Assessment of Naturally Occurring Radionuclides Accumulation in Palm Oil from Soil

O. B. Olafisoye, O. O. Oguntibeju, and O. A. Osibote

Abstract—Hyper Pure Germanium (HPGe) radiation detector was used to estimate the activity concentration of fifteen soil and palm oil samples collected from the oil palm plantations in the southwestern, southeastern, and south southern states of Nigeria, and the risk assessments was evaluated. The activity concentrations at a soil depth 0 – 15 cm ranged from 187.4 to 514.4, 2.328 to 6.571, and 1.509 to 6.121 Bq/kg for ^{40}K , ^{238}U , and ^{232}Th , respectively. The activity concentrations at a soil depth 15 – 30 cm ranged from 163.4 to 3188.8, 1.345 to 9.410, and 1.476 to 6.275 Bq/kg for ^{40}K , ^{238}U , and ^{232}Th , respectively. The activity concentrations in the palm oil ranged from 122.3 to 968.0, 1.240 to 6.651, and 1.199 to 8.061 Bq/L for ^{40}K , ^{238}U , and ^{232}Th . For the risk assessments of surface soil samples, the absorbed dose rate (D) ranged from 5.09 to 24.54 nGy/h, while the annual effective dose equivalent (E) ranged from 0.612×10^{-2} to 16.49×10^{-2} mSv/y. The radium equivalent, gamma absorbed dose rate, and the annual effective dose rate in the palm oil samples ranged from 9.981 to 88.00 Bq/L, 4.315 to 46.29 nGy/h, and 0.53×10^{-2} to 56.90×10^{-2} mSv/y, respectively. The activity concentrations reported for soil and palm oil samples were lower than the recommended world average values given by UNSCEAR. Hence, the hazard and risk assessments indicated a low radiation risk within the studied areas.

Index Terms—Activity concentration, oil palm plantations, pressed -palm fruit oil, risk assessment indices.

I. INTRODUCTION

The palm oil plantation is one of the cash producing crops in the south western, south eastern and south southern states of Nigeria supplying palm oil and palm kernel products for local farmers, chemical and allied industries. Vegetable oils or vegetable fats can be referred to as fats extracted from seeds or other parts of the fruit. They are similar to animal fats because they contain a mixture of triglycerides, saturated acids, palmitic acids and polysaturated acids. Palm oil is an edible vegetable oil that is reddish in color. It is extracted from the fleshy mesocarp of the fruit of the oil palm tree, which is indigenous to Africa and Asia. Red virgin palm oil is mechanically pressed from the flesh mesocarp of the oil palm fruit. The red orange color of the oil is derived from its high content of beta-carotene content. It is a highly saturated

vegetable oil and solid at room temperature. It is commonly used for cooking in parts of Africa, Asia, and South America [1]. It is a useful raw material for culinary purposes and also the food and chemical industry. Palm oil is favorable amongst food scientist due to its low cost and high oxidative ability and nutritional value as it contains a good amount of vitamin A and E known to cure various forms of cancer and heart disease [2], [3]. Unrefined, unbleached and un-deodorized virgin palm oil is rich in carotenes, (alpha and beta-carotenes) and lycopene. Palm oil is also used as a raw material in the production of biomass and biofuels and it is used extensively in industry because of its medicinal value and long shelf life [1], [4]-[7]. Nigeria is the third largest producer of palm oil with approximately 2.3 hectares of oil palm plantations under cultivation of small and large-scale processes of palm oil. [8]-[10] Other countries with relatively high yields in the production of palm oil are Thailand, Malaysia, and Indonesia [1].

The assessment of accumulation of radionuclides in pressed palm oil from contaminated soils is essential because the palm oil can be contaminated from other sources other than the soil. Apart from unwholesome agronomical practices, contamination may also arise during the extraction and pressing of the flesh using worn metallic vessels and contaminated water. The oil palm fruit can be contaminated in several ways; one of the ways involves the transfer of the radionuclides through soil and water [11]-[13]. This introduces radionuclides into the food chain and possesses risk to human life if the concentrations are high. The extent and concentration of radioactive materials in a particular region is dependent on geology, climate agronomical farming practices and more [14]-[17]. More of the effects of radiation are manifested in pulmonary and kidney cancer, leukemia and anemia [6], [18], [19]. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR, 2000) [18], stated that over one-eighth of the annual effective mean dose of radionuclides ingested by man is because of food. The concentrations of naturally occurring radionuclides in palm fruits can be more prominent in the rainy season when accumulation in fruits, shoots, and roots is put into consideration. This could be attributed to direct fallout or runoff from rain [11]-[13].

Radionuclides are accumulated by plants via soil through a process known as translocation from the roots to other parts of the plant [11], [12]. A complex mechanism exist through which radionuclides are transferred from soil/ground water to man and a correlation exists between this depending on the degree of accumulation in different types of plants [20], [21]. Naturally occurring radioactive materials are seen in the environment (air, water, soil, food and even in living things such as plants and animals). Naturally occurring radioactive materials (^{40}K , ^{238}U and ^{232}Th) are generally persistent in the

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O. B. Olafisoye is with the Department of Chemistry, Faculty of Applied Sciences, Cape Peninsula University of Technology, Cape Town, South Africa (e-mail: olafisoyeob@gmail.com).

