PRINT ISSN 1119-8362
Electronic ISSN 1119-8362

Full-text Available Online at
https://www.ajol.info/index.php/jasem
http://www.bioline.org.br/ja

J. Appl. Sci. Environ. Manage.
Vol. 26 (5) 975-981 May 2022

Spatial Distribution of Radiometric and Dosimetric Parameters in Soil Samples from Selected Areas in Bayelsa State, Nigeria

[1*]IKOKO, NLA; [2]BRIGGS-KAMARA, MA; [2]SIGALO, FB; [2]AMAKIRI, ARC; [3]UDE, HN

*[1]*Department of Minerals and Materials Development, Raw Materials Research and Development Council, Plot 17 Aguiyi-Ironsi Street, Maitama, Abuja, Federal Capital Territory, Nigeria.*
[2]Department of Physics, Rivers State University, Nkpolu, Port Harcourt, Rivers State, Nigeria.
[3]Department of Industrial Extension Services, Raw Materials Research and Development Council, Maitama, Abuja, Federal Capital Territory, Nigeria

**Corresponding Author Email: nengimote.lionel@outlook.com; Tel: +234 (0) 802 329 2291.*
Other Authors Email: briggskamara@yahoo.com; sigalo.friday@ust.edu.ng; amakiriarobo09@gmail.com; smallmummy2001@yahoo.com

ABSTRACT: Radiation from radioactive materials/radionuclides in the environment enhanced by anthropogenic activities is presently of a great concern globally. The objective of this study is to determine the radiometric and dosimetric parameters from soil samples collected randomly from the study area of Bayelsa State, Nigeria. The samples were prepared using standard methods and analyzed with a high resolution Hyperpure Germanium Detector configuration (HPGe). The results showed the clay samples to have higher activity concentration to the sands samples with activity concentration of clay samples ranging between 68.99±9.05 –189, 42±21.11Bq/kg and the sand samples with activity concentration range of 17.95±5.87 – 38.59±7.43Bq/kg. The activity concentration spatial distribution map in clay lithologies showed 2 peak values trending north-west, while the sand lithology showed a single peak central distribution. The result also showed the values of the absorbed doses with the 8 clay samples values ranging between 59.09 - 155.25nGy/h and sand samples values between 17.90 – 33.92nGy/h. The spatial distribution of the dose showed 2 peak central distribution in clay samples and north-east trending distribution of high peak values for samples with sand lithologies. In addition, the results showed an effective absorbed dose of range of 0.235-0.0616mSv/y for samples with clay lithology and 0.0071-0.0135mSv/y for samples with sand lithology The activity concentration of all the samples studied are below the 1000Bq/kg international reference limit for Radium 226, Thorium 232, uranium 238 and 10,000Bq/kg for potassium 40. The absorbed dose rate and annual effective absorbed dose are also below the international reference limits published by ICRP, 2007 and UNSCEAR, 2000 publications. Also, effective activity maximum limit of 370Bq/kg for input raw materials for public building is not exceeded.

DOI: **https://dx.doi.org/10.4314/jasem.v26i5.27**

Impact factor: **http://sjifactor.com/passport.php?id=21082**

Google Analytics: https://www.ajol.info/stats/bdf07303d34706088ffffbc8a92c9c1491b12470

Dates: Received: 11 April; Revised: 15 May 2022; Accepted: 18 May 2022

Key words: Radioactivity, Doses, Radionuclides, Hyperpure Germanium Detector,

The presence of radioactive elements from primordial and anthropogenic sources in the environment are considered to be the two major contributors to the level of radioactivity found or experienced in the environment. This heightened level of ionizing radiation emitted by industrial activities such as petroleum exploration, production and utilization; mining and minerals processing, development and utilization; water treatment; electrical power production process from nuclear material and others have been shown by several research works and analytical test to be harmful to human health, the ecosystem and the environment (IAEA, 2016; UNSEAR, 2000; ICRP, 2007). The health effect of exposure to ionizing radiation have been reported by UNSCEAR in their report Annex G: Biological effects at low radiation dose (UNSCEAR, 2000), stochastic and deterministic effects from radiation and their doses (ICRP, 2007), the effects on hindering mobility and maturation of spermatozoa (Makinta *et al*, 2017), the radiation damage / effect on eye (Kumah *et al*, 2011). Due to these health effects from radiation exposure,

