RADIOLOGICAL SAFETY ASSESSMENT OF AGRICULTURAL SOIL WITHIN THE BITUMEN BELT OF ONDO STATE NIGERIA, USING RESRAD-ONSITE AND RESRAD-BIOTA CODES

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 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 $0.015 \text{ x } 10^{-3}$ 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 $0.29 \text{ x } 10^{-3}$. 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

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 rise above background levels through human activities, posing a radiological risk and putting the public at risk [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 have revealed the consequences of radioactivity in living organisms, particularly in wildlife [3].

Bitumen exploited lands in Ondo State, Nigeria is 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 have 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 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, this study is targeted at providing a 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 (Figure 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.

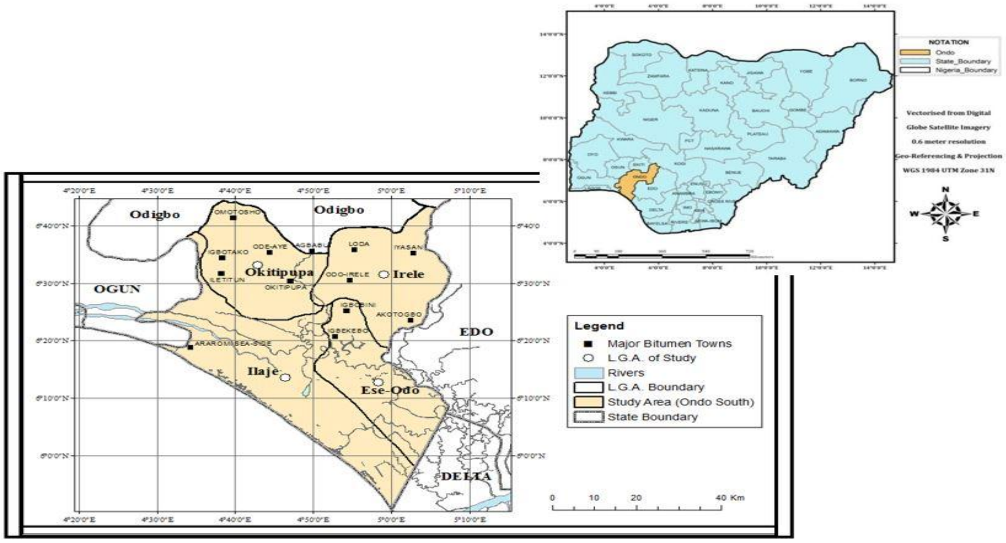

Figure 1: **Map of the study area**

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 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 size mesh. 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 its in-situ characteristics. The weights of the sealed samples were recorded using electronics 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**

The radioactivity measurement was done using Sodium Iodide (NaI-TI) scintillation detector. The detector is a lead shield Canberra 76mm x 76mm NaI (TI) crystal model number 802 series. It is a compatible sealed assembly which contains high-resolution NaI (Tl) crystal, a photomultiplier tube that detects the small visible light photons produced in the crystal and converts them into amplified electrical pulses, which is fed into analyzer systems through a preamplifier base. 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**

Both energy and efficiency calibration of the low background counting system was done using standard reference materials (SRM) from the International Atomic Energy Agency (IAEA). The energy calibration was done by obtaining the relationship between peak position in the spectrum and the corresponding gamma-ray. The height of each pulse output from a photomultiplier tube which was viewed on the display output and the channel corresponding to it, is directly proportional to the initial gamma energy producing 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 lets users specify their site's features and 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, is used to determine the release-rate of radionuclides from the contaminated zone. Equation 1 represents the radionuclide release [15].

$$\frac{R_i(t)}{d_t} = L_i \text{ x } \rho_b \text{ x } A \text{ x } T \text{ x } C_i \tag{1}$$

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 the 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.

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

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].

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

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].

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

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 are 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].

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

where, $BCG_{Soil\,,terrestrial\quad plant\,,\,i}$ (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].

