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Assessment of Natural Radionuclides and Radiological Health indices in Soil of Oil Producing Communities, Rivers State, Nigeria

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ABSTRACT
The natural radionuclides and radiological health indices associated with the use of soil in communities with history of oil spillage, gas flaring, oil bunkering and operation of illegal artisanal oil refining activities in Rivers State was here assessed and measured with gamma ray spectroscopy. The results showed that the mean activity concentration of radionuclides in soil samples ranged from 17.77±4.20Bq/kg to 31.84±3.20Bq/kg for ^{238}U, 22.75±3.30Bq/kg to 33.82±4.70Bq/kg for ^{232}Th and 110.44±9.60Bq/kg to 483.15±18.20Bq/kg for ^{40}K, and are within permissible standard, but are higher than the mean activity in the control. Results further revealed that there was statistically significant difference at $p<0.05$ in the mean variations of the activity concentrations of natural radionuclides in the soil within the five communities and the control. The radiological hazard indices are all within tolerable values except for Bunu-Tai community whose annual gonadal equivalent dose was about 19.6% or 1.19 times higher than the international permissible value of 300mSv/y. Remediation measure is therefore recommended to minimize the risk of radiation from enhanced natural radionuclides in the soil.

Keywords: Artisanal oil Refining, Committed Annual Effective Dose, Excess Lifetime Cancer Risk, Oil Bunkering, Radionuclides

I. INTRODUCTION

Geological materials such as soil, rocks, earth crust, etc contain naturally occurring radioactive materials (NORMs) and are encountered during geologically related activities. These radioactive materials naturally emit radiations to the environment at low levels, but become higher when the level of radionuclides is enhanced by extraneous activities. Radioactive wastes arising from industrial activities are released into the environment as by-products of members of the ^{238}U and ^{232}Th decay series which results in enhanced level of natural radionuclides and higher radiation exposure to inhabitants in the environment. Oil and gas production and operations have been known to cause NORMs to accumulate at elevated concentrations in by-product waste streams (Smith et. al., 1999; Jibiri and Emelue, 2008). The discharge of industrial waste as well as deposition of particulate matter from gas flare stacks during crude oil and gas industrial operations has inevitably led to alterations in the quality of the environment. Knowledge of radionuclide distribution levels in the environment is therefore important in assessing the effects of radiation exposure due to natural and man-made sources.

Radionuclide activity concentration in soils is one of the main determinants of the natural occurring radiation because when rocks are disintegrated through natural process, radionuclides are carried to soil by rain through infiltration process (Taskin et. al., 2009). In the coastal areas of Nigeria, particularly the Niger Delta, oil and gas exploration and production industries as well as operation of illegal artisanal oil refining/oil bunkering activities

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are very dominant. The uncontrolled discharge of waste from these activities into the soil may elevate the activity concentration of natural radionuclides in the environment. Oni et. al. (2011) opined that apart from medical exposure, the petroleum industry which is the largest importer and consumer of radioactive materials discharges wastes containing radioactive materials in the soil and water bodies in the Niger Delta thereby exposing inhabitants in the area to radioactive radiations. It has been shown from studies by Taskin et. al. (2009) that human exposure to radiation leads to cataracts, sterility, atrophy of the kidney, leukaemia, hepatic cancer as well as cancer of the lung, pancreas, kidney, skin and bone. Knowledge of natural radioactivity present in soil would help to assess any possible radiological hazard to humans when it is used for building purpose and other domestic activities since soil is a major component of an ecosystem that is most endangered due to the influence of various human activities. This study is therefore aimed at applying statistical approach to access the level of radionuclide concentration in the soil of communities with history of oil spillage, oil bunkering activities, illegal artisanal oil refining, emission of particulate matter from flare stacks by operating oil and gas companies and to estimate the radiation health hazards associated with exposure of humans to radiations from soil radionuclides in some communities of Rivers State, Nigeria.

II. THE STUDY AREA

The study areas are five communities comprising Eleme, Bunu-Tai, Ban-Ogoi, Bodo and Giokoo. Eleme lies within Latitude 04º46'37.6"N and Longitude 007º07'51.0"E, Bunu-Tai lies within Latitude 04º45'41.0"N and Longitude 007º14'29.4"E, Ban-Ogoi lies within Latitude 04º36'43.4''N and Longitude 007º06'41.0''E, Bodo lies within Latitude 04º44'46.2''N and Longitude 007º06'32.1''E while Giokoo lies within Latitude 04º37'41.0"N and Longitude 007º16'21.1"E. The five communities respectively belong to Eleme Local Government Area (LGA), Tai LGA and Gokana LGA of Rivers State, Nigeria (Figure 1). The general topography is relatively flat lying and consists of terrestrial and marine environment. Due to the crude oil spills that covered the land, the terrestrial environment has patchy regenerating vegetation which consisted mostly of scanty and secondary type residual grasses. Each of the five communities are within 1,000m radius of the spilled sites, gas flaring at flow stations, oil bunkering and illegal artisanal oil refining activities. The soils are dark brown loamy soil to clay loam soil (Avwiri and Agbalagba, 2014).