**Corresponding Author Email: nengimote.lionel@outlook.com; Tel: +234 (0) 802 329 2291*

continuous periodic monitoring of the environment for these radioactive materials (radionuclides) is desirable to protect the public, and environment. Although there have been extensive studies (Chad-Umoren, 2012; Zare *et al*, 2012; Nwankwo *et al*, 2014; Chad-Umoren and Umoh, 2014; Chad-Umoren and Briggs-Kamara, 2010; Ndubisi *et al*, 2021; Avwiri *et al*, 2009).in this field globally, there is still gaps which this study has set to close. Therefore, the objective of this research is to determine the radiometric and dosimetric parameters in soil samples from selected areas in Bayelsa State, Nigeria.

MATERIALS AND METHODS

Study Area: The study was conducted in Bayelsa State, bounded between longitude 4.7710^0N and latitude 6.0699^0E; a region within the Niger Delta of Nigeria. The area is characterised by brackish water and associated vegetation in the north, north-east areas and salty water, mangrove vegetation down the south, south-east areas and bounded in the south-south by the Atlantic Ocean.

Sample Collection: The state area was subdivided into 8 grids with each grid representing a local government area (LGA). Samples of soil was collected in 2 locations in each grid totalling 16 samples. Core samples from over burden to 900mm using hand field auger was collected from each location applying grid random sampling approach, with selection criteria predominately of soil mining sites for building, road, and other construction purposes as presented in the IAEA TECHDOC 1415. (IAEA, 2004). The soil samples were packed and stored in polyethylene bags and sealed with plastic polypropylene sellotape, and each bag label outside with a paper tape marked with an ink marker of the location and soil type for easy sample identification according to location and sample type.

Sample Preparation: The samples were dried individually in an oven at 60^0C for a period of 24hours to reduce water moisture. Each sample is then briquetted to establish homogeneity in particle size and mixed thoroughly in a plastic container. A representative sample of 500 grammes of each sample was then collected and place into a labelled Marinelli beaker with lid and sealed with plastic transparent Sellotape tape. According to soil type and location from which samples was collected.

Sample testing and Analysis: The representative sample of 500 grammes collected in the labelled Marinelli beaker is then subjected to analytical test which is conducted to determine each of the sample activity concentration in Becquerel per Kilogram (Bq/kg) utilizing a high resolution Hyperpure Germanium detector configuration (HPGe) at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan, Oyo State Nigeria.

Radiometric and Dosimetric Parameters Estimation: Absorbed Dose Rate (nGy/h) is determined in accordance with ICRP (2007) method. The Effective Activity (Bq/kg) is estimated in accordance to EC Directive 96/29/ Euratum as published by IAEA (2007), Directive 112(EC, 1999), EU Directive 2013/59/Euratom (EU, 2014) as condition for utilization of material for building construction purposes. The Annual Effective Absorbed Dose Rate (mSv/y) is estimated/evaluated according to UNSCEAR (2000), Directive112 (EC, 1999), EU directive 2013/59/Euratom (EU, 2014) procedures.