O. O. Oguntibeju is with Department of Biomedical Sciences, Faculty of Health and Wellness, Cape Peninsula University of Technology, Cape Town, South Africa (e-mail: oguntibejuo@cput.ac.za).

O. A. Osibote is with the Department of Mathematics and Physics, Faculty of Applied Sciences, Cape Peninsula University of Technology, Cape Town, South Africa (corresponding author; e-mail: osibotea@cput.ac.za).

environment because they have long half-life and it takes days and years to completely decay [22]-[25]. It is pertinent to assess these naturally occurring radionuclides concentrations. According to (UNSCEAR, 2000) [10] the global mean dose of natural radiation is estimated to be 2.4 m Sv/y and from artificial or human-made uses 0.8 m Sv/y. Scientist have analyzed the radioactivity concentration in soil and palm oil samples globally and in Nigeria [1, [16], [21]-[23], [25]-[31].

Terrestrial radiation is transferred to water bodies from sediment [32]. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR 2000) [18] states that more than half of the radiation released on earth is from natural and non-cosmic sources. Amongst the terrestrial radionuclides is uranium, which is prevalent and persistent.

The entry of radionuclides that are present in the terrestrial environment and find entry into the food chain is controlled in the long term by their uptake by plant roots known as the transfer factor, T_f .

This is empirically addressed and modelled in an equation as seen below.

For the radionuclide 'i' in the edible part of the plant 'p', it is assumed that C_i^p (BqL⁻¹ dry weight) is linearly related to its concentration in soil within the rooting zone C_i^s (15-30 cm) depth. This is to say:

$$T_f = (\text{activity concentration of nuclide per liter}) / (\text{activity concentration in dry soil within the rooting zone}) \quad (1)$$

Globally more studies are carried out on the determination of radiation in different areas of the world either as routine checks or baseline studies in order to update previous investigations or investigate fallouts of radionuclides [30], [33]-[36]. Such studies are important for routine and baseline studies and the assessment of the possibility of health risk posed by radionuclides.

The analysis of radionuclides using the Hyper Pure Germanium Detector (HPGe) provided analyzed values of radionuclides and other required data for the calculations of these radionuclides which were compared with standard and permissible values reported by UNSCEAR, 2010 [35] and a comparison with previous studies

Palm plantations are mostly located in the south western region of Nigeria and the palm fruits are cultivated for the production of red palm oil. Such areas are endowed with crystalline basement rocks which are rich in Naturally Occurring Radioactive Materials (NORM) [37], [38]. Hence there is likelihood for soil to plant radionuclide transfer factor enhanced by the physio chemical properties of the soil. Activity concentration and hazard risk assessment were performed to check for risk to human and the environment. A summary (Table I) of a perception into the key findings of some of such investigations indicated that the activity concentration of the naturally occurring radionuclides (²³⁸U, ⁴⁰K and ²³²Th) and hazard indices were below the permissible limits laid down by regulatory bodies such as IAEA, UNSCEAR and ICRP [22], [35].

TABLE I: PREVIOUS WORKS IN AGREEMENT WITH PRESENT WORK

Reference	Region	Indices Investigated	Instrument Used	No of Samples	Results obtained
Alausa <i>et al.</i> , 2017 [21]	Elere Oil Palm Plantation, Ibadan, Oyo State, Nigeria	Activity Concentration of NORM. Transfer Factor from Soil to Palm Oil. Hazard & Risk Assessment	Na(Tl) Detector	Twenty samples of Soil & palm Oil from respective Palm Oil Trees	Within Recommended Limits by UNSCEAR
Augustine Kolapo, 2019 [39]	Oil Palm Plantation, Oyo State, Nigeria	Activity Concentration of NORM. Transfer Factor from Soil to Palm Oil. Hazard & Risk Assessment	HPGe	84 soil samples, 36 food crop samples, & 48 vegetable samples	Within Recommended Limits by UNSCEAR & ICRP
Usikalun et al, 2014 [40]	Ewekoro Cement Factory, Ogun State, Nigeria	Activity Concentration of NORM in Soil Samples used for Construction. Hazard & Risk Assessment	HPGe	Sixty Soil Samples	Within Recommended Limits by UNSCEAR
Chad-Umoren & Umoh, 2014 [41]	Soil samples in Abak, Nigeria	Activity Concentration of NORM in Soil Samples used for Construction. Hazard & Risk Assessment	HPGe	Ten soil samples	Within Recommended Limits by UNSCEAR & ICRP
Oladapo, 2012 [42]	Wasteland around Olusosun Dumpsite, Ojota, Lagos, Nigeria	Activity Concentration of NORM in Soil Samples used for Construction. Hazard & Risk Assessment	Na(Tl) Detector	Thirty Soil Samples	Within Recommended Limits by UNSCEAR
Jibiri & Amakom, 2010 [43]	Samples of soil waste stream in the sedimentation tanks of an oil & gas production well site Petroleum Company in Warri, Delta, State, Nigeria	Activity Concentration of NORM. Risk assessment, Cumulative Cancer Mortality & Morbidity Risk	HPGe	Samples of soil waste stream	Within Recommended Limits by UNSCEAR
George <i>et al.</i> , 2018 [44]	Samples of soil in a Kaolin Deposit of the mining field of Ifonyintedo Town, Nigeria.	Activity Concentration of NORM in Soil Samples used for Construction. Hazard & Risk Assessment	HPGe	Eleven Soil Samples	Within Recommended Limits by UNSCEAR
Olalekan <i>et al.</i> , 2019 [45]	A review of soil, rock, sediment, & water samples used in agriculture & construction industry in the northern and southern area of Nigeria.	Activity Concentration of NORM in Soil Samples used for Construction. Hazard & Risk Assessment	HPGe	A review of over fifty samples	Within Recommended Limits by UNSCEAR