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

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].

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

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 0.7SvGy^{-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.

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

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 × 24 × 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].

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	-	
26.	Outdoor time factor	0.5	-	[20]
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]

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.

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.

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	-	2	-

	Metabolic Rate			
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	-

4. **Results and Discussions**

4.1 **Sum Total Dose for ONSITE Residents**

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 was determined by taking into account the total dose (mSvy^{-1}) received at the times 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} is exceeded by none of the anticipated dosage values [31].

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**

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 characteristics calculated using the RESRAD-ONSITE Code and shown in Table 4. The results demonstrate that the predicted 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 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.

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

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]. Figure 2a shows the variation of SRF in biota due to soil media in the study area.

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 $\left(\frac{\textbf{dose in biota}}{\textbf{dose limit}}\right)$	^{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	^{40}K	7.87E-06	7.02E-06	6.54E-06

(Gy d^{-1})				
	^{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. Figure 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 figure 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.

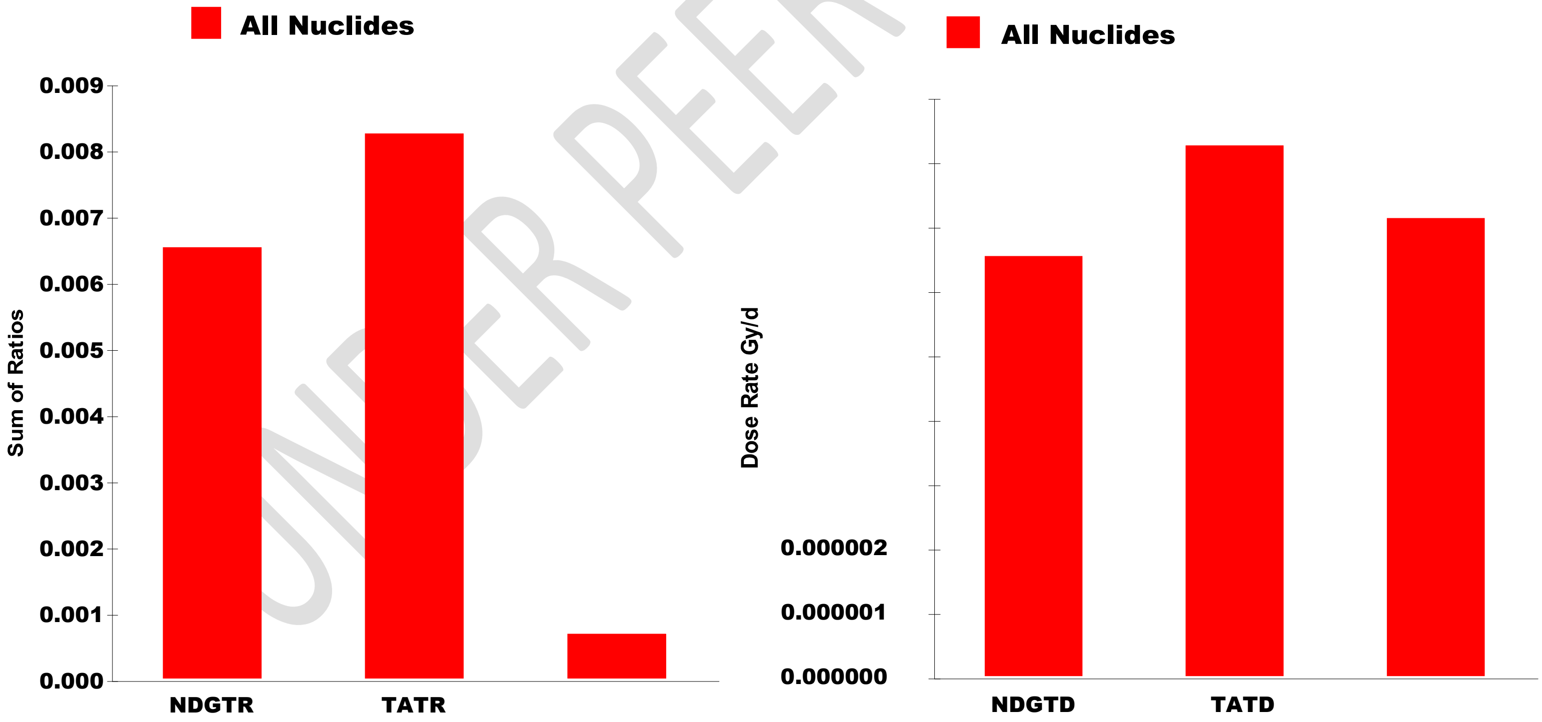

Fig. 2: (a) Sum Ratio Factor (SRF) in Biota

(b): Total Dose Rate in Biota

Conclusion

The presence of bitumen had a negligible effect on the study's annual effective dose rates and excess cancer risk estimated using the RESRAD- ONSITE code version 7.2, most likely because exploitation activities have not yet started 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 0.29×10^{-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.

