International Journal of Ecology and Environmental Sciences 46 (3-4): 211-221
ISSN: 0377-015X (Print); 2320-5199 (Online)

Investigation of Radiological Baseline Parameters of Proposed Nuclear Facility Site in South - South Nigeria

Godwin B. Ekong[1]*, Timothy C. Akpa[2], Ibrahim Umaru[3], Isa Sambo[4] and Samuel John Ogana[5]

[1,2,4]*Department of Radiological Safety, Nigerian Nuclear Regulatory Authority, Abuja, FCT, Nigeria.*
[1,2,3.4.5]*Department of Physics, Nasarawa State University, Keffi, Nigeria.*
Email IDs: [1]gobass04@yahoo.com; [2]timakpa@yahoo.com; [3]jamazara@gmail.com; [4] isasambo@yahoo.com; [5]samjoh2014@gmail.com
*Corresponding Author

ABSTRACT

Countries with insufficient electrical seek other alternatives amongst others in nuclear power. However, its perceived threats which adversely impact on people and the environment, has made radiological baseline assessment vital prior to nuclear power development. The aim was conducting radiological baseline evaluations on proposed nuclear power plant site in Itu, Southern, Nigeria situated at $5^0 10'0''$ N; $7^0 59'0''$ E. A systematic random method in demarcated radiological monitoring zones was employed, using RDS-31S/R survey meter, Hyper Pure Germanium detector and Channel Protean Instrument Corporation equipment. The Background Ionizing Radiation ranged from 0.041 ± 0.002 to 0.045 ± 0.002 µSv hr^{-1} with mean of 0.042 ± 002 µSv hr^{-1}. Also, the gross alpha concentration ranged from 0.02 ± 0.01 to 0.15 ± 0.02 Bq L^{-1} with mean of 0.06 ± 0.014 Bq L^{-1}, and gross beta concentration ranged between 0.015 ± 0.01 and 0.40±0.03 Bq L^{-1} with mean of 0.12±0.02 Bq L^{-1} for water samples. Furthermore, the mean activity concentration for soil, sediment samples were recorded as 47.98 ± 80 Bq kg^{-1}, 15.15 ± 1.0 Bq kg^{-1}, 38.65 ± 6,0 Bq kg^{-1} and 41.55 ± 6.0 Bq kg^{-1} for ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K respectively. Lastly, ^{137}Cs ranged from 1.08 ± 0.3 to 2.97 ± 0.4 Bq kg^{-1} with mean of 0.32 ± 0.1 Bq kg^{-1}. The radiological hazard indices estimations for mean Gamma Dose Rate was 32.15 nGy hr^{-1}, Annual Effective Dose Rate outdoors and indoor mean were 41.31 µSv yr^{-1} and 165.23 µSv yr^{-1}, respectively. Radium Equivalent mean of 99.16 Bg kg^{-1}, External Hazards index mean of 0.28 mSv yr^{-1}. The Committed Effective Dose of 7.17 $x10^{-02}$ mSv and 1.80$x10^{-02}$ mSv were estimated water intake for adult and infant respectively. These analysed and evaluated values were within admissible limits. The evaluated hazard indices pose no significant radiological threat to humans and environment, and can be used to establish radiological baseline prior to commencement of the nuclear facility in the area.

Key Words: Radiological Baseline; Hazard Indices; Activity Concentration; Gross Alpha/Beta; Nuclear Facility

INTRODUCTION

One essential element in economic development of any nation is energy. As population increases, it puts more demands on energy to cater for infrastructural development, industrialization etc, all these helps in growing nation's economy and thereby impacting on living standard of its populace (UNDP 2005). However, energy utilization per capita in Nigeria is about one-sixth of energy which is an express correlation to poverty level, and affects GDP which is total market value of all final goods and services produced within a given country over time (Karekezi 1997).

The Nigeria's major sources of energy supply are hydro and thermal power. Currently, there is an exponential increase of energy demand, due to population increase with corresponding decrease of electricity energy generation (Mordi *et al*. 2000, Famuyide *et al.* 2004). The major charge has been to supply electricity energy to cities and various industrialized places, creating an energy imbalance in Nigeria's socioeconomic/ political landscapes, and thereby causing rural-urban migration, deforestation due to bush burning causing pollution and global warming (Mordi *et al.* 2000, Famuyide *et al.* 2004). Evaluating the present epileptic electricity, ever growing population vis-à-vis existing energy, has prompted an alternative consideration of Nuclear Power Plant (NPP) to add to its energy mix, through a pronouncement and proposed four candidate sites selection which includes Itu, Nigeria (Onwuemenyi 2010, Anuforo *et al.* 2016, Youdeowei 2017). However, despite sites selection, Radiological

Impact Assessment (RIA), an aspect of Environmental Impact Assessment (EIA) is yet to be conducted.

Nuclear power reactors generally rely mostly on uranium as fuel with neutrons (^{1}n) bombardment, and split to generate a great amount of heat to raise steam, which drives turbines that convert into mechanical energy, a generator then converts mechanical power supplied by the turbine into electrical power (William 2013, Lilley 2001, Martin *et al.* 2012). In addition to the heat, fission products from a nuclear reaction are also released in varying amount either in control reaction (power or research reactor) or uncontrolled reactions (nuclear accident or testing) to the environment and environmental media thereby impacting on humans and other biota resulting in radiological health hazards (ICRP 2009, BBC 2011, IAEA 2005, 2014a, UNSCEAR 2008).

In the siting of nuclear power plant, an EIA comprising of aspects like geography and demography, meteorology and atmospheric dispersion, industry, transportation and military, geology, hydrology and Radiological Impact Assessment (RIA) are a prerequisite and is undertaken prior to commencement (STUK 2016, IAEA 2014a). However, this paper seeks to evaluate the existing situation in respect of RIA aspects as regards to background radiation level (BIR), Activity Concentrations (AC), gross alpha and gross beta concentration and Fission Products (FP) concentration that might be present in the environmental media of the area. BIR measures ambient radiation level, AC evaluates the primordial radionuclides (^{238}U, ^{226}Ra, ^{232}Th and ^{40}K) concentration in environmental samples, while gross alpha and gross beta concentration provides fairly accurate suggestion of radionuclide quantity in water and/or the extent of contamination but are not radionuclides specific (Avwiri and Agbalagba 2007). However, gross alpha emanates from ^{238}U decay series while gross beta from ^{232}Th decay series and ^{40}K non-decay series (Nguelem et al 2013), The FP concentration are fragments of nuclear test fall outs that may find their way to the environment over time from the biosphere (IAEA 2005, Ekong 2016).

The aim of the study was to establish a radiological baseline, useful for possible logical arguments to any contributions of nuclear fission reaction related activities before construction, check for incremental or build-up radiation values in future and for valuable estimation of radiological impact through various exposures pathways to the environment.