RESULTS AND DISCUSSION

Activity Concentration: The activity concentrations for the radionuclides ^{226}Ra, ^{232}Th, ^{238}U and ^{40}K is shown in the activity concentration datasheet in Table 1 As observed in Table 1, the ^{226}Ra radionuclide concentration is distributed among the analyzed soil sample with degree of activity peaks variability dependent on soil sampled location and sample soil type. The sample CSO12807KBN (S5) is noticed to have the maximum peak activity concentration of 189.42 ± 21.11Bq/kg and the sample SSO21808SBN (S12) with the lowest peak activity concentration with a value of 17.95±5.87Bq/kg. Also noticed is the variation of activity concentration between the clay samples and the sand samples. The clay samples are observed to have peak values that are greater than the sand samples. The peak range values of the clay materials range from 68.99±9.05 – 189.42 ± 21.11Bq/kg and the sand samples have a range from 17.95±5.87 – 38.59±7.43Bq/kg. Also observed from Table 1, is that the activity concentration (Bq/kg), of ^{238}U peak values of the soil sample in study areas shows variability with location and lithologic type. The radionuclide low peaks activity concentration also indicates low concentration of the radionuclide in the soil. The maximum peak value of the activity concentration of 63.14 ± 4.60 Bq/kg is noticed in sample CSI12707EBN (S3). The activity peak values of the samples are distributed between concentration peak value range of 5.64 ± 0.99 - 63.14 ± 4.60 Bq/kg, with the minimum peak value seen in the soil sample SSO21808SBN (S12). The clay and sand soil samples' activity concentration peak values observed to have the range of 16.78±1.57 - 63.14 ± 4.60 Bq/kg and 5.64 ± 0.99 – 10.94 ± 1.66Bq/kg.

Table 1: Activity Concentration Analysis of Soil Samples (in Bq/kg)

s/no.	Soil ID	^{226}Ra	^{238}U	^{232}Th	^{40}K
1	CSB12507BBN(S1)	95.60±3649	37.15±5.62	64.96±9.55	528.68±34.70
2	SSB22608BBN)S2)	21.82±6.13	6.09±1.08	9.67±1.13	152.04±9.26
3	CSI12707EBN(S3)	162.25±18.80	63.14±4.60	80.30±7.65	596.05±34.06
4	SSA22708EBN(S4)	25.02±5.13	5.98±1.05	8.48±1.35	206.48±12.03
5	CSO12807KBN(S5)	189.42±21.11	57.16±4.00	96.38±8.63	497.47±28.60
6	SSS22808KBN(S6)	33.59±8.45	8.84±1.56	12.35±2.14	208.88±12.92
7	CSB10308NBN(S7)	68.99±9.05	16.78±1.57	29.65±2.61	320.49±18.00
8	SSO22808NBN(S8)	27.77±6.50	6.25±1.18	7.31±1.27	236.41±13.97
9	CSO12807OBN(S9)	141.67±15.91	44.27±3.50	80.78±6.97	612.09±34.56
10	SSO22808OBN(S10)	38.59±7.43	8.53±1.36	15.32±1.95	218.07±12.88
11	CST11008SBN(S11)	181.83±19.62	48.04±4.01	74.01±7.19	580.99±33.84
12	SSO21808SBN(S12)	17.95±5.87	5.64±0.99	6.44±1.24	164.69±10.02
13	CSA110085SBN(S13)	179.05±19.95	51.89±4.04	95.39±8.32	521.26±29.97
14	SSA21908SBN(S14)	34.79±11.04	10.94±1.66	15.54±3.65	242.51±15.12
15	CSZ12208YBN(S15)	150.15±21.78	52.46±4.19	81.40±7.69	483.49±28.36
16	SSZ216608YBN(S16)	19.10±7.21	6.66±1.00	6.33±0.83	152.73±9.85

