Original Research Article

Outdoor gamma dose rates and excess lifetime cancer risks due to exposure rates at Salt Water Lakes, Ebonyi State, Nigeria

ABSTRACT

Exposure rates, gamma dose rates and excess lifetime cancer risk around saltwater lakes in Okposi Okwu and Uburu town, Ebonyi State, Nigeria were carried out, *in situ,* using two nuclear radiation meters (Radalert – 100 and Digilert – 50) and geographical position system (GPS). Measurements were taking randomly (at about 5 cm to 20 cm away from each lake) in thirty one (31) sampling locations each around the saltwater lakes at the standard level of one meter (1 m) above the ground to determine the exposure rates (in mRh^{-1}). Outdoor absorbed dose rate (D_{Out}), outdoor annual effective dose (AED_{Out}) and the excess lifetime cancer risk (ELCR) were evaluated and compared with similar reports in other countries and standards. Comparatively, the exposure rates, D_{Out}, AED_{Out} and ELCR values obtained for Uburu were similar to that of Okposi Okwu salt lake traceable to bluish black shale, with minor sandstone and silt lithology of the study locations. The mean results recorded for the two salt lakes exceeded the suggested safety limit of 0.013 mRh^{-1}, 60 $nGy\, h^{-1}$, 0.07 $mSv\, y^{-1}$, and 0.290×10^{-3} for general public respectively. In general, the results showed that terrestrial background ionizing radiation due to radionuclides in soil within the salt lakes is relatively higher and chance of developing cancer by immediate populace is very significant. Baseline study has been provided in the locations. Length of time spent within the salt lakes either at nearby farmlands and residential buildings should be minimized. Food crop cultivated near the salt lakes should be investigated for radioactivity concentrations.

Keywords: Lithology, background ionizing radiation areas, safety limit, radiation meters, saltwater lakes

1. INTRODUCTION

Saltwater lake refers to a body of surface water that is landlocked, having about three grams of salt per liters (3g/L), typically table salt of sodium chloride and other dissolved solids (DS) and minerals. Its total dissolved solids (TDS) is higher than freshwater lakes characterized by having a lower TDS. Some of the saltwater lakes in the world are Great Salt Lake in the northern part of Uttah, USA; Sambhar Salt Lake Rajasthan State, India [1]; Okposi Okwu and Uburu salt lakes which are neighbouring town in Ohaozara Local Government Area, Ebonyi State, Nigeria [2, 3].

Background ionizing radiation in an environment is principally influenced by variation in terrestrial composition, cosmic rays and lithology. Radioactivity in the earth's crust and water bodies comes majorly from radionuclides of Uranium and thorium series and radioisotopes of potassium (^{40}K) in soil and bedrock [4]. Their concentrations in the environment significantly affect terrestrial gamma dose levels [5] and the major pathways of human exposure to radiation are through direct external exposure from gamma rays and internal exposure; comprising of inhalation of radioactive gas or particulate and ingestion of water, food and other substances. It is possible to have alpha, beta and gamma emitting radioisotopes and radionuclides in an environment. Major radioactive elements found in air come from radium gas (^{222}Rn); a daughter product of ^{226}Ra and radon (^{220}Rn); a daughter product of ^{232}Th, which on release from 10 to 30 cm subsurface soil, enters the human cells through inhalation pathway.

These particles could attack the deoxyribonucleic acids (DNA) molecules resulting in acute or chronic biological effects depending on radiation doses, time of exposure, radiosensitivity of the cells, organs exposed and the age of the individual. Alpha and beta particles in biological cells are far more hazardous than gamma radiation. This is because of their ionizing power than gamma radiation, however, the penetrating power of gamma rays are more than the two particles. The main stochastic effects in the context of ionizing radiation are cancer and genetic effects. Individual develop cancer whether or not they are exposed to carcinogenic agents, however, exposure to carcinogen increases the probability of cancer; the greater the exposure, the greater is the increased likelihood.

Saltwater lakes in Okposi Okwu and Uburu Okposi have existed for over 400 years [6]. The two towns lie between latitude 06° 02′ and 0°6 07′ and longitude 07° 42′ 31″ and 07° 51′ 37″. The area is underlain by sedimentary rocks that belong to the Asu river group of Abian age [7] comprising generally of bluish black shale with minor sandstone lithology [8]. Enhanced levels of naturally occurring radionuclides and radioisotopes might be present in Okposi Okwu and Uburu saltwater lakes leading to increased levels of background ionizing radiation that could present a risk to human cells. Farmlands are cultivated about 10 m away from the lakes while residential buildings are between 25 m to 100 m away from each of the saltwater lakes.