This study aims to investigate the concentrations of radionuclides in red palm oil pressed from oil palm fruits

cultivated on anthropogenically contaminated oil palm plantation soils and evaluates the associated risk it posed. This will generate the baseline data of the level of radiation exposure in the region of study. It is also aimed for routine monitoring for environmental risk assessment in such region. The radionuclides of interest are the naturally occurring radionuclides ^{40}K , ^{238}U and ^{232}Th in palm oil pressed from oil palm fruits grown on fifteen independent oil palm plantations soils that may have been polluted anthropogenically by human made activities, as a baseline or monitoring evaluation to ascertain they do not exceed the permissible levels in the environment.

II. MATERIALS AND METHOD

A. Geology of Area

The study area is characterized by few mountains and steep terrains, which are rough with vegetation that is mostly rain forest. Most of the terrain is flat land with rivers. The climate is characterized into two major climates, which are the raining season and the harmattan. The raining season is between March and November and lasts for more than half the year. The soil receives a lot of rainfall all through the year and percolation of ground water into soil is to be considered in the transportation of radionuclides from water into soil and accumulation in the fruit. Hence, the transport of rainfall and the translocation from ground water to soil is of paramount importance [19].

The selected sampling locations (Table II) in states of Nigeria are home to rocks and sediments enclosing valleys and mountains from the south to the western regions of Nigeria. The geology of Nigeria was formed in the Archean and Proterozoic eras. Its province and more than half of the surface is igneous and metamorphic rocks with a crystalline and sedimentary basement. Massive sedimentation was under way in these basins as it returned to its terrestrial conditions within the Pan African mobile belt. The western and southern states lie between eight degrees North latitude and ten degrees south longitude. The terrain is mostly swampy, forest and some marshy areas with various rivers, landscapes, meadows, springs, peninsulas, and islands adorning the regions. The vegetation of the area is mostly forest, shrub land, and wetland, which support the growth of a lot of plantation and cash crops such as the oil palm, rubber, and cocoa tree plantations.

B. Description of Sampling Areas

Fig. 1 is the map of Nigeria showing all the fifteen sampling points. A brief description of some of the major cities and towns is given. Acharu is a town in Dekina local government area of Kogi state. Kogi state is popularly called the confluence state because of the confluence of river Niger and Benue. Flora Shaw coined the name Nigeria out of the river Niger in Lokoja. The Acharu town is blessed with reserves of oil palm. Agbarho is a town in the Ughelli North local government area of Delta state, Nigeria. This area is called the Niger delta and it is affected by oil spillages. In the Niger Delta – oil spillages or leakages are constant features of oil production and have caused physical damage. Benin City is famous for its bronzes and carved works. Deposits of bronze, tin and zinc are scattered around the metropolis.

Agriculture is the main occupation of the locality that provides income and employment for about 75% of the population.

Fig. 1. Map of Nigeria showing sampling locations.

TABLE II: SAMPLING LOCATION

Code	Location	Latitude	Longitude	Elevation above sea level (m)
PP1	Abak	4.9833	7.7833	174
PP2	Acharu	7.5320	7.2792	210
PP3	Agbarho	5.5833	5.8667	111
PP4	Ago-Emokpae	7.3400	6.4500	200
PP5	Apoje	6.9644	4.1064	24
PP6	Badagry	6.4166	2.8833	36
PP7	Benin city	6.3176	5.6145	88
PP8	Igede-Ekiti	7.6667	5.1321	576
PP9	Ikire	7.3533	4.1833	207
PP10	Iresa-apa	8.1504	4.2567	118
PP11	Nsukka	6.8667	7.3833	552
PP12	Okitipupa	6.5025	4.7795	305
PP13	Onishere	6.7150	5.1001	68
PP14	Ubiaja	6.6597	6.3822	255
PP15	Umuabi	6.17 36	7.2233	221