The mean activity concentration of the study area (SA) value of 26.86Bq/kg for ^{238}U radionuclide is observed to be inconsistent with the worldwide mean soil concentration of ^{238}U radionuclide value in soil of 33.0Bq/kg. On the other hand, there is a good degree of consistency between the mean value of the concentration of the study area and the worldwide range value of the radionuclide with the activity value of 26.86Bq/kg falling with the upper and lower boundaries of the worldwide mean activity concentration value range of 17 – 60Bq/kg. Observation of a similar trend of variability of the magnitude of the concentration peaks of the radionuclide ^{232}Th with the location of sample soil collection/sampling and lithologic type of the soil samples. The clay samples concentration ranges from 29.65±2.61 - 96.38±8.63Bq/kg while that of the sand samples range from 6.33±0.83–15.54±3.65 Bq/kg. The sample CSO12807KBN (S5) of clay lithology is noticed to have the activity concentration peak value relatively higher with concentration of 96.38±8.63Bq/kg as shown in table 1. The mean value of the concentration (^{232}Th) of 42.77±1.65 shows inconsistency with published UNSCEAR worldwide mean value of 45Bq/kg. The mean value of ^{232}Th in the study area is lower than the published value but is consistent with the worldwide range values of 11 – 60Bq/kg (UNSCEAR 2000). The activity concentration of ^{40}K radionuclide show significantly high value in concentration and the soil sample CSO12807OBN(S9) seen to have the maximum activity concentration value of 612.09±34.56Bq/kg. The minimum activity observed from ^{40}K is found in the soil sample SSB22608BBN (S2) with concentration value of 152.04±9.26Bq/kg. The values of the activity concentrations are observed to be considerably higher than other radionuclide concentrations in each of the soil samples. Most of the concentrations found in the sample are noticed to be high and far higher than the mean worldwide values of 400Bq/kg. The mean value 357.66Bq/kg ^{40}K is noticed to be in inconsistent with the UNSCEAR(2000) worldwide concentration mean values with approximately 42Bq lower in concentration which an uncertainty in measurement will hardly make up for such variation for the possibility of consistency of values. However, the mean value of activity concentration of the study area is consistent with the worldwide average mean activity concentration range of 140 – 850Bq/kg.

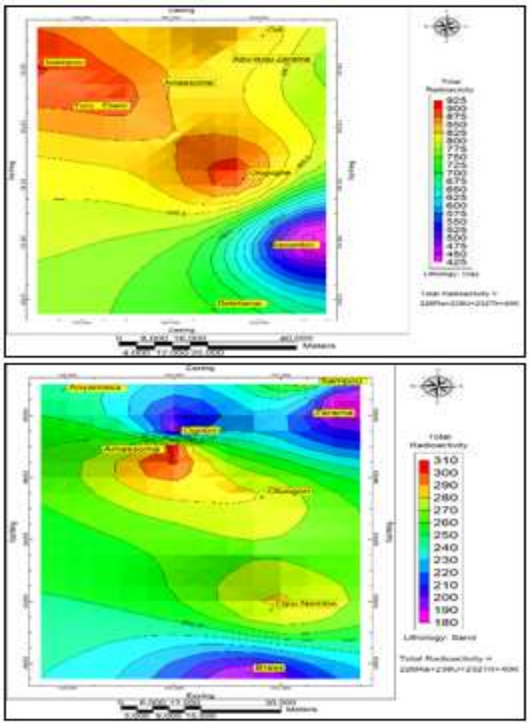

Fig 1: Spatial distribution of map of Activity Concentration in Sand and clay lithologies

The total activity concentration distributions map of the study area in sand lithologies as shown in figure 1, is observed to have a peak value distribution around the north central area of Amassoma with concentration level above 300Bq/kg. The activity concentration then trended to lower values in the north, east, west and south of the peak values below 200Bq/kg in areas around Brass in the south and Zarama in the northeast areas., For the clay lithology also shown in figure 1, the activity concentration distribution shows a high peak above 875Bq/kg in the north east area of Isampou trending to a more central districts around Toru Ebeni and dropping in value between Toru Ebeni and Ologoghe were it peaks to 800Bq/kg. The activity concentration then drops in value towards the southern area around Basambiri.

Absorbed Dose Rate (nGy/h): The absorbed dose rate for the studied soil samples and the fractional contribution from the radionuclides ^{232}Th, ^{226}Ra and ^{40}K estimated values are expressed in table 2. The result of dose rate in table 2 shows a maximum absorbed rate of 155.25nGy/h by the sample CSO12807KBN (S5) and a minimum dose rate of 17,9nGy/h by sample SSZ216608YBN (S16). The clay samples are also noticed to have dose rate values that are higher than the sand samples, for example the 8 clay samples have values ranging between 59.09 - 155.25nGy/h while the sand samples have values between 17.90 – 33.92nGy/h. In addition, 7 samples are noticed to have dose rate values above the mean value of the doses.