MATERIALS AND METHODS

Study Area

Itu (5°10′0 N 7°59′0 E) is a Local Government Area in Akwa Ibom State, Nigeria. It occupies about 606.10 km² of land mass with an approximate distance of 27 km from Uyo, the capital city of Akwa Ibom State as presented in Figure 1. The projected population as in 2013 was 161,572 with farming, fishing and trading being the major occupations of the Itu people (AkS 2014). The study area is bounded by four villages/LGAs from the north by Eki/Odukpani of Cross River State, the south

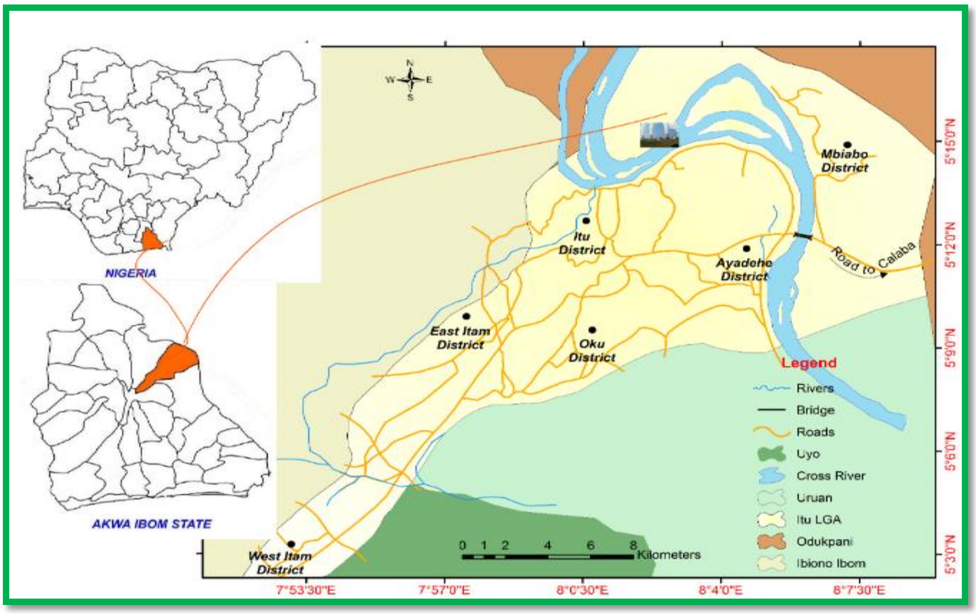

Figure 1. Presents Map of the study area Itu LGA Akwa Ibom State, Nigeria

by Uyo, the east by Anakpa/Uruan, and the west by Oko Ita/Ibiono Ibom all in Akwa Ibom State. The climate is tropical and made up of rainy and dry seasons. Rainy season is approximately averaged 2409 mm annual precipitation falls with temperatures ranging between 25.5 - 28.3 °C (Ayoade 1998).The hydrology of this area shows that Itu river, is drained by the Cross River on the east which branches and flows to form part of Itu River, the Imo River flows from the southwest, and Qua Iboe River flows from the South-central parts, all these rivers flow from the northern highlands of the State and drain into Atlantic Ocean in the south. The topography ranges between 66 – 131 meters above sea level (Beka and Udom 2014, Udom 2004). The hydrology of this area and perhaps the presence of river for cooling purpose is the major reason for proposed candidate site selection.

Equipment

Equipment used in the study was a RDS-31S/R Multi-purpose survey meters, Channel Protean Instrument Corporation gas free proportional counter, Hyper Germanium detector (Canberra co-axial type, 50% Relative efficiency, with Resolution of 2.4 keV-FWHM and at 1.33 MeV of Co-60) for gamma spectroscopy analysis. The calibration of the HpGe detector was performed using IAEA calibration Multi-Gamma Ray Standard (MGS6M315) standards, to acquire spectrum peaks of radionuclides spanning through energy lines of ^{241}Am at 59.5 keV to ^{208}Tl at 2614 keV, with which all other unknown radionuclides were dully detected and identified (Lilley 2001, Knoll 2010, Ekong and Audu 2014).

Sampling and Measurement Process

A systematic random method of sampling collection was applied in accordance with an NPP radiological monitoring plan subdivided into four (4) zones at various distance from a perceived point, these zones are: the Exclusion Zone (EZ) of about 1.5 km, the Sterilized Zone (SZ) of about 5 km, the Emergency Planning Zone (EPZ) of about 16 km and the Impact Assessment Zone (IAZ) of about 30 km radius (MoEF 2010), and four villages/LGAs bounded to Itu, LGA at 5 km radius incorporated into the map as can be clearly seen in Figures (2-4).

Data size analysis for this study was 225 BIR measurements were conducted, and a total of number 51 samples were collected for laboratory analysis from 40 villages, 4 villages/LGAs bounded to Itu, Nigeria at 5km distance, 7 sediments and 4 soils samples from each zone were sent for comparative activity concentration analysis. A two liters of Fourteen (14) polyethylene were used to collect water samples at seven (7) different points of Itu River and its tributary.

BIR measurements were conducted through a process of scanning around 360^0 with survey meter at each data points before taking reading at 1 meter from ground. Also, the soil samples collection were through a process of clearing the vegetation and other debris, taking samples upon measuring at a depth of 10 - 15cm by laser measuring meter. It is pertinent to note that there was thorough cleaning of the tool after each collection point to avoid any cross contamination of samples. Each sample was carefully labelled with codes for proper identification, well packed in a polyethylene bag and sealed. Furthermore, two litres of polyethylene container used for water collection were washed with detergent, rinsed with distilled water and finally cleaned with acetone before water collection from source. 10ml of concentrated nitric acid was added into each for preservation to inhibit microbial activities and to avoid reaction, between the container surfaces. Each water container was closed tightly and labelled accordingly for onward transportation to the laboratory for analysis (IAEA 1999, 2005b).

Determination of Gross Alpha / Beta, Activity Concentration and Hazards Estimations

Gross Alpha – Beta Screening

PIC a gross counting system for radioactivity measurement was used for speedy screen matrices for both high and low activities of alpha and beta emitting radionuclides in water, soils, sludge, waste water and solvents. The measurements technique are applicable for energies above 3 MeV for alpha emitters and 0.1 MeV for beta emitters and is calibrated for background counts rate and efficiencies using ^{90}Sr beta source and ^{239}Pu alpha source.

1000 ml of Water sample measured and transfered into the beaker and placed on the hotplate, and the temperature control to below 100 ^{o}C to prevent the water sample from boiling, in order to achieve the required residue. The weight of residue require for measurement is 77 mg (0.077 g) and is transferred into a sterilized planchette and weighed on the analytical balance. The planchette with the residue is mounted on the proportional counter for measurement to obtain the alpha and beta count rates.

For accurate result to be obtained, the counter characteristics (channel efficiency and background count rate), volume of sample used and sample efficiency have to be entered. The sample efficiency was calculated as given as (ASTM 2005, Avwiri and Agbalagba 2007):

$$\textbf{Sample Efficiency} = \left({}^{M_T}/_{0.1}\right) \times 100\% \quad (1)$$

where, M_T is the mass of residue in the planchette obtained from the sample preparation, approximately 0.1 mg is the expected mass of the residue in the planchette.