C. Sampling Procedure

Fifteen samples (S1-S15) were collected from topsoil (0-15 cm) and furthermore from a depth of soil (15-30 cm) by conventional methods of diagonal systematic sampling using an auger. Diagonal sampling was performed for each sampling point and the samples mixed for homogeneity to give a sample per location. The soil samples were left to dry in a cool airy cupboard for a month. Palm oil samples were taken from the same sampling points as soil samples. Palm oil was collected in 1L plastic bottles and the containers were labeled PO1-PO15 with respect to the fifteen sampling points as revealed in Table II. After the drying period for the soils, the previously dried samples were pulverized, crushed, and sieved using a 2 mm mesh sieve size to obtain soils with definite and homogeneous fine sizes. Sieved samples of soils were dried in an oven set at 100 °C for 24 hours then transferred to previously cleaned Marinelli beakers. This was properly sealed with paraffin film to prevent any escape of radon gas. Palm oil samples were treated similarly and sealed accordingly. The soil and palm oil samples were kept for a month for the radon gas and its progeny to attain secular equilibrium after which, gamma spectrometry measurements of the samples were carried out. The sampling locations, elevation, and coordinates are listed in Table II.

D. Gamma Spectrometry

The gamma-counting equipment was a Canberra vertical high-purity coaxial germanium (HPGe) crystal detector, model GC2018-7500, series number b 87063 enclosed in a 100 mm thick lead shield and coupled to a Canberra Multichannel Analysing (MCA) computer system. Calibration of the energy and efficiency of radionuclides was performed with the aid of a well-calibrated standard soil reference standard source supplied by the International Atomic Energy Agency (IAEA), Vienna. The MCA was calibrated to display gamma photopeaks in the energy range of 200–1500 keV, this being the energy range covering all the gamma energies of radionuclides of interest. The detector chamber was shielded with three layers of copper, cadmium, and lead of 30 mm, 3 mm and 100 mm thick, respectively. The photo-peaks observed with regularity in the samples were identified to belong to the natural radioactive decay series headed by ^{238}U and ^{232}Th , and a third non-series natural radionuclide, ^{40}K , for a counting time of 36000 seconds.

The activity of the natural radionuclides was calculated using equation 2.

$$As = \frac{Ca}{EPrMs} \quad (2)$$

where

Ca is the net counting rate of gamma ray (counts per second), E is the detector efficiency of the specific gamma ray, Pr is the absolute transition probability of gamma decay and Ms the mass of the sample (kg).

E. Radium Equivalent (Ra_{eq})

Radium Equivalent was used to describe the gamma radiation from the varying mixtures of the radionuclides in the soil and is calculated using the relation

$$Ra_{eq} = CRa + 1.43CTh + 0.077CK \quad (3)$$

where: CRa , CTh and CK are the activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K respectively. The index represents a weighted total of the above-mentioned radionuclides' activity concentrations because of an assumption that states that 1 Bq/Kg of ^{226}Ra , 0.7 Bq/Kg of ^{232}Th and 13 Bq/Kg of ^{40}K produce an equal amount of gamma radiation dose [19].

F. Absorbed Dose (D)

Absorbed dose rate is defined by United Nations Scientific Committee on the Effects of Atomic Radiation and provide the characteristic of the external gamma ray. This was calculated using the equation 4.

$$D \left(\frac{nGy}{h} \right) = 0.462CRa + 0.604CTh + 0.0417CK \quad (4)$$

This is the absorbed dose rate in air outdoor at 1 m above the ground surface due to specific activity concentrations of ^{238}U , ^{232}Th and ^{40}K (UNSCEAR, 2000).[18]

G. Annual Effective Dose Equivalent (E)

Annual effective dose equivalent, E is the parameter to determine the overall effects of the radiation on health due to the absorbed dose rate and calculated by the equation

$$E \text{ (mSv/y)} = D \text{ (nGy/h)} \times 8760 \text{ (h/y)} \times 0.2 \times 0.7 \text{ (Sv/Gy)} \times 10^{-6} \quad (5)$$

where the values 0.7 Sv/Gy is the conversion coefficient from absorbed dose in the air 1m above ground to effective dose received by adults, 8760 is the time taken in hours in a particular year, 0.2 represents the outdoor occupancy factor and is the observed dose rate [19].

H. Excess Lifetime Cancer Risk

The results of the statistics of cancer in Nigeria revealed that the age normalized occurrence estimate for all intrusive cancers was 66.4 per 100 000 men and 130.6 per 100,000 women. Data was based on the Population Based Cancer Registry (IBCR) and the Abuja Population Based Cancer Registry (ABCR) covering a 2 year period which was from 2009–2010 [46]. The term excess life time cancer risk describes the risk of death of cancer in excess of the natural background risk existing from a lifetime of exposure to carcinogenicity. Excess Life Time Cancer Risk ($ELCR$) was computed from the calculated values of the annual effective Doses as seen in equation [20], [46].

$$ELCR = AEDE \times D_L \times R_F$$

where D_L and R_F are the life time duration (70 years) and fatal cancer risk factor for the stochastic effect (0.055 Sv^{-1} for the general public respectively).