Table 2: Dose Rate of Soil Sample (nGy/h)

Sample	Th-232 Fractional Dose Rate	Ra-226, Fractional Dose Rate	K-40 Fractional Dose Rate	Total Dose rate D(nGy/h)
CSB12507BBN(S1)	39.23	38.43	22.2	99.86
SSB22608BBN)S2)	5.84	8.77	6.38	20.99
CSI12707EBN(S3)	48.5	65.22	25.03	138.75
SSA22708EBN (S4)	5.12	10.06	8.67	23.85
CSO12807KBN(S5)	58.21	76.15	20.89	155.25
SSS22808KBN(S6)	7.45	13.5	8.77	29.72
CSB10308NBN(S7)	17.9	27.73	13.46	59.09
SSO22808NBN(S8)	4.42	11.16	9.93	25.51
CSO12807OBN(S9)	48.79	56.95	25.71	131.45
SSO22808OBN(S10)	9.25	15.51	9.16	33.92
CST11008SBN(S11)	44.7	73.1	24.4	142.2
SSO21808SBN(S12)	3.89	7.22	6.92	18.03
CSA110085SBN(S13)	57.62	71.98	21.89	151.49
SSA21908SBN(S14)	9.39	13.99	10.19	33.57
CSZ12208YBN(S15)	49.17	60.36	20.31	129.84
SSZ216608YBN(S16)	3.82	7.67	6.41	17.9

Also, on comparism with world published values, dose rate values from 6 samples are noticed to be inconsistent with worldwide values range of 18 – 93 nGy/h while 9 sample dose rate values of the study area are seen to be consistent with worldwide range as published by UNSCEAR. The dose rate spatial distribution map in figure 2, shows that the dose rate received by the workers and public is greater around Odi town in the north-northeast of the study area with a distribution that spreads to Amassoma environs. The dose rate drops from above 550nGy/h at the peaks to below 145nGy/h between the peak distributions. The value of the dose diminishes to a low level below 65nGy/h around Basambiri in the southeast area of the study locations.

Effective Activity: The estimation of the Effective activity concentration of the soil samples showed in table 3, indicates that all sample are in consistency with the 370 Bq/kg reference limit stipulated by regulations for building materials. The soil samples CSO12807KBN (S5) and CSA110085SBN (S13) effective activity is observed in table 3 to be the maximum values of effective activity exhibited by the samples with values of 357Bq/kg and 348Bq/kg respectively, other samples with values close to the limit are sample CST11008SBN (S11), CSI12707EBN (S3) with values 328 Bq/kg and 318 Bq/kg.