High background radiation areas had been reported in Guarapari in Brazil, Orissa and Kerala coast in India, Ramsar in Iran and Yangjiang in China [9, 10]. Higher absorbed dose rate was established in Saline Qarun Lake, South of Cairo, Egypt [11]; from samples of river sediments in

Northern Pakistan [12]; in beach sand along North-east coast of Tamilnadu, India [13]. [14 – 17] reported high background ionizing radiation at Abeokuta (southwestern) and Jos (Northcentral) in Nigeria. Background ionizing radiation studies in Nigeria were also carried out in Market environment of oil-producing area of Rivers State [18] and coal mining areas of Gombe State [19]. Studies in Southeastern Nigeria are quite limited as some other localities including saltwater lake areas in Ebonyi State have not been investigated, therefore, the need for this study; to measure and evaluate the exposure rates, absorbed dose rate, annual effective dose and excess lifetime cancer risk due to the contributions of radionuclides and radioisotopes in the environment which are the objectives of this study.

2. MATERIALS AND METHOD

Measurement was taken, *in situ,* between December to February identified as the peak of dry season of the area using Digilert – 50 and Radalet – 100 radiation monitor (S.E International, Inc., summer town USA), containing a Geiger Muller Tube capable of detecting charged particles (alpha and beta) and photons (gamma rays and x - rays) within a temperature range between – 10℃ and 50℃. A geographical positioning system (GPS) was employed to measure the thirty – one (31) sampled locations at the salt lakes at about 5cm away from the lake water. During measurement in the site, the tube of the radiation monitors was raised to a standard height of 1.0 m above the ground with its windows facing vertically upward, thereafter, vertically downward while the GPS reading was taken at that spot. To account for any fluctuation in the environment, readings were repeated three times and then the average exposure rate was determined in milli – Roentgen per hour ($mR\ h^{-1}$) at each site on different days between the National Council on Radiation Protection and Measurement, (NCRP) recommended hours of 1300 and 1600 [20] within the 3 months.

Plate 1. Okposi Okwu salt water lake in Ohaozara LGA, Ebonyi State, Nigeria

Plate 2. Uburu saltwater lake in Ohaozara LGA, Ebonyi State, Nigeria

3. RESULTS

Dataset for *in situ* measurement of outdoor exposure rates within Okposi Okwu and Uburu salt lakes were converted to absorbed doses rate, annual effective dose and excess lifetime cancer risks, presented in Table 1. Table 1 also compares the results obtained in the two salt lakes with available generally accepted worldwide standards. Figure 1 shows the frequency distribution histogram of the exposure rates at Okposi Okwu salt lakes while Figure 2 shows the frequency distribution histogram of the exposure rates at Uburu salt lakes. Figure 3 showed the regression plot between exposure rate at Okposi Okwu and Uburu salt Lakes from which the coefficient of correlation (ρ) was determined. Skewness and kurtosis statistics of the distribution of exposure rates at the salt lakes were also determined using SPSS version 21 software package.

Table 1. Exposure doses rate at the salts lakes and associated potential radiological risk

Sample location/Standards	Minimum exposure rate $(mR\ h^{-1})$	Maximum exposure rate $(mR\ h^{-1})$	Mean exposure rate $(mR\ h^{-1})$	D_{out} $(nGy\ h^{-1})$	AED_{out} $(mSv\ y^{-1})$	ELCR 10^{-3}
Okposi Okwu	0.016±0.003	0.031±0.002	0.0216±0.003	187.75±29.09	0.288±0.045	1.007±0.156
Uburu	0.015±0.001	0.0411±0.002	0.025±0.006	218.90±53.96		1.169±0.282
[21]			0.013*	60	0.07	
[22]						0.29

0.013* was adopted from [18]

Table 2. Distribution of exposure rate $(mR\ h^{-1})$ at Okposi Okwu salt water lake environ

Exposure rate $(mR\ h^{-1})$	Frequency	Percent (%)	Cumulative Percent
0.0160	2	6.5	6.5
0.0170	1	3.2	9.5
0.0180	3	9.7	19.4
0.0190	2	6.5	25.8
0.0200	3	9.7	35.5
0.0210	6	19.4	54.8
0.0220	2	6.5	61.3
0.0230	4	12.9	74.2
0.0240	4	12.9	87.1
0.0251	1	3.2	90.3
0.0270	2	6.5	96.8
0.031	1	3.2	100
Total	**31**	**100.0**	