Activity of gross alpha screening results displayed from the counter after counting are as raw counts, count rate (count/min) activity and standard deviation. Acquiring data for alpha mode only and from its count rate, its activity is determined with (ASTM 1995, IAEA 1999):

$$\textbf{Activity } \boldsymbol{\alpha} = \frac{\text{Rate } \alpha \times \text{Background} \times \alpha \text{ Unit Coefficient}}{\text{Channel } \alpha \text{ Efficiency} \times \text{Sample Efficiency} \times \text{Sample volume}} \quad (2)$$

Where, α is the multiplication coefficient, efficiency and Background detection limit are well represented. From Equation (2), Alpha-activity concentration (c) can be calculated as given in Equation (3) (Avwiri and Agbalagba 2007).

$$\alpha_c = \frac{R_b - R_0 \times \alpha_s \times M \times 1.02}{R_b - R_0 \times 1000 \times V} \quad (3)$$

Where, R_b is observed sample count rate (s^{-1}), is the background count, αs is the specific activity of the alpha standard, V is the volume of the evaporated sample in liter and M (mg) of the residue from volume V and correcting factor of 1.02 added for 20 mL of nitric acid per liter as a stabilizer.

Gross Beta Screening results displayed after counting are as raw counts, count rate (count/min) activity and standard deviation. acquiring data for beta mode only and from its count rate, its activity is determined with (ASTM 1995, IAEA 1999):

$$\text{Activity } \beta = \frac{\text{Rate } \alpha \times \text{Background} \times \alpha \text{ Unit Coefficient}}{\text{Channel } \alpha \text{ Efficiency} \times \text{Sample Efficiency} \times \text{Sample volume}} \quad (4)$$

$$\text{Where Rate } \beta \text{ (cps)} = \frac{\text{Raw } \beta \text{ count } \times 60}{\text{Count time (sec)}} \quad (5)$$

Beta-activity concentration β_c (Bql^{-1}) can be calculated with (Avwiri and Agbalagba 2007):

$$\beta_c = \frac{R_b - R_0 \times \alpha_s \times M \times 1.02}{R_b - R_0 \times 1000 \times V} \times \frac{14.4}{1000} \quad (6)$$

Where, is introduced to represent the specific activity of ^{40}K in KCl, and other terms represented remains as already defined.

Committed Effective Dose

Radionuclides ingestion may gets to gastrointestinal tract directly or to the respiratory tract indirectly through inhalation where they are finally absorbed in the body fluids. The annual committed dose due to radionuclide absorption to the body is (Avwiri *et al*. 2016).

$$E_{Ave\,(\alpha/\beta)} = \Sigma A_{i(\alpha/\beta)} \times DCF_{i(\alpha/\beta)} \times CR_{i(Adult\,/Infant\,)} \quad (7)$$

The annual committed dose due to Alpha is considered to be majorly from ^{226}Ra of ^{238}U with a Dose Conversion Factor (DCF) of $2.8E^{-4}$Sv/Bq for evaluation and Beta is considered to be majorly from ^{210}Po, ^{228}Ra of ^{238}Th with a DCF of $6.9E^{-4}$Sv/Bq for evaluation purposes. Also, the annual Consumption Rate (CR) of water for both adult and infant are considered to be 730 litres/year and 183 litres/year respectively (Avwiri *et al*. 2016).

Activity Concentration

The soil and sediment sample collected, went through open air drying at room temperature and subsequent oven drying at a certain temperature 50 - 150°c, mesh sieve of about 500, packaged in Marinelli beaker and stored for 28 days for secular equilibrium between parent and daughter nuclide be attained before counting on the HpGe detector. The samples were then counted for 18,000 seconds with HpGe detector. Efficiency of the HpGe detector was estimated using the standard IAEA source to calibrate the detector prior to sample analysis. The absolute efficiency (E_γ) of a HpGe detector at specific gamma energy is given by Equation (8) (ASTM 2005).

$$\varepsilon_\gamma = \frac{C_{net}}{A \times I_\gamma x T} \quad (8)$$

Where A is the activity in Bq of gamma ray sources used in calibration and $I\gamma$ is absolute gamma decay intensity of specific energy peak (is the probability of emission per transformation for a photo peak specific energy). Activity Concentration (A_c) was calculated from analyzed sample using the Equation (9) (ASTM 2005): as:

$$A_c = \frac{C_{net}}{\varepsilon_\gamma \times I_\gamma \times m x T} \quad (9)$$

where mass of the sample is denoted as m in the expression. The unit of activity concentration of soil sample is given as Bq kg^{-1}. The radiological hazards indices was evaluated from the activity concentration. These parameters are but not limited to Gamma Dose Rate (GDR), Outdoor and Indoor Annual Effective Dose Rate (AEDR), External Hazard index.

Gamma Dose Rate (D) - was determined by postulation that all the progenies of ^{226}Ra and ^{232}Th are in radioactive equilibrium with their predecessors. This is given as given (UNSCEAR 2000a, 2000b, Rani -Asha 2005).

$$D = 0.461A_{Ra} + 0.623A_{Th} + 0.0414A_{K} \quad (10)$$

The Annual Effective Dose Rate (AEDE) - The factors used are from D obtained from the with a conversion factor of 0.7 Sv/Gy of absorbed dose in the air. The Occupancy factor (Of) considered is the fraction of time spent indoors and outdoors and were assigned values as 0.8 and 0.2, respectively (Al-Sulaiti, 2009, UNSCEAR, 2000):

$$AEDE_{\mu Sv} = D_{nGy/h} \times 8760_{h/y} \times Of \times 0.7_{Sv/Gy} \times 10^{-3} \quad (11)$$

Radium Equivalent Activity (Ra_{eq}) - For relative purposes, assessing the hazard associated with material containing different concentrations of ^{226}Ra, ^{232}Th and ^{40}K, Radium Equivalent Activity was estimated by the expression (Taskin *et al*. 2009,Usikalu *et al.* 2011).

$$Ra_{eq} = A_{Ra} + 1.43A_{Th} + 0.007A_{K} \quad (12)$$

Where A_{Ra}, A_{Th} and A_{K} are the specific activities of ^{226}Ra, ^{232}Th and ^{40}K (in Bq/kg). In defining Ra_{eq} activity the assumption is made that 370 Bq kg-1 for ^{226}Ra, 259 Bq kg-1 for ^{232}Th and 4810 Bq kg-1 for ^{40}K yields the same gamma dose rate (Mantazul 1979, Beretka and Mathew 1985).

External Hazards Index (Hex) was evaluated from natural gamma radiation and the prime objective is to limit the activity concentration (A) of ^{226}Ra, ^{232}Th and ^{40}K to ensure that a permissible dose rate of 1 mSv/y and is not exceeded by the expression (Beretka and Mathew 1985, Al-Sulaiti 2009).

$$H_{ex} = \frac{A_{Ra}}{370} + \frac{A_{Th}}{259} + \frac{A_{K}}{4810} \leq 1 \quad \textit{(without doors and windows} \quad (13)$$

For the hazard to be considered as negligible, the H_{ex} value must be less than unity. However, the denominator values for A_{Ra} changes to 740 and A_{Th} changes to 540 with doors and windows (Hewamanna *et al.* 2001). Also the denominator value for A_{Ra} changes to 185 if internal hazards are taken into account (Beretka and Mathew *19*85, Xinwei 2005).

RESULTS

Table 1 presents the summary averages of Activity material concentrations of primordial radionuclides (^{226}Ra, ^{238} U, ^{232}Th and ^{40}K) and Fission product from soil, sediment and water samples (Bq/kg) and also BIR measurements (µSv/hr) from all the radiological monitoring zones in the study area. However, specific details of each study of BIR, Activity Concentration from soil/sediment and gross alpha/beta concentrations are published in relevant journals (Ekong *et al.* 2019).