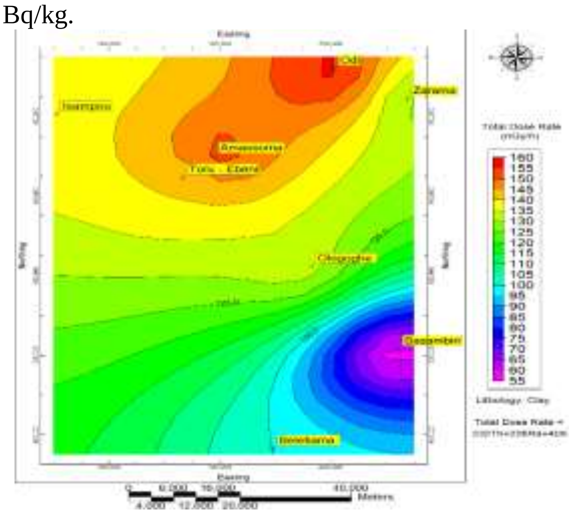

Fig 2: Spatial distribution map of dose rate (nGy/h) in clay Lithology

Table 3: Effective Activity of Samples in Study Area

Sample ID	^{226}Ra	$1.31^{232}Th$	$0.085^{40}K$	Effective Activity Concentration
CSB12507BBN(S1)	95.6	85.1	44.94	225.64
SSB22608BBN)S2)	21.82	12.67	12.92	47.41
CSI12707EBN(S3)	162.25	105.19	50.66	318.1
SSA22708EBN(S4)	25.02	11.11	17.55	53.68
CSO12807KBN(S5)	189.42	126.26	42.28	357.96
SSS22808KBN(S6)	33.59	16.18	17.75	67.52
CSB10308NBN(S7)	68.99	38.84	27.24	135.07
SSO22808NBN(S8)	27.77	9.58	20.09	57.44
CSO12807OBN(S9)	141.67	96.95	52.03	290.65
SSO22808OBN(S10)	38.59	20.07	18.54	77.2
CST11008SBN(S11)	181.83	96.95	49.38	328.16
SSO21808SBN(S12)	17.95	8.44	14	40.39
CSA110085SBN(S13)	179.05	124.96	44.31	348.32
SSA21908SBN(S14)	34.79	20.36	20.61	75.76
CSZ12208YBN(S15)	150.15	106.63	41.1	297.88
SSZ216608YBN(S16)	19.1	8.29	12.98	40.37

The consistency of these values of effective activity indicates that the materials are suitable for utilization in housing construction project from the radiologic point of view.

In the spatial distribution map of effective activity distribution in the study area shown in figure 3, it is observed that there is a north southwest trending high peak value level of effective activity above 340Bq/kg from Odi trending southwest in a ridge-like outstretch to Amassoma, a centrally located area of the study area.

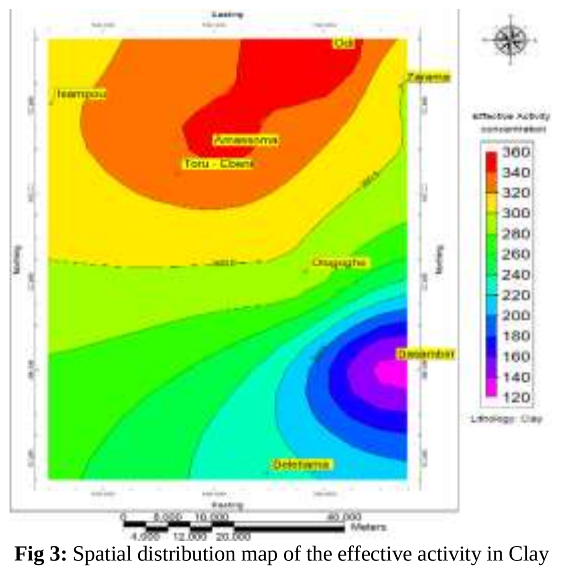

Fig 3: Spatial distribution map of the effective activity in Clay lithology

Also observed in figure 3, is a succession of diminishing effective activity values encircling the peak value. The diminishing values trended outward with Isampou having an effective activity distribution value between 320 – 240Bq/kg and Ologoghe values falling between 240-2260Bq/kg and effective activity values diminishing to values below 140Bq/kg around Basambiri environ, southeast of the study area.

Annual Effective Absorbed Dose Rate (mSv/y): The effective absorbed dose measured in mSv/y is a dosimetric parameter that determination provides the knowledge of the biomedical effects and biological damage that occurs in a tissue, organ, or system. For a 9hours a day and 6 days a week exposure, translating to occupancy of 2,835 hours a years, the annual effective dose for the samples is shown on table 4.