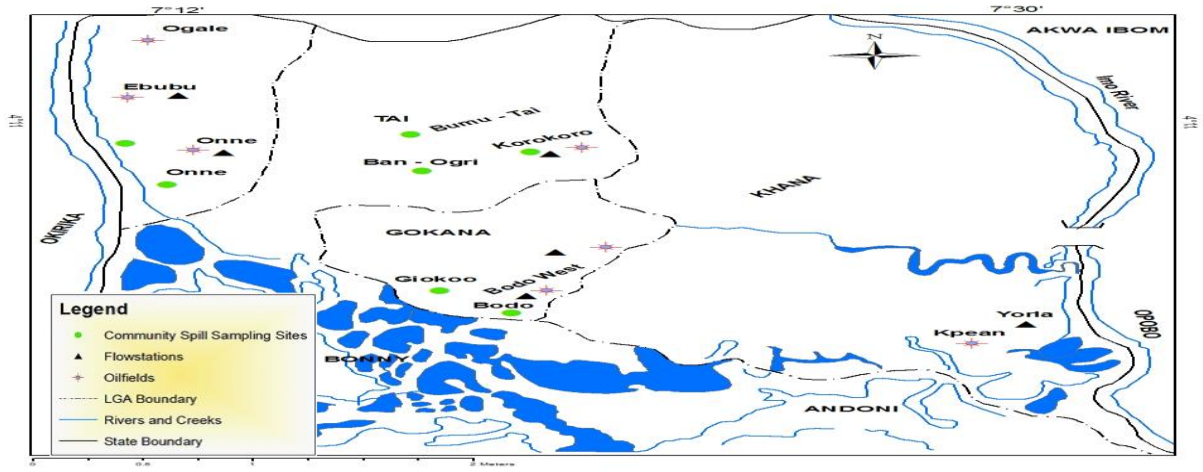

Figure 1: Map of the Study Area

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2.1 Regional Geology

The study area falls within the Niger Delta region which is made up of thick clastic sedimentary sequence with age ranging from Eocene to Recent and it sits astride the Niger flood plains, which overlies the Benin formation that is often called the coastal plain sand (Tattam, 1943). This formation consists predominantly of coarse grained sandy soils with few shale intercalations. The unconsolidated, highly porous sands of the Benin formation is a fresh water bearing sands zone (Amajor, 1991), and all aquifers in this region are located within this lithio-stratigraphic unit. The Benin formation comprises multiple layers of clay, clay conglomerates, peat and/or lignite all of variable thickness and texture and covered by overburden soil (Short and Stauble, 1967).

III. MATERIALS AND METHODS

3.1 Sample Collection and Preparation

The sampling strategy adopted was the purposive and stratified sampling methods, and samples were collected according to internationally established experience (ASTM, 1983, 1986; IAEA, 2004). The sites were split into sampling areas and were divided into cells of 50m by 50m grids. The grid blocks were assigned numbers, where a number generator such as N identical cards was used to select the grid points at which samples were collected within defined boundaries of the area concerned. Five cores were drilled in a zigzag pattern (randomly) within each cell and samples were collected from the cores within a 10-foot radius of the centre point for the sample. The samples so collected at different points randomly were mixed together thoroughly to give a composite sample. Each sampling point was selected independent of the location of all other sampling points such that all locations within the area of study had equal chance of being selected.

Five samples of soil were collected from the five communities (Table 1). Two samples each of soil were randomly collected from Eleme, Bunu-Tai, Ban-Ogoi, Bodo and Giokoo communities across the grids and were thoroughly mixed together to get a composite sample. The site of soil collection have close proximity with the oil spilled sites, flow stations flaring gases, and areas of oil bunkering and illegal artisanal refining activities. Three samples of soil were also collected from areas without history of oil spillage, gas flaring, oil bunkering and artisanal oil refining activities located about 57km away from the sampling communities which serves as control samples. The soil samples were collected with a steel hand geological coring tool (soil auger). The soil auger was cleaned with acid, detergent and rinsed with tap water before it was used to drill to a depth of 20cm. Avwiri and Agbalagba (2014) recommended that sampling for the average activity concentration in soil be taken in the top 20cm as this is the acceptable international compromise arising from alternate measures that are often based on deposition per unit area assuming atmospheric fallout. For each site, soil samples of about 2kg (wet weight) were collected and put in labeled vacuum black plastic bag directly after collection to prevent them from atmospheric humidity. The samples were transported to the laboratory where stones and organic materials were removed then air dried for room temperature to constant weight and sun-dry at 25±2^{o}C to remove the moisture content. The samples were further oven dried at a temperature of 105^{o}C for 1-2 hours to remove any remaining moisture content. The removal of the moisture took care of self absorption in each of the sample. The dried samples were pulverized into fine grains so as to increase the total emission area and then were passed through a sieve mesh of 150µm so that clay and mineral particle may homogenize. Thereafter, a sample of 250±0.05% was weighed and sealed with adhesive tape in air tight plastic containers of diameter 6.5cm that could seat in the detector head. The sealing with adhesive tape was to prevent the escape of the gaseous radionuclides in the samples. The samples were left for 4 weeks to allow for secular equilibrium between the long-lived parent radionuclide and their short-lived daughter radionuclides (^{226}Ra up to ^{210}Pb and ^{228}Th up to ^{208}Pb) in the ^{238}U and ^{232}Th decay series before counting.