Background Ionizing Radiation

The BIR measurement obtained ranged (0.041 ± 0.002 - 0.045 ± 0.002) µSv/hr with overall mean of 0.042 ± 002 µSv/hr, which was lower than the world mean of 0.2 µSv/hr. Radiological hazard indices arising from the BIR were evaluated and found to be within the admissible limits (UNSCEAR 2000a, Ekong *et al.* 2019).

Activity Concentration

The activity concentration results obtained using Equations 9 from analyzed results present in soil samples analysis from Exclusion Zone ranges from 9.03±1 to 41.95±3 Bq/kg for ^{238}U; 13.92±2 to 68.44±6 Bq/kg for ^{232}Th; 23.21±7 to 110.72±14 Bq/kg for ^{226}Ra and 21.85±3 to 84.20±39 Bq/kg for ^{40}K. Also, result from Sterilized Zone ranges from 2.04±1 to 40.27±3 Bq/kg for ^{238}U, 6.54±2 to 67.50±7 Bq/kg for ^{232}Th, 41.79±9 to 125.60±15 Bq/kg for ^{226}Ra and 35.57±4 to 350.12±78 Bq/kg for ^{40}K. Furthermore, results from Impact Assessment Zone ranges from 5.83±1 to 45.99±3 Bq/kg for ^{238}U; 14.96±2 to 77.03±7 Bq/kg for ^{232}Th; 28.93±7 to 112.37±15 Bq/kg for ^{226}Ra and 20.64±2 to 128.11±9 Bq/kg for ^{40}K. Lastly, results from Emergency Planning Zone for primordial radionuclides ranges from 10.78±1 to 51.25±4 Bq/kg for ^{238}U; 19.77±3 to 109.27±9 Bq/kg for ^{232}Th; 0.54±0.2 to 1.13±0.3 Bq/kg for ^{226}Ra and 0.11±0.01 to 0.20±0.01 Bq/kg for ^{40}K.

Seven set of water samples collected were measured and analyzed with same process used for soil and sediment, and reason why the unit is in Bq/kg. The primordial radionuclide from analyzed water samples ranges 0.55±0.3 to 1.33±0.4 for ^{238}U; 0.48±0.4 to 2.26±0.5 Bq/kg for ^{232}Th; 7.66±3 to 16.11±4 Bq/kg for ^{226}Ra and 19.35±2 to 36.95±3 Bq/kg for ^{40}K. Also, the sediments samples results ranges from 0.02±0.01 to 0.07±0.02 Bq/kg for ^{238}U; 25.20±13 to 139.20±29 Bq/kg for ^{232}Th; 19.77±3 to 112.37±15 Bq/kg for ^{226}Ra and 26.14±8 to 137.31±18 Bq/kg for ^{40}K. Furthermore, the mean activity concentration results of 5km impact from 4 villages/ LGAs surrounding Itu, Nigeria which serve as control were evaluated; the mean value of 45.67±10 Bq/kg, 15.28±1 Bq/kg, 25.61±3 Bq/kg and 33.99±4 Bq/kg were recorded for ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K respectively. These mean activity concentration values were lower than the admissible limits of 33Bq/kg, 45Bq/kg and 420Bq/kg for ^{238}U, ^{232}Th and ^{40}K respectively (UNSCEAR, 2000a).

The low activity concentrations of ^{226}Ra, ^{238}U, ^{232}Th, ^{40}K in the entire study area implies that there are no NORM generated as a result of human activities that has impacted on land that may have alter the concentration level of soil, but present concentrations are only attributed to geological formations of the area (Njinga *et al.* 2015). The ggeological data of the area suggest Itu, Nigeria is underlain by Imo formations and lies within south eastern edge of Anambra basin. The mineral analyses reveals that there are mineral deposits of kaolinite, smectitites, palygorskite etc found in the rocks having medium gray to dark gray color of clay/shale and sandstone (Okunlola and Egbulem 2015). Also, the Nigerian coastal plain is believed to transverse through Niger Delta sedimentary

Table 1: Radioactive material concentrations analysis results of primordial radionuclides (^{226}Ra, ^{238}U, ^{232}Th and ^{40}K) from soil, sediment and water samples (Bq/kg) and BIR measurements (μSv/hr).

Monitoring Zones		Dose Rate	^{226}Ra	^{238}U	^{232}Th	^{40}K	^{137}Cs
	Min		23.21±7	9.03±1	13.92±2	21.85±3	
EZ	Max	0.042±0.001	110.72±14	41.95±3	68.44±6	84.20±38	
	Ave		58.65±11	20.55±2	38.45±4	39.07±11	
	Min		41.79±9	2.04±1	6.54±2	35.57±4	
SZ	Max	0.041±0.002	125.60±15	40.27±3	67.50±7	350.12±78	
	Ave		77.09±13	20.62±2	43.58±5	92.02±15	
	Min		28.93±7	5.83±1	14.96±3	20.64±2	0.8±0.2
IAZ	Max	0.042±0.002	112.37±15	45.99±3	77.03±7	128.11±9	1.77±0.3
	Ave		64.42±10	20.84±2	39.73±4	40.75±4	1.45±0.2
	Min		26.14±8	10.78±1	19.77±3	19.29±3	0.37±0.2
EPZ	Max	0.041±0.002	137.31±18	51.25±4	109.27±9	98.40±8	1.65±0.4
	Ave		57.49±11	19.97±2	37.50±4	39.63±4	0.87±0.3
5km	5km Ave		45.67±10	15.28±1	25.61±3	33.99±4	1.87±0.3
	Min		7.66±3	0.55±0.3	0.48±0.4	19.35±2	
Water	Max		16.11±4	1.33±0.4	2.26±0.5	36.95±3	
	Ave		13.78±3	1.13±0.3	1.48±0.5	29.23±2	0.32±0.1
	Min		0.54±0.2	0.02±0.01	25.20±13	0.11±0.01	
Sediment	Max		1.13±0.3	0.07±0.02	139.20±29	0.20±0.01	
	Ave	0.042±0.002	0.96±0.2	0.06±0.02	77.14±24	0.16±0.01	