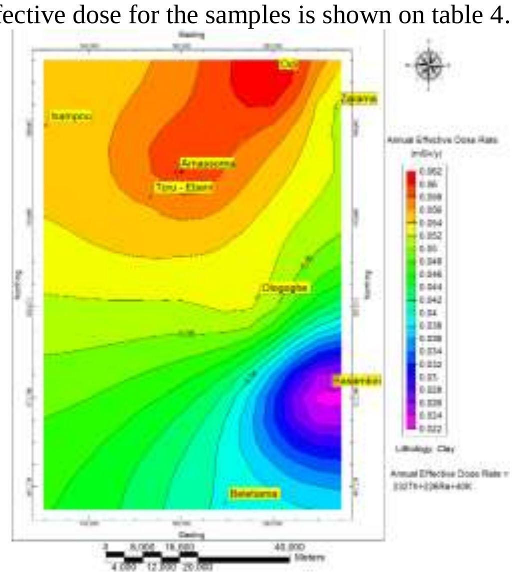

Fig 4: Spatial distribution map of absorbed effective dose in clay lithology

It can be observed in table 4 that the annual effective absorbed dose rate from all the studied samples is below 1mSv/y. Six (6) peak values are noticed to be above 0.05mSv/y which is observed to be produced by the clay lithologic samples. The annual effective absorbed dose rate from the sand samples is all noticed to be below 0.02msv/y. This therefore implies that the dose to humans (public and occupational workers) and the environment is within the international reference level and the radiologic impact from the radionuclides is very low and regulatorily acceptable since it is as Low as Reasonably Possible (ALARP)

Table 4: Annual Effective Absorbed Dose Rate of Soil Samples in Study Area

Sample	Th-232 Fraction Dose Rate	Ra-226, Fractional Dose Rate	K-40 Fractional Dose Rate	Total Dose rate D(nGy/h)	Annual Effective Dose Rate (mSv/y)
CSB12507BBN(S1)	39.23	38.43	22.2	99.86	0.0396
SSB22608BBN)S2)	5.84	8.77	6.38	20.99	0,0083
CSI12707EBN(S3)	48.5	65.22	25.03	138.75	0.0551
SSA22708EBN (S4)	5.12	10.06	8.67	23.85	0.0095
CSO12807KBN(S5)	58.21	76.15	20.89	155.25	0.0616
SSS22808KBN(S6)	7.45	13.5	8.77	29.72	0.0118
CSB10308NBN(S7)	17.9	27.73	13.46	59.09	0.0235
SSO22808NBN(S8)	4.42	11.16	9.93	25.51	0.0101
CSO12807OBN(S9)	48.79	56.95	25.71	131.45	0.0522
SSO22808OBN(S10)	9.25	15.51	9.16	33.92	0.0135
CST11008SBN(S11)	44.7	73.1	24.4	142.2	0.0564
SSO21808SBN(S12)	3.89	7.22	6.92	18.03	0.0071
CSA110085SBN(S13)	57.62	71.98	21.89	151.49	0.0601
SSA21908SBN(S14)	9.39	13.99	10.19	33.57	0.0133
CSZ12208YBN(S15)	49.17	60.36	20.31	129.84	0.0515
SSZ216608YBN(S16)	3.82	7.67	6.41	17.9	0.0071

The spatial distribution of the annual effective dose received by the public and environment seen in figure 4, shows a peak values distributed in a ridge - like trend of above 0.06mSv/y from Odi in the northeast to Amassoma a south central area. The ridge like trending peak values is encircled by diminishing trend of concentric annual effective absorbed dose rate values with values at the southeast to Toru Ebeni, an area south of Amassoma with annual effective absorbed dose rate distribution values of 0.056 to 0.058mSv/y. The lowest distribution values are observed in the southeast area of Basambiri were the values falls below 0.024mSv/y values in the study area.

Conclusion: The activity concentration of all the samples studied are below the 1000Bq/kg international reference limit for Radium-226, Thorium-232, uranium-238 and 10,000Bq/kg for potassium- 40. The absorbed dose rate and annual effective absorbed dose are also below the international reference limits published by ICRP, 2007 and UNSCEAR, 2000 publications. The effective activity maximum limit of 370Bq/kg for input raw materials for public building is not exceeded.