References:

1. Idris, M. M., Rahmat, S.T., Musa, M., Muhammed, A. K., Isah, S. H., Aisha, B. & Umar, S. A. (2021). Outdoor background radiation level and radiological hazards assessment in Lafia Metropolis, Nasarawa State, Nigeria. *Aseana Journal of Science and Education*. 1(1): 27 – 35
2. UNSCEAR (2000). Radiation Sources and effects of Ionizing Radiations. United Nations Scientific Committee on the Effects of Atomic Radiation, New York. Report of the United Nations Scientific Committee on the Effect of Atomic Radiation to General Assembly.
3. Gondji, D.S., Mohamadou, L.L., Shouop, C.J.G., Ateba, J.F.B. & Saïdou. (2022). Assessment of trace elements pollution and their potential health risks in the cobalt–nickel bearing areas of Lomié, East Cameroon. *Environ. Monit. Assess*. 194, 127.
4. Nwankwo, J.N. & Ifeadi, C.N. (1988). Case studies of environmental impact of oil production and marketing in Sada, P.O. and Odemerho, F.O eds: Issues and Management in Nigeria Development. Ibadan: Evans Brothers, Nigeria Limited. 208-223
5. Vukašinovi´c, I.; Todorovi´c, D.; Đordevi´c, A.; Rajkovi´c, M.B. & Pavlovi´c, V.B. (2018). Depth distribution of 137Cs in anthrosol from the experimental field 'Radmilovac' near Belgrade, Serbia. Arch. Ind. *Hyg. Toxicol*. 64: 425–430.
6. Samuel, O.O., Pascal, T.F., Cornelus, A. & Muyiwa, M.O. (2018). Assessment of radioactivity levels and transfer factor of natural radionuclides around Iron and Steel Smelting Company located in Fashina Village, Ile-Ife, Osun State, Nigeria. *Working and Living Environmental Protection*. 15(3), 241 – 256.
7. Ogundele, L.T., Ayeku, P.O., Inuyomi, S.O., Ogunsakin, O.M., Oladejo, O.F. & Adejoro, I.A. (2020). Assessment of naturally occurring ^{40}K, ^{232}Th and ^{238}U and their associated radiological hazard indices in soils used for building in Ondo West Local Government Area, Southwestern, Nigeria. *EQA-International Journal of Environmental Quality*. 37:11–21.
8. Isinkaye, M.O., Jibiri, N.N., Bamidele, S.I., & Najam, L.A. (2018). Evaluation of radiological hazards due to natural radioactivity in bituminous soils from tar-sand belt of Southwest Nigeria using HpGe-Detector. *Int J Radiat Res*. 16(3): 351-362.
9. Jang, J., Kim, T.M., Cho, C.H. & Lee, D.S. (2021): Assessment for a near-surface disposal facility using RESRAD-ONSITE Code. *J. Nucl. Fuel Cycle Waste Technol*. 19: 123–132