Table 1: Communities where soil samples were collected

Community	LGA
Eleme	Eleme
Bunu-Tai and Ban-Ogoi	Tai
Bodo and Giokoo	Gokana

3.2 Sample Analysis

The activity of the natural radiouclide of the prepared soil samples were counted at the Centre for Energy Research and Training, Zaria with gamma ray spectrometer detector for 36,000 seconds to produce strong peaks at gamma emmiting energies at

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1,460Kev. The detector is a Thallium activated Canberra 7.6cm x 7.6cm sodium iodide [NaI(TI)] detector (model 803 series) coupled to a Canberra series 10 plus Multichannel-Analyzer through an ORTEC 456 amplifier base. The detector, enclosed in a 10 cm thick lead shielding lined with 1.5mm thick cadmium and 0.8mm thick copper, was connected to a computer program Maestro window that matched gamma energies to a library of possible isotopes. The lead shield was to reduce environmental background radiation. The ^{238}U and ^{232}Th activities were determined indirectly through the activities of their daughter products. The activities of ^{238}U was determined from the average activities of ^{214}Pb at 352kev and ^{214}Bi at 609Kev while that of ^{232}Th was determined from average activities of the decay products of ^{208}Ti at 583kev and ^{228}Ac at 911Kev. The activity of ^{238}U in the samples was calculated after subtracting decay correction. The background spectra measured under the same conditions for both the standard and sample measurements were used to correct the calculated sample activity concentrations. The net area under each photopeak, after background corrections, was used to calculate the activity concentration (Cs) of each radionuclide in the soil in accordance with Arogunjo et. al. (2005):

$$Cs\ (Bq/kg) = \frac{C_n}{\varepsilon P_\gamma M_s} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (1)$$

Where: Cs is the activity concentration of radionuclide in the sample, C_n is the count rate under each photo peak due to each radionuclide, ε is the detector efficiency for the specific γ-ray, P_γ is the absolute transition probability of the specific γ-ray, M_s is the mass of the sample (kg).

3.3 Radiation Hazard Indices

To assess the health status of radiated persons in an environment, UNSCEAR (2008) and ICRP (2012) recommended the following hazard indices for radiological risk assessment:

(i) Radium Equivalent Activity (Ra_{eq}): The most hazardous radionuclide that is released during the decay of ^{238}U is radium (^{226}Ra). Since 98.5% of the radiological hazard of uranium series is due to radium and its decay products, ^{238}U is replaced with concentration of ^{226}Ra in hazard assessment. Arising from non-uniform distribution of ^{226}Ra, ^{232}Th and ^{40}K in soil, uniformity with respect to exposure to radiation has been defined in terms of radium equivalent activity (Ra_{eq}) to compare the activity of materials containing different amounts of ^{226}Ra, ^{232}Th and ^{40}K. Therefore, for the purpose of comparing the radiological effect or activity of materials that contain ^{226}Ra, ^{232}Th and ^{40}K by a single quantity which takes into account the radiation hazards associated with them, a common index termed the radium equivalent activity is used (Baratta, 1990). This index makes possible the use of a single regulatory limit on radionuclide containing building materials rather than having to limit uranium, thorium and potassium separately (Farai and Ademola, 2005). This index also provides a useful guideline in regulating the safety standards on radiation protection for the general public residing in an area. The Ra_{eq} index represents a weighted sum of activities of ^{238}U, ^{232}Th and ^{40}K and it is based on the estimation that 370Bq/kg of ^{238}U, 259Bq/kg of ^{232}Th and 4810Bq/kg of ^{40}K provide the same gamma radiation dose rates.

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.077A_K \quad \ldots\ldots\ (2)$$

Where A_{Ra}, A_{Th} and A_k are the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K respectively measured in Bq/kg. The allowable limit of Ra_{eq} in soil is 370 Bq/kg (UNSCEAR, 2000, 2008) therefore the use of a material whose Ra_{eq} concentration exceeds 370Bq/kg is discouraged to avoid radiation hazards (OECD/NEA, 1979).

(ii) Absorbed Dose Rate (D): It is imperative to calculate the absorbed dose rate based on the fact that radiation exposure pathways involved dermal from soil by the inhabitants in the area. The absorbed dose rates (D) due to terrestrial gamma radiation and radionuclide concentrations at 1.0m above the ground surface was calculated from ^{238}U, ^{232}Th and ^{40}K activity concentration values in soil assuming that other radionuclides such as ^{137}Cs, ^{90}Sr and ^{235}U decay series are neglected since they contribute very little to the total dose from environmental background.

$$D = 0.462A_u + 0.604A_{Th} + 0.0417A_K \quad \ldots.\ (3)$$

Where: A_u, A_{Th} and A_K are the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg respectively. The unit of D is ηGyh^{-1}.