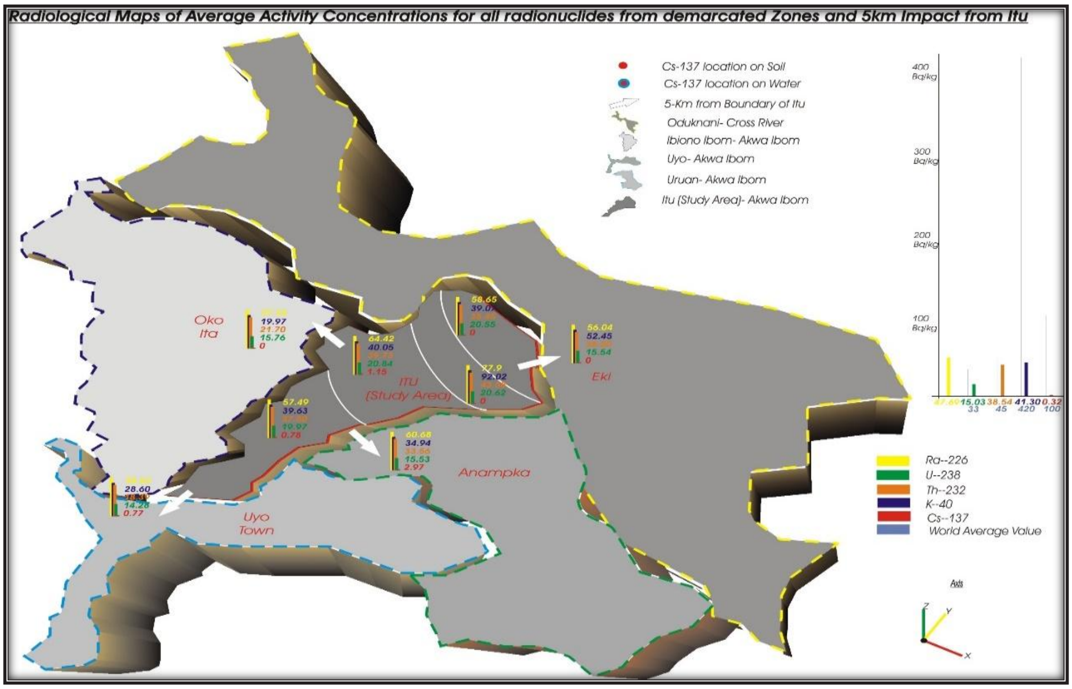

Figure 2. 3-Dimentional Arc-Gis plot of Activity Concentration of ^{226}Ra, ^{238}U, ^{232}Th and ^{40}K from all radiological monitoring zones in Itu, Nigeria vis-à-vis World mean.

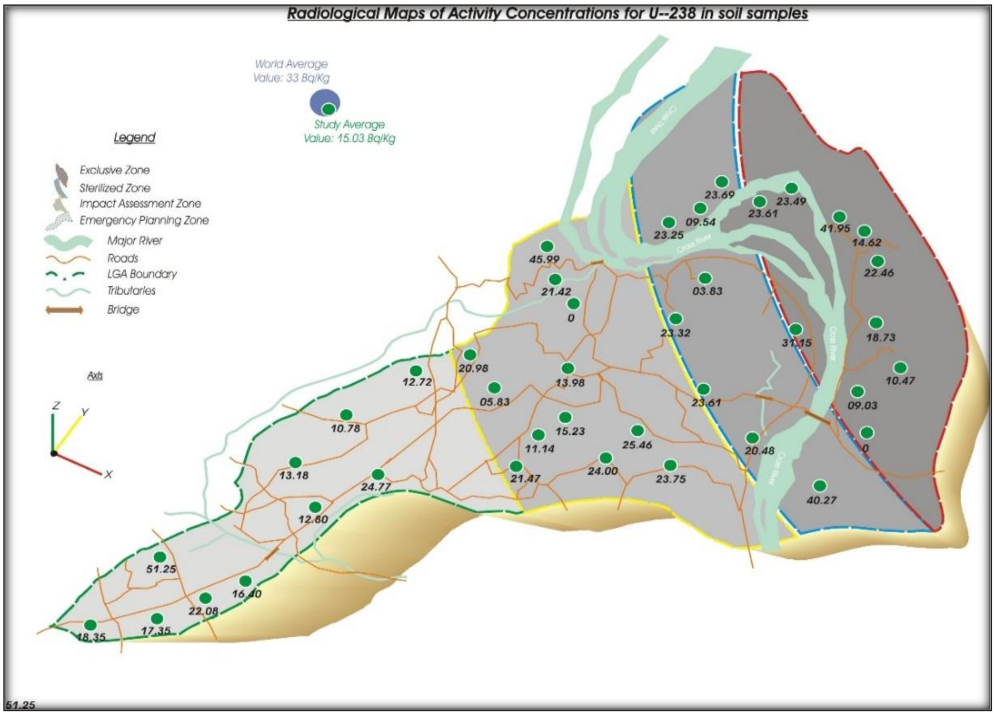

Figure 3. 3-Dimentional Arc-Gis plot of Activity Concentration of ^{238}U from all radiological monitoring zones in Itu, Nigeria vis-à-vis World mean.

basins, a pro- grading depositional complex within the formation of Abalaliki Trough in Eastern to Benin Flank in Western Nigeria which opens up to Atlantic Ocean. The sedimentary source in the area consist of mainly crystalline rock of Guinea high-lands basement complex alone with cretaceous and tertiary sediments derived from Cameroun volcanic zone (Allen 2011).

Fission Products

As could be seen in Table 1, the analysed ^{137}Cs was the only fission product that was evaluated using Equation 9. The infinitesimal activity concentration was obtained in Itu, Nigeria, also spotted at Uyo and Anakpa, 5km bounded by the south and east of Itu respectively.

The ^{137}Cs concentration (Bq kg^{-1}) ranged between 0.32±0.1 - 2.97±0.4 with a mean concentration of 1.07± 0.3 Bq kg^{-1}, which is quite below regulatory limits of 100 Bq kg^{-1} (IAEA 2011). Although the concentration of ^{137}Cs radionuclide was very low, its presence in the environment was a source of concern being artificial radionuclide, but poses no radiological threat at the present concentration level. The obvious reason is that it is not commonly found in an environment, but oftentimes emanates from scrap metal recycling facility, direct nuclear fission reaction or indirect processes from sequential beta decay of precursor radionuclides of fission process (^{137}Te decays to ^{137}Cs). It may also have been spread into the stratosphere and troposphere, then gradually returns to the earth long while as radiological fallout after nuclear test, and is the most dangerous kind of radioactive contamination to the environment (IAEA 2005a, Martin *et al*. 2012, Ogundare and Nwankwo 2014, Ekong *et al.* 2016).

Gross Alpha-Beta

Gross Alpha/ Beta concentration result were obtained from water samples collected from seven locations of Odiok Afaha Itam 1, Odiok Afaha Itam 2, Odiok Afaha Itam 3, Ayadehe 1, Ayadehe 2, Itu 1 and Itu 2 in Itu, Nigeria using Equations (1-6) are herewith presented in Table 2, while Figure 4 presents a 3-Dimentional View of Gross Alpha/Beta Concentration for Itu, Nigeria compared with the world limit.

The ranged gross alpha concentrations values were (0.019±0.009 - 0.148±0.022) Bq L^{-1} with overall mean values of 0.055±0.014 Bq L^{-1} and ranged beta concentration values were (0.015±0.013 - 0.401±0.033) Bq L^{-1} and with overall average values 0.120±0.019 Bq L^{-1}. The average values of gross alpha and gross beta activity concentration levels were below the World Health Organisation guidelines of 0.5 Bq L^{-1} for gross alpha and 1.0 Bq L^{-1} for gross beta (WHO 2011). The reason of this low gross alpha/ beta concentration shows that the level is only from natural radioactivity and there are no human activities links to radiation in the area to increase radioactivity level of the area. Gross alpha/

beta concentration is not radionuclide specific but the determined concentration provides a fairly accurate suggestion of the radionuclide quantity in water by really providing the extent of contamination (Ekong *et al.* 2020).

DISCUSSION

Radiological hazards indices considerations arising from analysed activity concentration results were evaluated using Equations (10 - 14), which are but not limited to: Gamma Dose Rate (GDR), Outdoor and Indoor Annual Effective Dose Rate (AEDR), Radium equivalents, External Hazard index.