I. Spectrochemical Analysis

The prepared samples were analysed by gamma ray spectroscopy with the use of a Hyper Pure Germanium (HPGe) Detector. The counting time for the analysis was 36000 seconds and the soil reference material IAEA-375 was prepared in the same way as the sample and counted in triplicates alongside the sample. The photo peak of the gamma ray for the (^{214}Bi) 1764 keV; (^{228}Ac) 911.21 keV; (^{40}K) 1461 keV. The Absolute Full Energies were 0.02, 0.001 and 0.04 respectively. These were used to determine the activity of the naturally occurring radionuclides ^{238}U , ^{232}Th and ^{40}K . Their percentage emission probabilities corresponded to 14.9, 62.8 and 12.4 respectively. The detector was calibrated using the standard source which was a mixture of ^{22}Na , ^{57}Co , ^{60}Co . Spectra analysis was performed using Genie software 2000 developed by CANBERRA. The background contribution was removed by subtracting this from the result of the analysis.

The calculation of the full energy peak was achieved using the equation below [18].

$$E = N/TAB \quad (6)$$

N , is defined as the net count (count per seconds), T , is the time (seconds). A , is the activity in Becquerel and B , is the branching fraction ratio.

The Detection Limit (DL) is the net signal above which a signal can be considered to have been reliably detected. In this study, the Detection Limit (DL) and the Minimum Detectable Activity (MDA) was achieved by modelling the Curies Model formula which presents the background counts, branching ratio, sample mass and detector efficiency.

$$DL = 2.71 + 4.66\sqrt{N_B} \quad (7)$$

$$MDA = DL/TEBm \quad (8)$$

M is the mass the sample (kilograms) and N_B is the background counts (counts per second).

For the photo peak of the gamma ray (^{214}Bi) 1764 keV; (^{228}Ac) 911.21 keV and (^{40}K) 1461 keV, the Detection Limit (DL) the and the Minimum Detectable Activity (MDA), was calculated using equation and as 59.0 ± 0.3 , 52 ± 0.01 , 77 ± 0.01 and 3.5 ± 0.1 , 6.6 ± 0.1 , 8.2 ± 0.2 , respectively [18].

III. RESULTS AND DISCUSSION

Table III presents the concentrations (mean $\pm$ SD) of radionuclides (Bq/kg) of ^{40}K , ^{238}U and ^{232}Th in soil and palm oil samples collected from the various plantations. An unusual variation is seen in the sampling location. The activity concentrations of ^{40}K from soil depth of (0 – 15 cm) ranged from 187.4 – 514.4 Bq/kg (lowest and highest values

were recorded in Benin City and Ikire respectively). The activity concentrations of ^{40}K soil with depth (15 – 30) cm ranged from 163.4 – 602.7 Bq/kg and the minimum and maximum values were recorded at Iresa-apa and Okitipupa plantations respectively. The activity concentrations of ^{238}U from soil depth of (0 – 15) cm ranged from 2.328 - 6.571 Bq/kg and that of soil with depth (15 - 30) cm ranged from 1.345–9.410 Bq/kg. The activity concentrations of ^{232}Th from soil depth of (0–15 cm) ranged from 1.509–6.121 Bq/kg and that of soil with depth 15–30 cm ranged from 1.476–6.275 Bq/kg. Meanwhile, variations of activity concentrations values of radionuclides are better explained by the properties of the soil and accumulation of humus. In the uppermost layer, due to decay and mobility distribution, will require more advanced techniques and studies to determine if an area is safe or unsafe as far as health hazards is concerned. The values for Palm oil were in a similar pattern. Table III represents the Activity Concentration Values for NORM in Soils (Bq/kg) and Palm Oil (Bq/L)

TABLE III: CONCENTRATION VALUES FOR NORM IN SOILS (BQ/KG) AND PALM OIL (BQ/L)