(iii) Annual Gonadal Dose Equivalent (AGDE): The gonads, the bone marrow and the bone surface cells are considered as organs of interest by UNSCEAR (2000, 2008) and ICRP (2012) because of their sensitivity to radiation. An increase in AGDE has been known to affect the bone marrow, causing destruction of the red blood cells that are then replaced by white blood cells. This situation results in a blood cancer called leukemia which is fatal (Avwiri et. al., 2014). Therefore, the AGDE due to the activities of ^{238}U, ^{232}Th and ^{40}K in the soil for residents in a community using this environmental material for building and other purposes was

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evaluated by with the equation (Avwiri et. al., 2012; UNSCEAR, 2008):

$AGDE(mSv/y)=3.09A_U+4.18A_{Th}+0.314A_K$.. (4)

Where A_u, A_{Th} and A_K are respectively the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg for the soil samples.

(iv)The External Hazard Index (H_{ex}): Most radionuclides occur naturally in terrestrial soils and rocks and upon decay, these radionuclides produce an external radiation field to which all human beings are exposed to. In terms of dose, the principal primordial radionuclides are ^{232}Th, ^{238}U and ^{40}K. Thorium and uranium head series of radionuclides that produce significant human exposure. The external hazard index becomes another parameter of interest. It is defined as (UNSCEAR, 2000; Beretka and Mathew, 1985):

$$H_{Ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots\ldots\ldots\ldots \quad (5)$$

Where A_u, A_{Th} and A_K are respectively the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in Bq/kg for the soil samples. The value of this index (H_{ex}) must be less than unity for the radiation hazard to be negligible (UNSCEAR, 2008) while H_{ex} equal to unity corresponds to the upper limit of radium equivalent dose of 370Bq/kg (Beretka and Mathew, 1985).

(v) The Internal Hazard Index: Radon (Rn) is the product of natural decay of radium (Ra), which is nearly in all rocks. The internal exposure to radon is very hazardous to the respiratory organs and can lead to respiratory diseases like asthma and cancer (Tufail et. al., 2007). Hence it has become imperative to evaluate and quantify the internal hazard index H_{in} by the relation (UNSCEAR, 2000; Beretka and Mathew, 1985):

$$H_{in} = \frac{A_{Ra}}{185} + \frac{A_{Th}}{259} + \frac{A_K}{4810} \leq 1 \quad \ldots\ldots\ldots \quad (6)$$

Again, the value of the internal hazard index (H_{in}) must be less than unity for the radiation hazard to be negligible (UNSCEAR, 2000).

(vi)The Representative Gamma Index ($I_{\gamma r}$): This is also known as gamma radiation representative level index (RLI) and it is used to estimate the gamma radiation hazard associated with the natural radionuclide in specific investigated samples. The representative gamma index is also used to correlate the annual dose rate due to the excess external gamma radiation caused by superficial materials. It is a screening tool for identifying materials that become of health concern when used for construction and other purposes (Tufail et. al., 2007). The representative gamma index is given by OCED/NEA (1979):

$$I_{\gamma r} = \frac{C_{Ra}}{150} + \frac{C_{Th}}{100} + \frac{C_K}{1500} \quad \ldots\ldots\ldots\ldots \quad (7)$$

(vii)The Committed Annual Effective Dose (AEDE): The fact that the inhabitants in the environment use soil and concrete bricks as building materials, 2 scenarios of external exposure are considered viz: outdoor (living within and near the study area) and indoor (living in the house built with concrete bricks made of soil) exposure. The annual effective dose equivalent received outdoor by a member of the public is evaluated from the absorbed dose rate by applying dose conversion factor of 0.7Sv/Gy and occupancy factor for outdoor while the annual effective dose equivalent received indoor by individuals living in the house or working in an enclosed office in factories is evaluated from the absorbed dose rate by applying dose conversion factor of 0.7Sv/Gy and occupancy factor for indoor. The occupancy factor for outdoor and indoor are taken as 0.2 and 0.8 respectively (Veiga et. al., 2006; UNSCEAR, 2000). According to UNSCEAR (2000), the occupancy factor for outdoor is taken as 0.2 because it was assumed that a person receives 5 hours of radiation outdoor within 24 hours annually (that is 5/24 = 0.2) whereas the indoor occupancy factor taken as 0.8 was assumed that a person is irradiated 19 hours indoors in every 24 hours (that is 19/24 = 0.8). The AEDE indoors occurs within a house whereby the radiation risks due to building materials are taken into consideration or within the factory whereby the radiation risks due to the materials on the workers are taken into consideration. AEDE outdoors involves a consideration of the absorbed dose emitted from radionuclides in the environment such as ^{238}U, ^{232}Th and ^{40}K. AEDE of the soil samples for outdoor and indoor exposure was therefore determined using the relation by UNSCEAR (2000).

For **outdoor occupancy:**

$AEDE\{Outdoor\}(mSv/y)=D(\eta Gy/h)\times 8760(h/y)\times 0.2\times 0.7(10^3 mSv/10^9)\eta Gy$

$$AEDE\{Outdoor\}(mSv/y)=D\times 1.2264\times 10^{-3} \ldots. \quad (8)$$

And for **indoor occupancy:**

$AEDE\{Indoor\}(mSv/y)=D(\eta Gy/h)x8760(h/y)\ x0.8x0.7\ (10^3 mSv/10^9)\ x10^{-3}$

$$AEDE\{Indoor\}(mSv/y)=Dx4.9056x10^{-3} \ldots\ldots (9)$$

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Where D is the average absorbed dose rate; 8760 hours (that is 365 days x 24 hours).