10. Tawfik, A.A. & Ahmed, E.M. (2014). Radiological doses and risk assessment of NORM scrap metal by using RESRAD-RECYCLE computer code. *Open J. Model. Simul*. 34–42.
11. Yu, C.; Zielen, A.J., Cheng, J.J., LePoire, D.J., Gnanapragasam, E., Wallo III, A., Williams, W.A. & Peterson, H. (2001): User's manual for RESRAD version 6; ANL/EAD-4; Argonne National Laboratory, Environmental Assessment Division: Argonne, IL, USA.
12. Girigisu S, Ibeanu, I.G.E., Adeyemo, D.J., Onoja, R.A., Bappah, I.A. & Okoh, S. (2013). Assessment of radiological levels in soils from Bagega artisanal gold mining exercises at Bagega Zamfara State, Nigeria. *Archives of Applied Science Research*. 5(3):204-210
13. Setiawan, B., Prihastuti, S. & Moersidik, S.S. (2018). ^{137}Cs radiological risk estimation of NSD Facility at Karawang Site by using RESRAD-ONSITE application: Effect of cover thickness. *J. Phys. A*. 962(1):
14. Park, S.J., Byon, J., Ban, D.H., Lee, S., Sohn, W.S. & Ahn, S. (2020). Derivation of preliminary Derived Concentration Guideline Level (DCGL) by Reuse Scenario for Kori Unit 1 Using RESRAD-BUILD. *Nucl. Eng. Technol*. 52(6), 1231-1242
15. Njinga, R.L. & Tshivhase, V.M. (2018). Use of RESRAD-ONSITE 7.2 Code to assess environmental risk around Tudor Shaft Mine Tailing Sites. *Environment and Natural Resources Research*. 8(3): 138-147
16. Clapp, R. B. & Hornberger, G. M. (1978). Empirical equations for some soil hydraulic properties. *Water Resources Research*. 14(4), 601-604.
17. Yu, C. (1987). Modeling of low-level-waste disposal for environmental impact analysis (No. CONF-870306--70). Argonne National Lab.
18. Yu, C. (1999). RESRAD family of codes and comparison with other codes for decontamination and restoration of nuclear facilities. Chapter, 11, 207-231.
19. Sotiropoulou, M. & Florou, H. (2020). Radiological risk assessment in the terrestrial ecosystem: Comparative study of two software tools used for dose rate calculations. *Environ. Sci. Pollut. Res*. 27:18488–18497.
20. Bello, S., Garba, N.N., Muhammad, B.G. & Simon, J. (2022). Application of RESRAD and ERICA tools to estimate dose and cancer risk for artisanal gold mining in Nigeria. *Journal of Environmental Radioactivity*. 251-252
21. Tsukuda, H., Hidenao, H., Hisamastu, S. & Yamasaki, S. (2002). Transfer of 137Cs and Stable Cs from Paddy Soils to Polished Rice in Aomori, Japan. *Journal of Environmental Radioactivity*. 59 (3): 351-363.
22. Ajetunmobi, A.E., Mustapha, A.O., Okeyode, I.C., Gbadebo, A.M. & Al-Azmi, D. (2019). Assessment of radiological safety of abandoned tantalite mining sites in Oke-Ogun, Oyo State, Nigeria. *Radiation Protection and Environment*. 42 (1 & 2): 40-46
23. Alias, M., Hamzah, Z., Saat, A., Omar, M. & Wood, A. (2008). Assessment of absorbed dose and radiation hazard index from natural radioactivity. *The Malaysian Journal of Analytical Sciences*. 12 (1): 195-204.
24. Agbalagba, O.E. (2017). Assessment of excess life time cancer risk from gamma radiation level in Effurun and Warri city of Delta State, Nigeria. *Journal of Taibah University for Science*. 11: 367– 380.
25. Helsel, D.R., Hirsch, R.M., Ryberg, K.R., Archfield, S.A. & Gilroy, E.J. (2020). Statistical methods in water resources: USGS Techniques and Methods, Book 4, Chapter A3, 458p.
26. Ewuzie, U., Aku, N.O. & Nwankpa, S.U. (2021). An appraisal of data collection, analysis, and reporting adopted for water quality assessment: A case of Nigeria water quality research. HELIYON.