Sampling Location	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th
	Soil Depth (0-15)			Soil Depth (15-30)			Palm Oil		
Abak	430.9 $\pm$ 0.07	4.905 $\pm$ 0.02	4.929 $\pm$ 0.06	343.2 $\pm$ 0.03	2.467 $\pm$ 0.01	4.935 $\pm$ 0.09	236.1 $\pm$ 0.02	2.677 $\pm$ 0.98	6.881 $\pm$ 0.01
Acharu	444.66 $\pm$ 0.01	3.228 $\pm$ 0.07	1.820 $\pm$ 0.01	421.6 $\pm$ 0.01	2.392 $\pm$ 0.02	4.365 $\pm$ 0.01	214.3 $\pm$ 0.01	4.790 $\pm$ 0.34	5.432 $\pm$ 0.02
Agbarho	345.0 $\pm$ 0.17	5.176 $\pm$ 0.19	3.148 $\pm$ 0.05	463.2 $\pm$ 0.02	4.877 $\pm$ 0.03	5.041 $\pm$ 0.02	150.4 $\pm$ 0.54	4.790 $\pm$ 0.11	2.156 $\pm$ 0.03
Ago-Emokpae	389.7 $\pm$ 0.08	5.778 $\pm$ 0.02	3.426 $\pm$ 0.02	653.4 $\pm$ 0.03	6.575 $\pm$ 0.04	4.770 $\pm$ 0.02	187.5 $\pm$ 0.02	1.705 $\pm$ 0.12	4.243 $\pm$ 0.01
Apoje	434.6 $\pm$ 0.01	4.153 $\pm$ 0.04	1.777 $\pm$ 0.09	219.2 $\pm$ 0.01	4.680 $\pm$ 0.05	1.476 $\pm$ 0.13	367.0 $\pm$ 0.03	3.757 $\pm$ 0.45	3.461 $\pm$ 0.24
Badagry	193.9 $\pm$ 0.67	3.812 $\pm$ 0.45	2.732 $\pm$ 0.04	211.4 $\pm$ 0.02	1.802 $\pm$ 0.02	4.007 $\pm$ 0.22	122.3 $\pm$ 0.01	2.890 $\pm$ 0.01	3.443 $\pm$ 0.33
Benin City	187.4 $\pm$ 0.34	6.173 $\pm$ 0.23	4.816 $\pm$ 0.01	281.1 $\pm$ 0.02	9.410 $\pm$ 0.09	6.275 $\pm$ 0.34	347.2 $\pm$ 0.02	3.924 $\pm$ 0.39	4.311 $\pm$ 0.07
Igede Ekiti	411.5 $\pm$ 0.05	5.030 $\pm$ 0.01	6.121 $\pm$ 0.02	467.5 $\pm$ 0.05	6.579 $\pm$ 0.02	4.237 $\pm$ 0.98	327.8 $\pm$ 0.01	2.960 $\pm$ 0.11	6.378 $\pm$ 0.21
Ikire	514.4 $\pm$ 0.04	3.471 $\pm$ 0.13	4.237 $\pm$ 0.03	169.0 $\pm$ 0.01	1.726 $\pm$ 0.01	1.829 $\pm$ 0.22	266.7 $\pm$ 0.12	3.192 $\pm$ 0.15	4.109 $\pm$ 0.17
Iresa Apa	455.8 $\pm$ 0.03	6.571 $\pm$ 0.23	4.121 $\pm$ 0.09	163.4 $\pm$ 0.03	1.345 $\pm$ 0.03	3.613 $\pm$ 0.12	212.5 $\pm$ 0.15	2.661 $\pm$ 0.41	1.199 $\pm$ 0.03
Nsukka	309.2 $\pm$ 0.01	2.328 $\pm$ 0.11	4.760 $\pm$ 0.01	318.8 $\pm$ 0.02	1.789 $\pm$ 0.03	3.500 $\pm$ 0.32	128.2 $\pm$ 0.12	2.475 $\pm$ 0.08	5.249 $\pm$ 0.02
Okitipupa	302.7 $\pm$ 0.04	3.189 $\pm$ 0.02	5.988 $\pm$ 0.03	602.7 $\pm$ 0.04	3.788 $\pm$ 0.12	4.239 $\pm$ 0.11	179.4 $\pm$ 0.09	1.240 $\pm$ 0.01	8.060 $\pm$ 0.01
Onishere	405.5 $\pm$ 0.08	5.462 $\pm$ 0.11	3.855 $\pm$ 0.21	507.4 $\pm$ 0.05	5.775 $\pm$ 0.99	5.472 $\pm$ 0.01	968.0 $\pm$ 0.02	6.030 $\pm$ 0.02	5.200 $\pm$ 0.01
Ubiaja	458.5 $\pm$ 0.01	3.106 $\pm$ 0.03	5.476 $\pm$ 0.02	451.7 $\pm$ 0.02	5.064 $\pm$ 0.34	2.343 $\pm$ 0.01	229.8 $\pm$ 0.02	1.996 $\pm$ 0.01	5.042 $\pm$ 0.02
Umuabi	475.6 $\pm$ 0.03	2.884 $\pm$ 0.01	1.509 $\pm$ 0.02	281.3 $\pm$ 0.01	2.327 $\pm$ 0.15	4.264 $\pm$ 0.02	238.6 $\pm$ 0.01	6.651 $\pm$ 0.03	1.509 $\pm$ 0.01