(viii) Excess Lifetime Cancer Risk (ELCR): This deals with the probability of developing cancer over a lifetime at a given exposure level and it is presented as a value representing the number of extra cancers expected in a given number of people on exposure to a carcinogen at a given dose (Ononugbo et. al, 2013). The Excess lifetime cancer risk (ELCR) is given as (Taskin et. al., 2009):

ELCR = AEDE x DL x RF …… (10)

Where AEDE is the annual committed effective equivalent dose, DL is average duration of life (estimated to be 70 years for Nigeria) and RF is the risk factor (Sv^{-1}) i.e fatal cancer risk per sievert. For stochastic effects, ICRP (2012) uses RF as 0.05 for members of the public.

3.4 Statistical Analysis

Due to the oil bunkering/artisanal oil refining activities, previous occurrence of oil spillages and gaseous emission of particulate matter from flare stacks at flow stations in the investigated communities, statistical analysis using SPSS version 20 software was performed on the soil data of the mean activity concentration among the five communities. The essence of the statistical analysis was to establish if the different activities associated with oil mining operations in the area has in any way affected the activity concentration levels of the radionuclides within the area. A one way Analysis of Variance (ANOVA) was employed to ascertain if there is a significant difference in the mean activity concentrations of radionuclides in the soil of the five communities and the control. In using this statistical tool, two hypotheses were propounded, the null (H_o) and the alternative hypothesis (H_1) which states as follows:

H_o: There is no significant difference in the mean activity concentration values of natural radionuclides in the soil of the five communities and the control

H_1: There is a significant difference in the mean activity concentration values of natural radionuclides in the soil of the five communities and the control

The statistical analysis were performed at 95% confidence interval and the Duncan post hoc test was also applied to determine statistically significant differences among individual means at $p<0.05$.

IV. RESULTS AND DISCUSSION

4.1 Statistical Analysis Assessment of Soil Radioactivity

The mean activity of soil samples ranged from 17.77±4.20Bq/kg to 31.84±3.20Bq/kg for ^{238}U, 22.75±3.30Bq/kg to 33.82±4.70Bq/kg for ^{232}Th and 110.44±9.60Bq/kg to 483.15±18.20Bq/kg for ^{40}K. These values are higher than the mean activity concentrations of the 3 radionuclides in the control samples (Table 2). However, the mean activity concentration of ^{238}U, ^{232}Th and ^{40}K in the community soil samples are respectively lower than the UNSCEAR (2008) permissible standard of 33Bq/kg, 45Bq/kg and 420Bq/kg except for ^{40}K value at Bunu-Tai soil which is higher than the permissible standard by 15%. The high activity value of ^{40}K at Bunu-Tai agrees with the works of Ajayi et. al (2009) who noted that the activity of ^{40}K in sedimentary rocks is due to the presence of feldspar, clay minerals and mica that characterize the formation of the Niger Delta. Nevertheless, to determine if the activity concentration of radionuclides in soil samples has been elevated in the five communities compared to the control sample, the data in table 2 were subjected to statistical testing. The result of the one way ANOVA test at 95% confidence interval revealed that there was a statistically significant difference in the mean activity concentration of the three radionuclides (^{238}U, ^{232}Th and ^{40}K) in the soil of the five communities compared to the control (Table 3). The null hypothesis was therefore rejected. This is an indication that the community's topsoil has been enriched with the three radionuclides. However, in order to identify the community whose soil contributed to this significant difference, multiple comparison tests (post hoc analysis) (Table 4) was run and the result showed that: (i) Soil samples at Bodo and Giokoo have similar mean values of ^{238}U therefore do not differ from each other, but they are statistically significantly different from the ^{238}U mean values of the soil samples at the control sites, Ban-Ogoi, Eleme and Bunu-Tai at $p<.0.05$. ^{238}U radionuclide contents in the soil samples at the control sites, Ban-Ogoi, Eleme and Bunu-Tai are also statistically significantly different from each other at $p<0.05$ in the following order: Control<Eleme<Bunu-Tai<Ban-Ogoi. (ii) Soil samples at Eleme and Giokoo have similar mean values of ^{232}Th therefore do not differ from each other, but they are statistically significantly different from the ^{232}Th mean values of the soil samples at control sites, Ban-Ogoi, Bodo and Bunu-Tai at $p<0.05$. ^{232}Th

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radionuclide contents in the soil samples at the control sites, Ban-Ogoi, Bodo and Bunu-Tai are also significantly different from each other at $p<0.05$ in the following order: Control<Ban-Ogoi < Bodo < Bunu-Tai. (iii) Soil samples at the control sites and Ban-Ogoi, Eleme and Giokoo have similar mean values of ^{40}K therefore do not differ significantly from each other, yet they are statistically significantly different from the mean ^{40}K values of the soil samples at Bodo and Bunu-Tai at $p<0.05$. ^{40}K radionuclide contents in the soil samples at Bodo and Bunu-Tai are also significantly different from each other at $p<0.05$ in the following order: Bodo<Bunu-Tai.