Table 3. Distribution of exposure rate ($mR\ h^{-1}$) at Uburu salt water lake environ

Exposure rate ($mR\ h^{-1}$)	Frequency	Percent (%)	Cumulative Percent
0.0150	1	3.2	3.2
0.0170	3	9.7	12.9
0.0190	1	3.2	16.1
0.0200	1	3.2	19.4
0.0210	4	12.9	32.3
0.0220	2	6.5	38.7
0.0230	3	9.7	48.4
0.0240	2	6.5	54.8
0.0250	2	6.5	61.3
0.0270	1	3.2	64.5
0.0280	2	6.5	71.0
0.0290	1	3.2	74.2
0.0300	2	6.5	80.6
0.0310	1	3.2	83.9
0.0330	1	3.2	87.1
0.0340	2	6.5	93.5
0.0350	1	3.2	96.8
0.0410	1	3.2	100
Total	**31**	**100.0**	

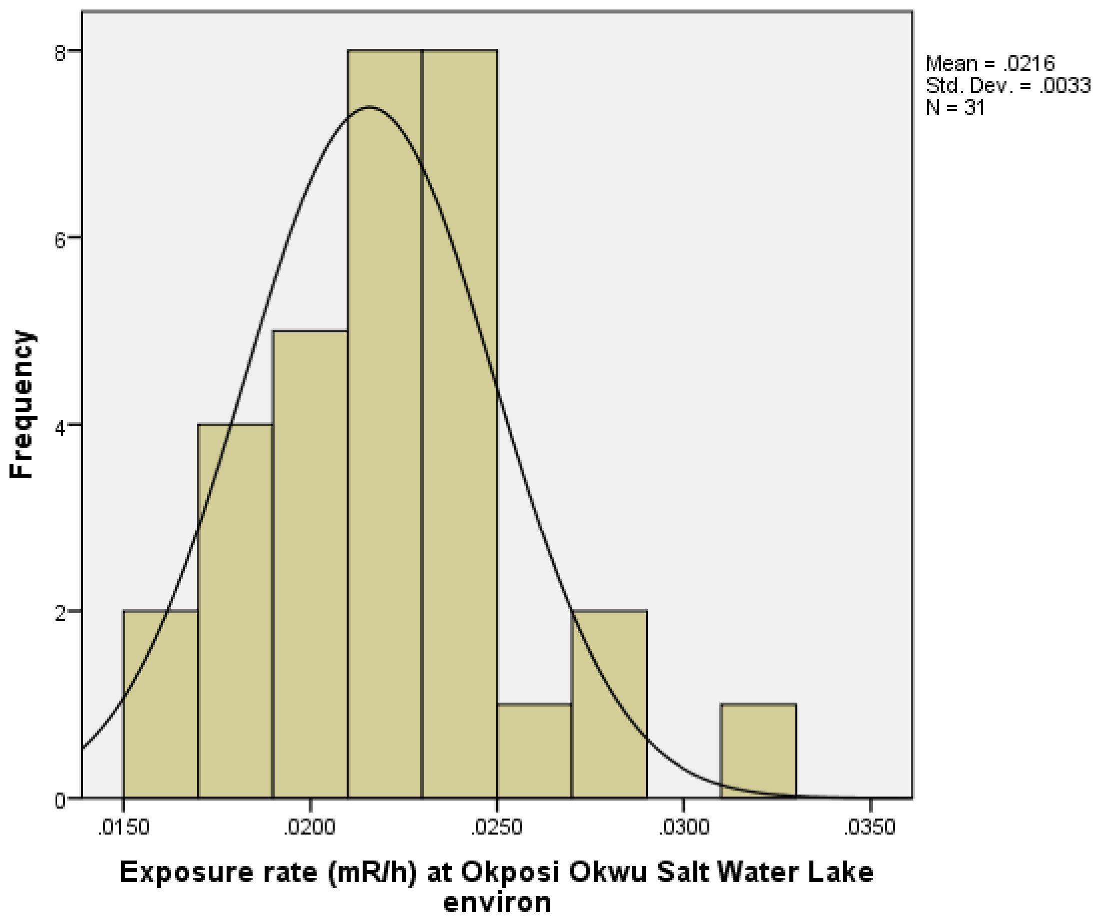

Figure 1. Frequency histogram distribution for Okposi Okwu Salt Water Lake environs