TABLE IV: VALUES FOR RA, D, & E IN SOILS AND PALM OIL

Sampling Location	Ra _(eq) (Bq/kg)	D (nGy/h)	E (mSv/y) ($\times 10^{-2}$)	Ra _(eq) (Bq/kg)	D (nGy/h)	E (mSv/y) ($\times 10^{-2}$)	Ra _(eq) (Bq/kg)	D (nGy/h)	E (mSv/y) ($\times 10^{-2}$)
	Soil Depth (0-15)			Soil Depth (15-30)			Palm Oil		
Abak	45.13	23.21	2.82	35.95	20.25	2.46	30.70	15.24	1.87
Acharu	38.07	18.54	2.25	41.10	21.32	2.59	29.06	14.43	1.77
Agbarho	36.25	21.12	2.56	47.76	24.61	2.99	19.45	9.787	1.20
Ago-Emokpae	40.69	20.99	2.55	63.71	38.17	4.63	22.22	11.17	1.44
Apoje	40.15	21.11	2.56	23.67	12.20	1.48	36.97	18.18	2.23
Badagry	22.65	11.50	1.40	23.81	12.07	1.46	17.23	8.514	1.05
Benin City	27.49	13.58	1.65	40.03	19.86	2.41	36.82	18.90	2.23
Igede Ekiti	45.47	23.18	2.81	12.64	5.60	0.68	37.32	18.90	2.23
Ikire	49.14	23.17	2.81	17.36	8.97	1.08	29.61	15.08	1.86
Iresa Apa	47.56	24.54	2.98	19.09	9.62	1.17	20.74	10.81	1.33
Nsukka	37.19	16.85	2.04	252.27	135.88	16.49	9.981	4.315	0.53
Okitipupa	11.75	5.09	0.62	56.26	29.44	3.57	26.58	12.92	1.60
Onishere	42.20	21.76	2.64	52.67	27.14	3.29	88.00	46.29	56.9
Ubiaja	46.25	23.87	2.90	43.20	22.60	2.74	26.90	13.55	1.67
Umuabi	41.66	22.07	2.68	30.09	5.39	6.54	27.18	13.93	1.71

Risk assessment indices can be used in the calculation of radionuclide dose in soils and palm oil. Table IV represents the risk assessment results for soil and palm oil obtained in the present study. The results showed the calculated values for Absorbed Dose Rates, Radium Equivalent Activities and Annual Effective Dose Rates for the naturally occurring radionuclides in soils and palm oil respectively. The absorbed

dose rate lies in the range of 5.09 nGy/h and 24.54 nGy/h in surface soils. The absorbed dose rate lies in the range of 5.09 nGy/h in Okitipupa and 24.54 nGy/h in Iresa -apa in surface soils (0-15 cm) and 5.39 nGy/h-135.88 nGy/h in Umuabi and Nsukka at depth 15-30 cm. The Annual Effective Dose equivalent was found to vary from 0.62×10^{-2} mSv/y to 2.98×10^{-2} mSv/y (0-15 cm) and these values were observed in

Okitipupa and Iresa-apa sampling locations in surface soils. The Annual Effective Dose equivalent was found to vary from 0.68×10^{-2} mSv/y to 16.49×10^{-2} mSv/y (15-30 cm) and these values were observed in Igede Ekiti and Nsukka sampling locations at depth 15-30 cm. The Radium equivalent values ranged between 11.75 to 49.14 (Bq/kg) in surface soils and these values were recorded in Okitipupa and Ikire plantations.

The Radium equivalent values ranged between 12.64 to 252.27 (Bq/kg) at soil depth 15-30 cm and these values were recorded in Okitipupa and Ikire plantations. The values were lesser than the worldwide values. The results in Table IV reveal that the Annual Effective Dose equivalent in soils was found to vary between 0.612×10^{-2} mSv/y to 16.49×10^{-2} mSv/y. R_{eq} , D and E values in palm oils were in the range of 9.981–88.00 Bq/L, 4.315–46.29 nGy/h and 0.53×10^{-2} –56.90 $\times 10^{-2}$ mSv/y respectively. The estimated average value of Radium equivalent (R_{eq}) in soils and palm oils were lower than the recommended value of 370 Bq/kg (UNSCEAR, 2010).[19] The gamma absorbed dose rates (D) in air in the present study were lower than the worldwide average limit value. The values for the Annual Effective Dose Rates (E) followed a similar trend. It was observed that decrease in these values was attributed to rainfall. Transport by rainfall is expectedly high due to changes in the elevation of the region. Radionuclides may be transported to new regions and values varied amongst different sampling locations due to the geographic structures, degree of rainfall and elevations of the region. Regions receiving higher degree of fertilizers, pre planting and post planting activities also contributed significantly to the level of radionuclide in the area. Values were generally lower than the global average limit value.

Table V show that the Transfer factor (T_f) in the pressed all palm oil was a little greater than unity/very close to unity.

TABLE V: T_f AND AEDE VALUES FOR NORM IN SOIL AND PALM OIL

Sampling Location	Transfer factor			Excess Life Time Cancer Risk		
	^{40}K	^{238}U	^{232}Th	AEDE		
	Soil Depth (15-30 cm)			Soil Depth (0-15 cm)	Soil Depth (15-30 cm)	Palm Oil
Abak	0.688	1.085	1.394	0.1086	0.0947	0.0720
Acharu	0.508	2.003	1.244	0.0866	0.0997	0.0682
Agbarho	0.325	0.982	0.428	0.0986	0.1151	0.0462
Ago-Emokpae	0.287	0.259	0.890	0.0982	0.1783	0.0554
Apoje	1.674	0.803	2.345	0.0986	0.0569	0.0859
Badagry	0.579	1.604	0.859	0.0539	0.0562	0.0404
Benin City	1.235	0.417	0.687	0.0635	0.0928	0.0859
Igede Ekiti	3.278	0.450	1.474	0.1082	0.0262	0.0859
Ikire	1.578	1.849	2.247	0.1082	0.0416	0.0716
Iresa Apa	1.301	1.978	0.332	0.1147	0.0451	0.0513
Nsukka	0.031	1.384	1.500	0.0785	0.6349	0.0204
Okitipupa	1.794	0.327	1.901	0.0239	0.1375	0.0616
Onishere	1.908	1.044	0.950	0.0264	0.1267	2.1907
Ubaja	0.509	0.394	2.152	0.1117	0.1055	0.0643
Umuabi	0.848	2.858	0.354	0.1032	0.2518	0.0658