The evaluated GDR arising from terrestrial gamma of activity concentration for entire study area values ranged (1.57 – 95.78) nGy hr^{-1} with a mean of 32.15 nGy/hr lower when compared with world mean of 59 nGy/hr (Al-Sulaiti 2009, UNSCEAR 2000b).

Also, the AEDR evaluations from both terrestrial outdoor and indoor gamma from GDR were subsequently estimated. AEDR outdoors ranged value was (1.92 – 117.46) µSv yr^{-1} with mean of 41.31 µSv yr^{-1} while AEDR indoor with ranged value was found to be (7.68 – 469.83) µSv yr^{-1} with mean of 165.23 µSv yr^{-1}. The sum values for both outdoors and indoors were lower when compared with world mean of 460 µSv yr^{-1}. However, the evaluations for indoors was higher than the outdoors which was quite expected in the sense that concentration will be more inside than the outside. The acceptable annual effective dose for public without any constraint is 1 mSv yr^{-1} for the purpose of safety and with constraint of 0.5 mSv yr^{-1} (Al-Sulaiti 2009, ICRP 1990, UNSCEAR 2000b, Rao 2016a).

Furthermore, the approximated Radium Equivalent arising from terrestrial gamma of activity concentration

Table 2: Gross Alpha/ Beta concentration (Bq/l) analysis result from water samples in Itu, Nigeria.

Location	Gross Alpha Concentration	Gross Beta Concentration
Odiok Afaha Itam 1 (By the Bridge)	0.023±0.013	0.048±0.018
Odiok Afaha Itam 2 (0.2km from the Bridge)	0.019±0.009	0.033±0.012
Odiok Afaha Itam 3 (0.5km from the Bridge)	0.076±0.015	0.135±0.020
Ayadehe 1 (0.1km Right from the Bridge)	0.148±0.022	0.401±0.033
Ayadehe 2 (0.1km Left from the Bridge)	0.066±0.014	0.073±0.017
Itu 1 (SZ 7 -By the Bridge)	0.038±0.010	0.055±0.014
Itu 2 (0.5km from the Bridge)	0.013±0.015	0.107±0.024
World Limit	0.5	1.0

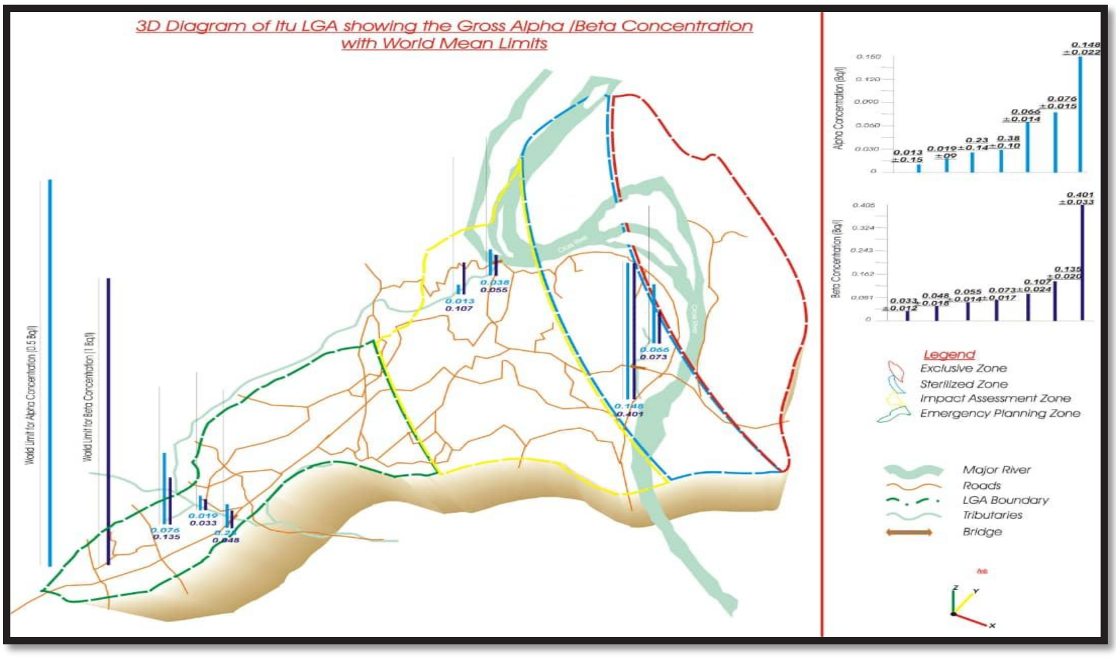

Figure 4. 3-Dimentional View of Gross Alpha/Beta Concentration for Itu, Nigeria compared with the world limit

for entire four zones ranged (10.20 – 294.25) Bg kg^{-1} with a mean of 99.16 Bg kg^{-1} which was lower when compared with world mean of 370 Bg kg^{-1} Also, evaluated External Hazards index for entire four zones of the study area was with a ranged (0.04 – 0.84) mSv yr^{-1} with a mean of 0.28 mSv yr^{-1} as against world mean of 1 mSv yr^{-1} (Al-Sulaiti 2009, UNSCEAR 2000b).

These low estimated values of radiological hazards indices considerations as regards to Gamma Dose Rate (GDR), Outdoor and Indoor Annual Effective Dose Rate (AEDR), Radium equivalent, External Hazard index suggest that materials pose no significant health threat to the populace and can be used without any further restrictions. The evaluated parameter above were below an annual effective dose of 1–2 mSv, which can at most be equated with annual average background doses worldwide reference. Thus, there was no basis for ELCR estimation, as there was no anthropogenic activity in the present site to have enhanced radiation level but result presented are of natural radioactivity (Rao 2016).

Radiological assessment of annual Committed Effective Dose (CED), from water ingestion arising from gross alpha/ beta concentration ranges of (0.019±0.01 - 0.148±0.02) Bql^{-1}/ (0.015±0.01 - 0.401±0.03) Bql^{-1}, respectively, were evaluated using Equation 7. The CED ranged between ($8.35x10^{-02}$ - $2.32x10^{-01}$) mSv with a mean of 7.17 $x10^{-02}$ mSv estimated for adult, and ($5.14x10^{-03}$- $1.43x10^{-02}$) mSv with a mean of $1.80x10^{-02}$ mSv estimated for infant. Therefore, evaluated CED.

The CED of infant was found to be greater than that of adult because of rate of digestion of the former than the later. However, the CED of water ingestion for both adult and infant were less than the recommended level of 0.1mSv (Avwiri *et al*. 2016), and poses no significant health threat to the populace of Itu, Nigeria, and hence water from this area can be used for any activity without any further consideration of treatment facility to lower the radioactivity level.