Table 2: Mean Activity of Radionuclides in the community's Soil Samples with Control

S/No	Sample Name	Specific Activity ($Bqkg^{-1}$)		
		^{238}U	^{232}Th	^{40}K
1	SS_{Eleme}	17.77±4.2	27.37±5.4	208.20±10.6
2	$SS_{Bunu-Tai}$	21.24±2.2	33.82±4.7	483.15±18.2
3	$SS_{Ban-Ogoi}$	31.84±3.2	22.75±3.3	110.44±9.6
4	SS_{Bodo}	30.29±3.7	24.25±2.4	248.90±15.4
5	SS_{Giokoo}	29.51±3.3	27.42±2.1	210.20±10.5
CONTROL SOIL SAMPLES				
1	S_{CS1}	2.91±0.5	4.58±1.2	35.20±5.3
2	S_{CS2}	3.85±1.3	7.02±1.4	118.42±11.4
3	S_{CS3}	3.12±2.2	6.48±3.1	120.04±8.5
UNSCEAR (2008) Standard		33	45	420

Table 3: ANOVA for ^{238}U, ^{232}Th and ^{40}K in the Soil Samples

		Sum of Squares	df	Mean Square	F	Sig.
Uranium-238	Between Groups	1339.885	6	223.314	431.009	.000
	Within Groups	7.254	14	.518		
	Total	1347.138	20			
Thorium-232	Between Groups	1800.210	6	300.035	1078.302	.000
	Within Groups	3.895	14	.278		
	Total	1804.106	20			
Potassium-40	Between Groups	310075.993	6	51679.332	153.070	.000
	Within Groups	4726.656	14	337.618		
	Total	314802.650	20			

Table 4: Multiple Comparison Test for ^{238}U, ^{232}Th and ^{40}K in the community soil samples with their Control

Radionuclides	Locations	Subset for alpha = 0.05						
		N	1	2	3	4	5	6
Uranium-238	Control	3	3.2933					
	Ban-Ogoi	3		31.8400				
	Eleme	3			17.7700			
	Bodo	3					30.2900	
	Giokoo	3					29.5100	
	Bunu-Tai	3						21.2400
	Sig.		1.000	1.000	1.000	1.000	.933	1.000
Thorium-232	Control	3	6.0267					
	Ban-Ogoi	3		22.7500				
	Bodo	3			24.2500			
	Eleme	3					27.3700	

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	Giokoo	3					27.4200	
	Bunu-Tai	3						33.8200
	Sig.		1.000	1.000	1.000	1.000	.933	1.000
Potassium-40	Control	3	91.2200					
	Ban-Ogoi	3	110.4400					
	Eleme	3			208.2000			
	Giokoo	3			210.2000			
	Bodo	3				248.9000		
	Bunu-Tai	3					483.1500	
	Sig.		.221	1.000	.896	1.000	1.000	
Means for groups in homogeneous subsets are displayed.								

4.2 Radiological Hazard Assessment of Soil Samples

The mean values of radium equivalent activity (Ra_{eq}), absorbed dose rates, indoor and outdoor annual committed effective dose, excess lifetime cancer risk, internal and external hazard indices, and gamma representative index due to the presence of ^{238}U, ^{232}Th and ^{40}K in the soil samples are all respectively lower than the permissible standards (Table 5). The mean value of Ra_{eq} in this study was found to be higher than the mean values of 60.75Bq/kg (for host community soil) and 74.71Bq/kg (for oilfield soil) reported in soils of Ogba/Egbema/Ndoni oil and gas fields by Avwiri and Ononugbo (2012). It is also higher than the average values of 6.03Bq/kg (for sediments) and 10.84Bq/kg (for soil samples) reported by Avwiri et. al (2014) in the soil, sediment and water around Mini-Okoro/Oginigba creek, PortHarcourt, Rivers State. This study Ra_{eq} mean value is higher than the mean value of 1380.74Bq/kg for radium equivalent activity obtained by Ononugbo et. al (2016) in the measurement of natural radioactivity and evaluation of radiation hazards in soil of Abua/Odual districts using multivariate statistical approach. The fact that the representative gamma index is less than unity helps to correlate that the annual effective dose of radiation of the soil sample to the inhabitants of Ogoniland is less than 1.0mSv/y and it agrees with the values reported by Ononugbo et. al (2013) and Ononugbo et. al (2016) on the external/internal hazard index and the representative gamma index for water and soils at Abua/Odual districts of RiversState, Nigeria. The values of the absorbed dose rates in the soil of the 5 communities are lower than the mean values of 654.2ηGy/h and 38.68ηGy/h respectively obtained by Ononugbo et. al. (2016) and Chad-Umoren and Nwali (2013). But this study mean values of the absorbed dose rate exceeded the 5.20ηGy/h reported by Avwiri et. al. (2014) in soil, sediment and water around Mini-Okoro/Oginigba creek, PortHarcourt, Rivers State. ^{238}U, ^{232}Th and ^{40}K constitutes 32%, 42% and 26% respectively to the absorbed dose rate in the soil samples with ^{232}Th contributing the highest to the absorbed dose rate (Figure 3) indicating that the absorption of radiation from^{232}Th by using the soil as construction material is more than the radiation from the other 2 radionuclides (ie ^{238}U and ^{40}K). The AGDE values of this study are 2.87 times higher than the average of 91.19mSv/y obtained by Avwiri et. al. (2012) for the soil profile of Udi and Ezeagu Local Government Areas of Enugu State. It is also over 7 times higher than the average value of 32.94mSv/y recorded by the works of Avwiri et. al. (2014) for soil, sediment and water around Mini-okoro/Oginigba creek, PortHarcourt, Rivers State. Again, the AGDE values of this study are found to be higher than 0.2143mSv/y obtained in the soil samples from petroleum oilfield at Oredo, Benin (Faweya et. al., 2014) but lower than 2398mSv/y obtained at Eastern Desert of Egypt by Arafa (2004) and the 4775.1mSv/y value obtained by Ononugbo et. al. (2016) in their study on the measurement of natural radioactivity and evaluation of radiation hazards in soil of Abua/Odual districts using multivariate statistical approach. The study found that the mean value of the AGDE in the soil sample at Bunu-Tai community is 1.19 times (i.e 19.6%) higher than the permissible limit of 300mSv/y (Figure 2) implying that the use of soil by the inhabitants of the community will pose serious threat to their bone marrow and cause bone surface cells disease. The mean values of AGDE in this study are lower than 27.9mSv/y obtained by Ononugbo et. al. (2016). Results showed that ^{238}U, ^{232}Th and ^{40}K constitutes