This is an indication of low concentration of NORM from soil to pressed palm oil. Factors responsible include rhizospheres and bioavailability of NORM supported by soil factors and pore size of soils [47]. Rhizospheres can be defined as the section or area around the plant root. Environmental scientists define bioavailability of metals in soil solution as the concentration of that particular metal or compound that is accessible for the plant or organism. For

uptake by plants, bioavailability is related to the abundance of nutrients or contaminants such as heavy metals and trace metals, persistent organic pollutants, soil water, soil organic matter, oxygen in soils and water available for plant uptake [48]. Risk assessment can also be determined by the bioavailability of such elements in soils and factors, which influence the uptake. These factors include pH, cation exchange capacity, soil size and texture, soil organic matter, sorption, diffusion and fractions of the soils. The bioavailability of the metals and radionuclides from soil to the edible part of the plant also depends on the competing ions [49]–[53].

IV. CONCLUSION

All the naturally occurring radionuclides were detected in all samples of the soil and palm oil on the oil palm plantation, but they did not exceed the recommended guidance levels for the ingestion of radionuclides in food. The concentration of ^{40}K was found to be high in comparison to other radionuclides due to transfer from soils and high transfer ratio. Potassium is found readily in soils especially due to preplanting and post planting operations and the use of pesticides and phosphate fertilizer. In addition, soil characteristics may favor its mobilization and translocation into plant tissues of a micronutrient. However, radioactive potassium, ^{40}K concentration must be monitored closely as it transports and translocate to fruits through roots/shoot. The radionuclide ^{40}K is regulated by the human body. The high concentration of potassium in soil samples may be due to the tiny potassium ions trapped inside the clay particle composition of the soil attributed to the crystalline forces that hold these potassium ions uptake [54].

CONFLICT OF INTEREST

The authors declare no conflict of interest.

AUTHOR CONTRIBUTIONS

Olafisoye OB performed data collection, the experiment, and data analysis, and wrote the first draft of the manuscript. Oguntibeju O.O and Osibote OA conceptualized the research, supervised the study and edited the manuscript.

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Olafisoye Oladunni Bola obtained her PhD degree in chemistry from the Cape Peninsula University of Technology, Cape town South Africa. She is also a staff of the Department of Chemistry, Bowen University Iwo. She has published several articles in journals of repute.

Oluwafemi O. Oguntibeju is a professor of biomedical science and group leader (Phytomedicine & Phytochemistry Group), Cape Peninsula University of Technology Bellville, South Africa. He has successfully supervised 25 honours' projects, 24 masters and 6 doctoral students and currently supervising 6 doctoral and 6 masters' students. He has mentored three postdoctoral research fellows. He has published over 150 scientific articles in peer-review journals, 20 chapters in books, editor of three books on diabetes, presented over 70 papers at international and national conferences. He is a member of editorial board of various scientific journals and reviews manuscripts for various scientific journals. He has received various awards such as the Gold and Platinum Research Excellence Awards at his current university. In 2015, he received "Award for Excellence" in recognition of his contribution to biomedical research. He is a National Research Foundation (NRF) C-rated researcher. He

qualified as a biomedical scientist in June 1992 and holds a Postgraduate Diploma (FIMLS) of the Institute of Medical Laboratory Science, Nigeria in Clinical Biochemistry (1994), MSc degree in Biochemistry from the University of Ibadan (1997), Nigeria and a doctoral degree in Biomedical Science, Central University of Technology, Free State (2005), South Africa.

Otolorin Adelaja Osibote obtained her Ph.D (medical physics) from Escola Nacional de Saude Publica (National School of Public Health)-FIOCRUZ, Brazil. She was a postdoctoral research fellow in the Department of Nuclear Energy, Universidade Federal de Pernambuco (Federal University of Pernambuco), Brazil and in the Department of Human Biology (Biomedical Engineering) of University of Cape Town, South Africa. She was a junior research associate of the Abdus Salam International Center for Theoretical Physics from 2002 to 2006. Dr. Osibote assumed a faculty position in the Department of Physics, Olabisi Onabanjo University in 1995 and presently in the Department of Mathematics and Physics, Cape Peninsula University of Technology, South Africa. She has carried out research on several areas including irradiation of foodstuffs, quality assurance in diagnostic radiology, developments of algorithms for automated focusing of a microscope for the detection of tuberculosis and measurement of heavy metals and radioactivity in food and environmental fields.