A few comparative studies within the South Nigeria indicated that, BIR study was conducted to estimate radiation hazard indices with associated Excess Life Cancer Risk within Uyo, South South Nigeria 5 km away from the study area, the average dose rate of 0.116μSv hr^{-1} was measured (Etuk *et al*. 2017). A radioactivity evaluation to determine primordial radionuclides concentration randomly from some quarry site soil samples within the similar locations was embarked upon. The radionuclide activity concentrations measured in Bq kg^{-1} of ^{40}K, ^{238}U and ^{232}Th were found to be 143.54±8, 2.47±0.3, 3.70±0.2, respectively, for Ayadehe, 73.69±3.9, 2.04±0.2, 2.47±0.3, respectively, for Oku Iboku, 33.96±2, 8.84±1, 3.01±0.2, respectively, for OdiokItamand 63.77±3, 7.81±1, 2.31±0.1, respectively, Ntak Inyang all in Itu, Nigeria. These activity concentration and radiological hazards exposure low and pose no significant health threat hence, the quarry products can be used as building material (Essien *et al*. 2016). A study to determined gross alpha and beta activities in groundwater from Niger Delta area was conducted and the analysis result showed a range of (0.01 - 0.50) Bq L^{-1} and average of 0.10 Bq L^{-1} for gross alpha and a range of (0.70 - 54.70) Bq L^{-1} and average of 8.90 Bq L^{-1} for beta concentration, where higher concentrations were attributed to human induce activities in the area (Avwiri and Agbalagba 2007).

It can therefore be summarised that, analysed activity concentrations from samples and gross alpha/ beta concentrations and radiological hazard indices from various pathways were lower than the world mean and recommended levels which is summarise in Table 3.

CONCLUSION

The radiological assessment of the proposed nuclear power plant site, with regards to BIR measurement, Activity Concentrations of primordial radionuclides and fission product, Gross Alpha and Beta concentrations,

Table 3: Summary radiological monitoring data values in Itu, Nigeria study vis-a-vis world mean for baseline consideration.

Parameters	Study Range	**Study mean**	World mean	Units
BIR	0.041±0.002 - 0.045±0.002	**0.042±.002**	0.2	μSv hr^{-1}
U - 238	0.02±0.01 - 51.25±4	**15.03±1**	33	Bq kg^{-1}
Th - 232	0.48±0.4 - 139.20±29	**38.54±6**	45	Bq kg^{-1}
K – 40	0.11±0.01 - 350.12±79	**41.30±6**	420	Bq kg^{-1}
Cs - 137	1.08±0.3 - 2.97±0.4	**1.07±0.3**	100	Bq kg^{-1}
Gross Alpha	0.02±0.01 - 0.15±0.02	**0.06±0.01**	0.5	Bq L^{-1}
Gross Beta	0.02±0.01 - 0.40±0.03	**0.12±0.02**	1.0	Bq L^{-1}

and associated radiological hazards were conducted and the evaluations were found to be within admissible limit. The present radioactivity level is attributed to geographical and geological formations of the area and not human induced activity. These evaluations poses no radiological health threat to populace and other environmental biota. Therefore, the methodology employed in this radiological baseline data assessment is hereby recommended to prospective NPP operators as valuable EIA input design parameters of the proposed NPP at Itu, Nigeria. However, these evaluated values should be validated by the regulatory body.

ACKNOWLEDGEMENTS

We hereby extend deeply appreciate the Management and staff of the Nigerian Nuclear Regulatory Authority for the approval granted to embark on the study, the university for providing the study platform and host community for the kind assistance during field exercise.

Authors' Contributions: The article presented is part of the corresponding Authors' PhD self-funded research titled "*Baseline Radiological Impact Assessment of proposed Nuclear Power Plant Site, Itu Nigeria*". All other Authors listed has played various roles in both supervisory and making valuable contributions towards the success of this research.

Conflict of Interest: The Authors hereby declare that there was no conflict of interest concerning this research work.

REFERENCES

Akwa Ibom State (AKS). 2014. Projected Population 2007 – 2015, Ministry of Economic Development Uyo, Akwa Ibom State, 1: 1-11.

Allen, J.R.L. 2011. The Nigerian Continental Margin, Bottom Sediments, Submarine Morphology and Geological Evolution. Journal of Marine Geology 1(4): 289-332.

Al-Sulaiti, H. 2009. Determination of Natural Radioactivity Levels of the State of Qatar Using High-Resolution Gamma-ray Spectrometry. MPhil to PhD Transfer Report, Department of Physics, University of Surrey.

American Society for Testing and Materials (ASTM). 1995. Standard test method for Alpha particle Radioactivity of Water. Standard test method for beta particle radioactivity of water. ASTM D1943-90 and 1890-90.

American Society for Testing and Materials (ASTM) 2005. Standard Guide for High- Resolution Gamma-Ray Spectrometry of Soil Samples, Annual Book of ASTM Standard International, Standard Worldwide 12(1): 1402-1404.

Anuforo, E. and Onyedika U.N. 2016. Nigeria Russia okay pact to build nuclear plants in Kogi, Akwa-Ibom. Guardian Newspaper online. Last Accessed: . 21, 2018, Available at https://guardian.ng/news/nigeria-Russia-okay-pact-to-build- nuclear-plants- in-kogi-akwa

Avwiri, G.O. and Agbalagba, E.O. 2007. Survey of Gross Alpha and Beta Radionuclide Activity in Okpare-Creek Delta State. Nigerian Journal of Applied Sciences, 7 (22): 3542-3546.

Avwiri, G.O., Osimobi, J.C., and Ononugbo, C. P. 2016. Gross Alpha and Beta Activity Concentration and Committed Effective Dose due to intake of water in Solid Mineral Producing Areas of Enugu State, Nigeria. International Journal of Physics and Applications 8(1): 33-43.

Ayoade, B.O. 1998. Adaptation to climate change in Agriculture, Forestry and Fisheries, Perspective framework and priorities, Food and Agriculture Organization of the United Nations, Rome.

Beka, J.E., and Udom, G.J. 2014. Quality Status of Groundwater in Akwa Ibom State, Nigeria. International Journal of Science Invention Today 3(5): 436-449.

Beretka, J., and Mathew, P.J. 1985. Natural Radioactivity of Australian Building, Materials, Industrial Wastes and By-products. Health Physics 48: 87-95.

British Broadcasting Corporation (BBC) 2011. Timeline, Nuclear Plant Accidents. Last Accessed 23rd March 2018, Retrieved at www.bbc.com/news/world-13047267.

Ekong, G.B., and Audu, B.N. 2014. Gamma Ray Spectroscopy, Effect of Strength and Distance Performance of the Detector. Journal of Science and the Environment 1 (2): 1-12.

Ekong, G.B., Sambo, I. and Sayaidi, S. 2016. Determination of Radionuclides Surface Concentration and Radiation level in Fukushima Prefecture, Japan. Modern Environmental Science and Engineering 2(1):757-764.

Ekong, G.; Akpa, T.; Umaru I.; Lumbi, W.; Akpanowo, M., Benson, N. 2019. Assessment of Radiological Hazard Indices from Exposures to Background Ionizing Radiation Measurements in South-South Nigeria, International Journal of Environmental Monitoring and Analysis 7 (2): 40-47

Essien, I.E. and Akpan, E.N. 2016. Evaluation of Radiological Hazard Indices Due to Radioactivity in Quarry Sites in Itu, Akwa Ibom State, Nigeria. International Journal of Scientific Research in Environmental Sciences 4(3): 71-77.

Etuk S.E.; Essiett A. A. and Agbasi, O.E. 2017. Measurement of outdoor ambient radioactive radiation and evaluation of radiation indices and Excess Life Cancer Risk within Uyo, Unity Park, Uyo, Nigeria. Journal of Geography, Environmental and Earth Science International 9(4):1-9.