27. Esendu, N. B., Avwiri, G.O. & Ononugbo, C.P. (2022). Activity concentration and radium equivalent significance in soil from oil and gas fields in Nembe Communities, Bayelsa State, Nigeria. *Global Scientific Journals*. 10(4): 2283-2295
28. Knoll, G. F (2010). Radiation detection and measurement, 4th ed. New York: John Wiley & Sons
29. Ghoshal, S. N. (2008). Nuclear Physics, 8th ed. New Delhi: S. Chand & Company Ltd, Ram Nagar, 110 055.
30. Yu, C., Zielen, A.J., Cheng, J.J., LePoire, D.J., Gnanapragasam, E. & Kamboj, S. (2001b). User's Manual for RESRAD Version 6. US Department of Energy Office of Scientific and Technical Information, Oak Ridge, TN.
31. NRC (2000). NUREG 1727: NMSS Decommissioning Standard Review Plan. Available from: http://www.nrc.gov/reading rm/ doc collections/nuregs/staff/sr1727/. [Last accessed on 11th May, 2023].
32. Yu, C., LePoire, D., Gnanapragasam, E., Arnish, J., Kamboj, S., Biwer, B. M., & Mo, T. (2000). Development of probabilistic RESRAD 6.0 and RESRAD-BUILD 3.0 computer codes. US Nuclear Regulatory Commission
33. Tomori, W. B., Yanful, E. K., Amoo, I. A. & Aiyesanmi, A. F. (2017). Assessment of polyaromatic hydrocarbons in the bitumen belt of Ondo State, Southwestern Nigeria. *International Journal of Environmental Monitoring and Analysis*. 5 (2). 41-47.
34. Mathuthu, M., Kamunda, C. & Madhuku, M. (2016). Modelling of radiological health risks from gold mine tailings in wonderfonteinspruit catchment area, South Africa. *Int. J. Environ. Res. Public Health*. 13: 570.
35. Yu, C., Loureiro, C.O., Cheng, J.J., Jones, L.G., Wang, Y.Y., Chia, Y.P. & Faillace, E. (1993). Data Collection Handbook to Support Modeling the Impacts of Radioactive Material in Soil, ANL/EAIS-8 Environmental Assessment and Information Sciences Division. Argonne National Laboratory, Argonne, HI.
36. Olalekan, W.I., Zamri, M.I. & Albani, A. (2020). The status of the development of wind energy in Nigeria. *Energies*. 13: 6219
37. NNR: National Nuclear Regulator (2013). RG-002 Safety Assessment to Radiation Hazards to Members of the Public from NORM Activities. NNR, Pretoria, South Africa.
38. Limen, R.N. & Makondelele, V.T. (2018). Use of RESRAD-onsite 7.2 code to assess environmental risk around tudor shaft mine tailing sites. *Environ. Nat. Resour. Res*. 8 (3):
39. Higley, K.A., Domotor, S.L., Antonio, E.J. & Kocher, D.C. (2003). Derivation of a screening methodology for evaluating radiation dose to aquatic and terrestrial biota. *J. Environ. Radioact*. *66: 41–59.*
40. Gbadamosi, M.R., Afolabi, T.A., Banjoko, O.O., Ogunneye, A.L., Abudu, K.A., Ogunbanjo, O.O. & Jegede, D.O. (2018a). Spatial distribution and lifetime cancer risk due to naturally occurring radionuclides in soils around tar-sand deposit area of Ogun State, Southwest Nigeria. *Chemosphere*. 193:1036–1048.