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32%, 45% and 23% respectively of the gross activity of the soil samples (Figure 4). This was calculated from the assumption that 370Bq/kg of ^{238}U, 259Bq/kg of ^{232}Th and 4810Bq/kg of ^{40}K produce equal gamma dose.

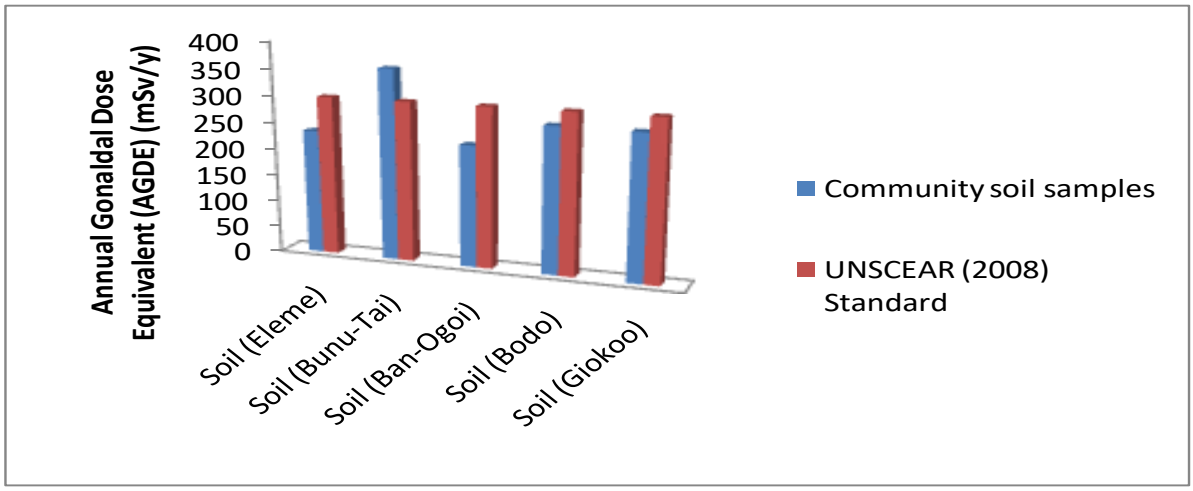

Figure 2: Annual Gonadal Dose Equivalent of the community soil samples

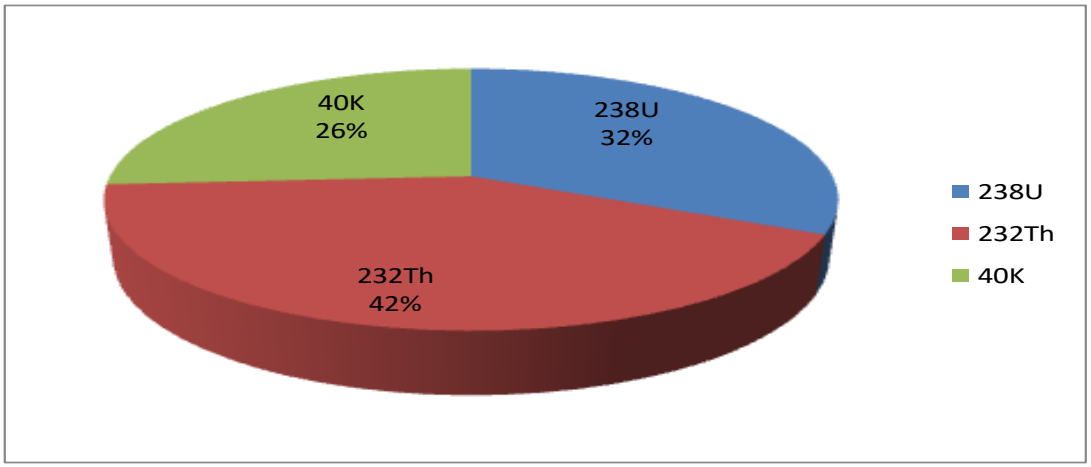

Figure 3: Percentage Contribution of the three radionuclides in the soil samples to the absorbed dose rates