Famuyide,, O.O.; Adu A.O., and Ojo M.O. 2004. Socio-Economic Impacts of Deforestation in the Sudano- Sahelian Belt of Nigeria. Journal of Forestry Research and Management 1(2): 94–106.

Hewamanna, R.; Sumithrarachchi, C.S.; Mahawatte, P.; and Nanayakkara, H. L. C. 2001. Natural radioactivity and gamma dose from Sri Lankan clay bricks used in building construction. Applied Radiation and Isotopes 54(2): 365- 369

International Atomic Energy Agency 2011. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA Safety Standard Series General Safety Requirement Part 3, IAEA, Vienna, Austria.

International Atomic Energy Agency (IAEA). 1999. Generic Procedures for Monitoring in a Nuclear or Radiological Emergency. IAEA Vienna Austria, IAEA- TECDOC–1092, 12-156.

International Atomic Energy Agency (IAEA). 2005a. Radiological Conditions at the Former French Nuclear Test Sites in Algeria: Preliminary Assessment and Recommendations, Radiological Assessment Report Series, IAEA, Vienna, Austria. 59 pages.

International Atomic Energy Agency (IAEA). 2005b. Environmental and Source Monitoring for Purpose of Radiation Protection, IAEA Safety Standard Series No. RS- G-1.8, IAEA,Vienna, Austria, 10-130.

International Atomic Energy Agency (IAEA). 2014a. The use of the international Nuclear and Radiological Event Scale (INES) for Event Communication, IAEA, Vienna, Austria.

International Atomic Energy Agency (IAEA). 2014b. Managing Environmental Impact Assessment for Construction and Operation in new Nuclear Power Programme, Nuclear Energy Series No. NG-T-3.11, IAEA, Vienna, Austria,1-30.

International Commission on Radiological Protection (ICRP). 1990. The Recommendations of the International Commission on Radiological Protection, ICRP Publication 60, Annals 21: 1-3.

International Commission on Radiological Protection (ICRP). 2009. Application of the Commission's Recommendation to the protection of people in Emergency Exposure Situation, ICRP Publication, 39: 5-12.

Karekezi, R. 1997. Renewable Energy Technologies in Africa. Zed Books Limited with African Energy Policy Research Network (AFREPREN) and Stockholm Environment Institute. Stockholm.

Knoll, G.F. 2010. Radiation Detection and Measurement. Fourth Edition, John Wiley, New York, 506 pages.

Lilley, J.S 2001. Nuclear Physics -Principle and Applications. Second Edition. John Wiley, Chichester, New York, 295 pages.

Mantazul, I. C. (1979. Concentration of Radionuclides in Building and Ceramic Materials of Bangladesh and Evaluation of Radiation Hazard. Journal of Radio- analytical and Nuclear Chemistry, 231(2): 122.

Martin, A; Harbison, S; Beach, K. and Cole, P. 2012. An Introduction Radiation Protection. Fifth Edition, Hodder Arnold, an imprint of Hodder Education, Hachette UK, 6 -209.

Ministry of Environment and Forests (MoEF) 2010. Environmental Impact Assessment Guidance Manual For Nuclear Power Plants, Nuclear Fuel Reprocessing Plants and Nuclear Waste Management Plants, Government of India, New Delhi, India.

Mordi, C.O, Englama, A., and Adebusuyi, B.S. 2000. The Changing Structure of the Nigerian Economy and Implications for Development. Research Department, Central Bank of Nigeria. Realm Communications Ltd, Lagos. Volume 260

Nguelem, E.J.M., Darko, E.O., Ndoutdueng, M. M., Schandorf, C. and Akiti, T.T. 2013. The Natural radioactivity in groundwater from selected areas of Greater Accra region of Ghana by gross alpha and gross beta measurements. Radiat Prot Environ 36: 14-19

Njinga, R.L.; Ibrahim, Y.V. and Ishoryiyi, I.J 2015. Radioactivity Analysis in underground drinking water sources in Niger State University of Nigeria, Pollution 1(3): 315-324.

Ogundare, F.O., and Nwankwo, C.U. 2014. Radionuclide Content of, and Radiological Hazards associated with Samples from different streams of Metal Recycling Facilities,Radioprotection, 50(1)55-58.

Okunlola, O., and Egbulem, C. 2015. Geological Setting, Compositional and Economic Appraisal of Shale Occurrence in Itu-Mbonuso/Iwere Area, South- Eastern Nigeria. Journal of Geography and Geology 7(1): 85-96.

Onwuemenyi, O. 2010. Agency picks four sites for nuclear power plants. Vanguard Newspaper online.

Rani, A. and Singh, S. 2005. Natural radioactivity levels in soil samples from some areas of Himachal Pradesh, India using γ-ray spectrometry. Atmospheric Environment 39(34), 6306-6314.

Rao, D.D. 2016a. Computation of excess lifetime cancer risk for environmental exposures: Is it needed? - An opinion. Radiat Prot Environ 2016; 39:1-2.

Rao, D.D. 2016b. Effective doses from terrestrial radiation and their comparison with reference levels. Radiat Prot Environ;39:51-2.

STUK Radiation and Nuclear Safety Authority (STUK) 2016). Radiological Monitoring of the Environment of Nuclear facility guide, YVL C.7, 6-7.

Taskin, H., Karavus, M., Topuzoghi, P. Ay., Hindiroglu, S. and Karaha G. 2009. Radionuclide concentrations in soil and lifetime cancer risk due to the gamma radioactivity in Kirklareli. Journal of Environmental Radioactivity 100: 49- 53.

Udom, G. J. 2004. Regional Hydrogeology of Akwa Ibom State, Nigeria Using Lithological, Pump Testing and Resistivity Data. (Unpublished) PhD Thesis, University of Calabar.

United Nation Development Programme 2005. A Guide to Energy's Role in Reducing Poverty. Energizing the Millennium Development Goals, United Nations Development Programme.

United Nations Scientific Committee on the Effects of Atomic Radiation 2000a. Exposures from natural radiation sources, Annex B New York, USA.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) 2000b. Effects and Risks of Ionizing Radiations. United. Nations. New York,

United Nations Scientific Committee on the Effects of Atomic Radiation 2008. Sources and Effects of Ionizing Radiation. New York, United Nations. New York. United Nations.

Usikalu M.R, Anoka O.C and Balogun F.A 2011. Radioactivity measurement was of the Tin Mine of the Jos Plateau Northern Nigeria, Scholars Research Library 2(2): 80-86.

William, K. 2013. A Review of the Effects of Radiation on Microstructure and Properties of Concretes Used in Nuclear Power Plants. NUREG/CR-7171 Nuclear Regulatory Commission, Washington, D.C.

World Health Organisation (WHO). 2011. Radiological aspects in Guidelines for drinking water quality. 4th ed. Geneva: World Health Organisation.

Xinwei, L. (2005. Natural radioactivity in some building materials of Xi'an, China. Radiation Measurements 40(1): 94-97.

Youdeowei, T. 2017. Nigeria signs pact with Russia on nuclear energy. Vanguard Newspaper-online. Accessed on 21st November, 2018, Available at: https://www.vanguardngr.com/2017/11/nigeria-signs-pact-Russia-nuclear-energy/.

Received: 05 June, 2020
Accepted: 04 October, 2020