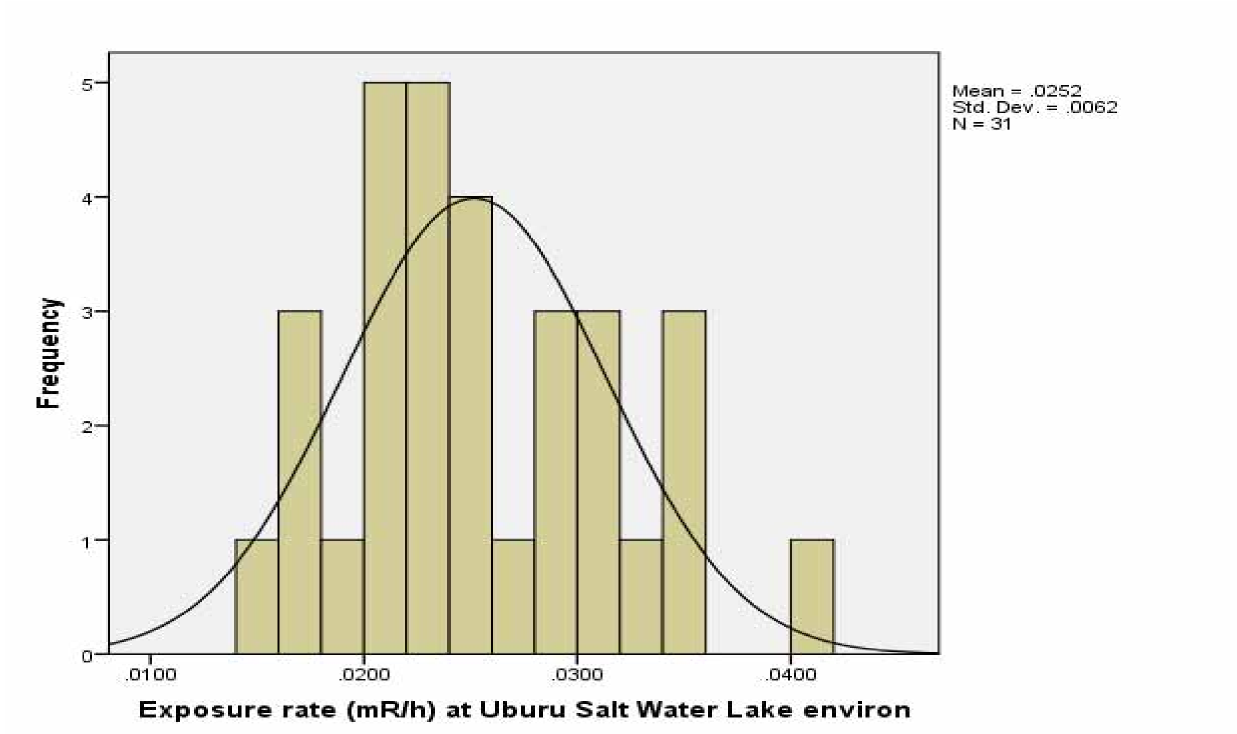

Figure 2. Frequency histogram distribution for Uburu Salt Water Lake environs

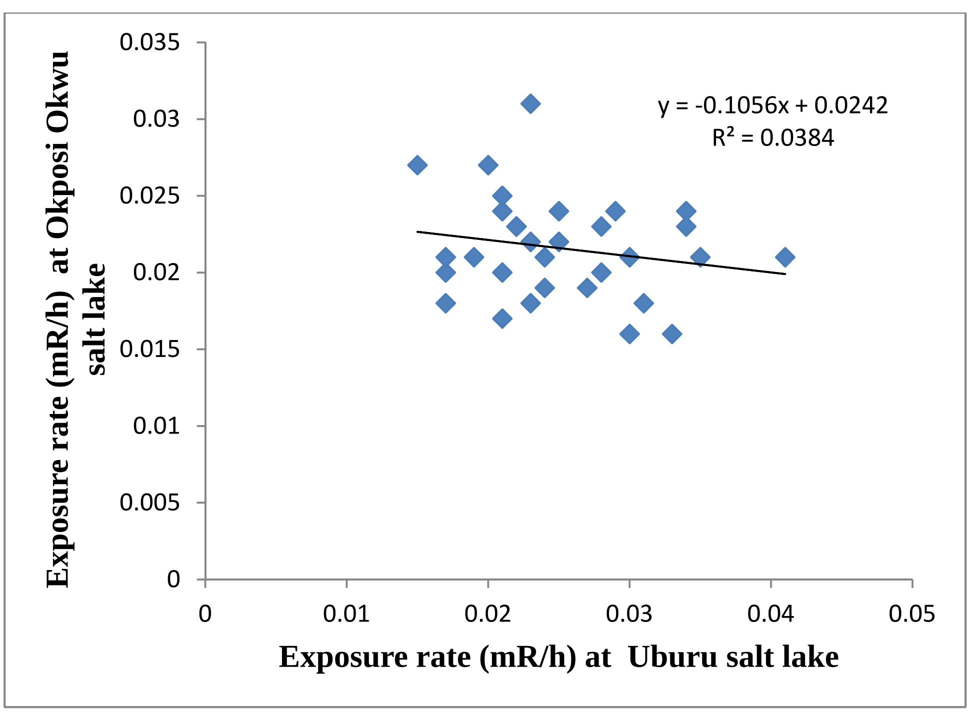

Figure 3. Regression plot between exposure rate in Okposi Okwu and Uburu salt lakes ($\rho = 0.195$)

3.1 Exposure rates and Outdoor Absorbed Dose Rate in air (D_{Out})

The unit of exposure is roentgen (R) while the unit of exposure rate is roentgen per hour ($R\ h^{-1}$). The outdoor exposure rate at 1 m above the ground was determined by averaging the 3 measurements in milli Roentgen per hour ($mR\ h^{-1}$). Using equation 1 [20, 23], data set obtained from outdoor exposure rate in ($mR\ h^{-1}$) were converted to absorbed dose rate (D) in $nGy\ h^{-1}$, and presented in Table 1 for Okposi Okwu and Uburu salt lake environments.

$$D_{Out}\ (nGy\ h^{-1}) = \text{Exposure rate}\ (mR\ h^{-1}) \times 8.7 \times 10^3 \qquad (1)$$

Observation from Table 1 showed that the outdoor exposure rate ranged from 0.016±0.003 $mR\ h^{-1}$ to 0.031±0.002 $mR\ h^{-1}$ with mean value of 0.0216±0.003 $mR\ h^{-1}$ and from 0.015±0.001 $mR\ h^{-1}$ to 0.0411±0.002 $mR\ h^{-1}$ with mean value of 0.025±0.006 $mR\ h^{-1}$ for Okposi Okwu and Uburu salt lakes respectively. The results were higher than standard limit of 0.013 $mR\ h^{-1}$ [18].

Outdoor absorbed dose rate (D_{Out}) for Okposi Okwu salt lake ranged from 139.2 $nGy\ h^{-1}$ to 269.7 $nGy\ h^{-1}$ with a mean 187.75±29.10 $nGy\ h^{-1}$ while Uburu result ranged from 130.5$nGy\ h^{-1}$ to 356.7 $nGy\ h^{-1}$ with a of 218.1±53.96 $nGy\ h^{-1}$. Both respectively were about 3.1 and 3.6 times higher than the world average report of 60 $nGy\ h^{-1}$ by United Nations Scientific Committee on the Effects of Atomic Radiation [21].