REFERENCES

Avwiri, G., Chad - Umoren, Y., Eyinna, P., Agbalagba, E. (2009). Occupational Radiation Profile of Oil and Gas Facilities during Production and Off Production Periods in ughelli, Nigeria . *facta universitalis Series : Work. Living Environ. Pollute 6 (1)*, 11 - 19.

Cahd-Umoren, Y., Briggs-Kamara, M. (2010). Environmental Ionizing Radiation Distribution in Rivers State , Nigeria. *J. of Environ. Engineering and Landscape Manage., 18*(2), 154-161.

Chad - Umoren, Y. E. (2012). ionizing Radiation profile of the Hydrocarbon Belt of Niegria. *in Current topics inIonizing Radiation Research, IntechOpen*.

Chad-Umoren, Y., Umoh, I. (2014). Baseline Radionuclide Distribution Patterns in Soil and Radiation Hazard Indices for Abak , Nigeria. *Adv. Phys.Theo. Appl., 32*.

EC. (1999). *Radiation Protection Report 112 ' Radiological Protection Principles Concerning the Naturally Radioactivity of Building Materials.* Brussels: European Union. Retrieved from https://eur-lex.europa.eu/oj/direct-access.html

EU. (2014). Unified Basic Safety Standards for Protection of Health of Humans and Environment Exposure Against the dangers Arising from Ionizing Radiatrion. *Directives 'Council Directive 2013/59. Euratom'(Basic Safety Standards), II*, 1-13. Jpurnal of the European Union. Retrieved from https://eur-lex.europa.eu/oj/direct-access.html

IAEA. (2004). *Soil Sampling for Environmental Contaminants.* Vienna, Austria: International Atomic Energy Agency(IAEA) IAEA TECHDOC1415.

IAEA. (2007). Naturally Occurring Radioactive Material (NORM). *Proceedings of the Fifth International Symposium on Naturally Occurring Radioactive Material.* Saville , Spain: International Atomic Energy Agency.

IAEA. (2016). Naturally Occurring Radioactive Material. *Proceedings of the 8th International Symposium on Naturally Occurring Radioactive*

Material (NORM VIII). Rio de janeiro: International Atomic Energy Agency(IAEA) .

ICRP . (2007). *ICRP Publication 103 - The 2007 Recommendations of the International Cpmmission of Radiological Protection* . Ammals of the ICRP - Elsevier.

Kumah, D., Cobbina, F., Duodu, D. (2011). Radiation-Related Eye Diseases Among Welders of Suame 'Magazine' in the Kumasi Metropolis. *J. of Sci. and Tech, 31*(1), 37.

Makinta, M., Brinders, J., Smith, K. (2017). Radiation Exposure Exerts its Adverse Effects on Sperm Maturation through Estrogen -Induced Hypothalamohyophyseal Axis Inhibition in Rats. *African Zool. 40*(2() 243- 251).

Ndubisi, O., Briggs-Kamara, M., Sigalo, F., Iyeneome, T. (2021). Analysis of Indoor Radon Level and its Health Risks Parameters in Three Selected Towns in Port Harcourt, Rivers State , Nigeria . *J. Nig. Soc. Phys. Sci.* 181 - 188.

Nwankwo, L., Adeoti, D., Folarin, A. (2014). Ionizing Radiation Measurements and Assay of Corresponding Dose Rate around Bottling and Pharmaceutical Facilities in Ilorin, Nigeria. *J. Sci. and Tech., 34*(2), 84 - 92.

UNSCEAR. (2000). *Sources and Effects of Ionizing Radiation - UNSCEAR 2000 report Volume 1 & 2* . New York: United Nations.

Zare, M., Mostajaboddavati, M., Kamali, M., Abdi, M., Mortazavi, M. (2012). 235U, 238U, 232Th, 40K, and 137Cs Activity Concentrations in Marine Sediments along the Northern Coast of Oman Sea using High Resolution Gamma ray Spectrometry. *Mar. Poll. Bull. 64*(9), 1956 - 1961.