V. CONCLUSION

The activity concentration of natural radionuclides (^{238}U, ^{232}Th and ^{40}K) in the soil samples in an environment with history of illegal artisanal oil refining/bunkering activities and gas flaring have been measured by gamma ray spectroscopy. The result showed that the activity concentrations of the three radionuclides in soil are within the permissible limits, but there was statistically significant difference at $p<0.05$ in the mean variations of the activity concentrations of natural radionuclides in the soils within the five communities considered and the control. The study also revealed that inhabitants of Bunu-Tai community have very high chances of contracting bone marrow and bone surface cells diseases when the soil is used as building materials due to its high annual gonadal dose equivalent value which is over 1.19 times higher than the international permissible standard of 300mSv/y. The authorities should therefore apply the international acceptable best practice technique to remedy the soil at Bunu-Tai community to minimize the risk of radiation from enhanced natural radionuclides in the soil.

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Table 5: Activity Concentration of Natural Radionuclides in the Soil Samples and the associated Radiation Hazard Indices

Sample ID	Specific Activity ($Bqkg^{-1}$)			Raeq (Bq/kg)	D (ηGy/h)	AEDE (Indoor) (mSv/y)	AEDE (Outdoor) (mSv/y)	AGDE (mSv/y)	ELCR (mSv/y)	Hex	Hin	$I\gamma_r$
	^{238}U	^{232}Th	^{40}K									
SS_{Onne}	16.67±5.7	25.60±6.2	151.90±13.8	64.97	29.50	0.15	0.04	206.21	0.13	0.18	0.22	0.47
SS_{Eleme}	17.77±4.2	27.37±5.4	208.20±10.6	72.94	33.42	0.16	0.04	234.69	0.14	0.19	0.25	0.53
$SS_{Bunu-Tai}$	21.24±2.2	33.82±4.7	483.15±18.2	106.81	50.39	0.25	0.06	358.71	0.22	0.29	0.35	0.80
$SS_{Ban-Ogoi}$	31.80±3.2	22.75±3.3	110.44± 9.6	72.84	33.04	0.16	0.04	228.04	0.14	0.19	0.28	0.51
SS_{Bodo}	30.29±3.7	24.25±2.4	248.90±15.4	84.13	39.14	0.19	0.05	273.12	0.17	0.23	0.31	0.61
SS_{Giokoo}	29.51±3.3	27.42±2.1	210.20±10.5	84.92	38.96	0.19	0.05	271.80	0.17	0.23	0.31	0.61
UNSCEAR (2008), WHO (2011); IAEA (2007), OECD (1979); ICRP (2012), and Taskin et. al. (2009) Standard	**33**	**45**	**420**	**≤ 370**	**59**	**0.41**	**0.07**	**300**	**0.29**	**≤ 1**	**≤ 1**	**≤1**

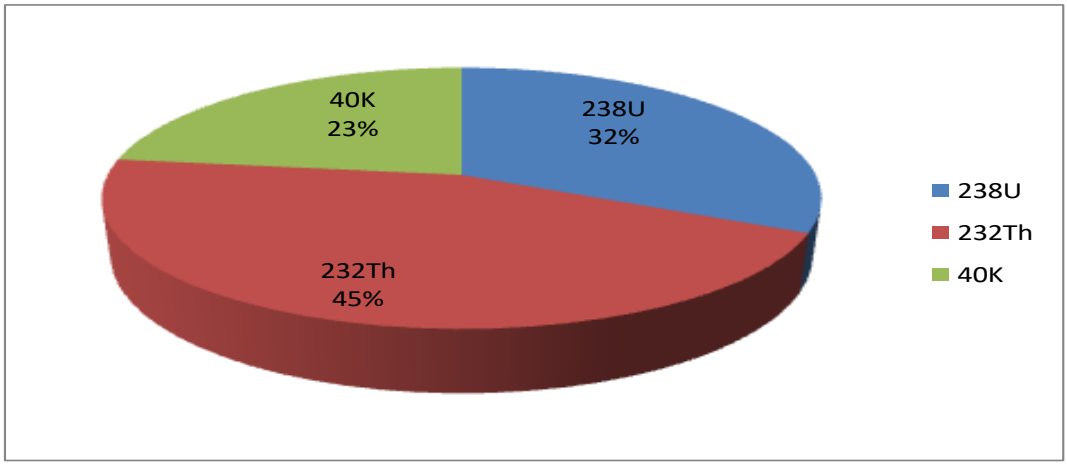

Figure 4: Percentage Contribution of the three natural radionuclides to the Gross activity of the soil samples

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