28E-06	7.15E-06	6.56E-06

Similarly, the external dose rates for terrestrial plants and terrestrial animals due to exposure to ^{238}U, ^{232}Th, and ^{40}K were observed to be the same with values as; 6.31E-08 Gy d^{-1}, 5.47E-10 Gy d^{-1}, and 3.34E-07 Gy d^{-1} respectively. While external dose for NDG varies, with values as 1.29E-09, 4.28E-12 and 4.78E-08 for ^{238}U, ^{232}Th, and ^{40}K. The internal dose rates values for terrestrial plants were 2.29E-08 Gy d^{-1}, 3.68E-08 Gy d^{-1} and 6.69E-06 for ^{238}U, ^{232}Th, and ^{40}K respectively and those for terrestrial animals were 4.55E-08 Gy d^{-1}, 3.03E-07 and 7.54E-06 Gy d^{-1} respectively. While internal dose for NDG was found to be 2.22E-08, 5.88E-09 and 6.49E-06 for ^{238}U, ^{232}Th, and ^{40}K respectively. Fig. 2b shows the total dose rate in terrestrial animals, terrestrial plants and NDG for all nuclides summed in soil media within the study area. In Fig. 2 (a and b) NDGTR, TATR, TPTR, NDGTD, TATD and TPTD denote; Nigerian Dwarf Goat Total Ratio, Terrestrial Animal Total Ratio, Terrestrial Plant Total Ratio, Nigerian Dwarf Goat Total Dose, Terrestrial Animal Total Dose and Terrestrial Plant Total Dose respectively.

6. CONCLUSION

The presence of bitumen had a negligible effect on the study's annual effective dose rates and excess cancer risk predicted using the RESRAD- ONSITE code version 7.2, most likely because exploitation activity is yet to commence within the bitumen belt. Since the expected doses are less than the permissible limit of 0.25 mSvy^{-1} while the excess cancer risk values are below the world safe limit of 0.29 x 10^{-3}, the results obtained indicate that the sites may not have a negative impact on the health of the inhabitants (resident farmers) due to radioactivity from the agricultural soil, but there could be radiological health consequences as a result of bitumen exploration and exploitation over a long period of time within the study area.

Likewise, the overall total dosage due to all radionuclides summed, projected by RESRAD-BIOTA in this investigation, however, was higher in terrestrial animals, with value as 8.28E-06. NDG has 6.56E-06 as the lowest value of total dosage due to all radionuclides summed, while the value was 7.15E-06 for terrestrial plant. To be clear, none of the dose rate readings exceeded the US DOE standard dose limits of 0.01 for terrestrial plants and 0.001 for terrestrial animals, which shows that the biota is not in any danger from radiation.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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