The D_{Out} results were higher than the range of 51.61 – 171 $nGy\ h^{-1}$ obtained in Saline Qarun Lake in Egypt [11]; Mean results reported in Kirklareli Turkey [22]; at Gold mining site, Itagunmodi, South – western Nigeria [24] and the outdoor external dose of 87.47 $nGy\ h^{-1}$ from river sediments of Northern Pakistan [12]. However, the study agreed favourably with the highest results obtained at Rukpokwu International Market, in oil producing area of Rivers State [18].

3.2 Outdoor Annual Effective Dose (AED_{Out})

The annual effective dose (AED_{Out}) in $mSv\ y^{-1}$ was calculated from the absorbed dose rate by applying the dose conversion factor of 0.7 $Sv\ Gy^{-1}$ adopted from [21] report with outdoor occupancy factor of 0.25, expressed in equation 2 and results presented in Table 1 for Okposi Okwu and Uburu. The outdoor occupancy factor of 0.25 was employed instead of the popular 0.2 since the people living and farming within the salt lakes area spends average of six hours outdoor.

$$AED_{Out} = D(nGy\,h^{-1}) \times 8760 \times 0.7(Sv\,Gy^{-1}) \times 0.25 \qquad (2)$$

As observe from Table 1, the values for Okposi Okwu salt lake ranged from 0.213 to 0.413 $mSv\,y^{-1}$ with a mean of 0.288±0.045 $mSv\,y^{-1}$ which is about 4.1 times higher than the [21] report of 0.07 $mSv\,y^{-1}$ as the average outdoor annual effective dose. While Uburu salt lake ranged from 0.200 to 0.547 $mSv\,y^{-1}$ with a mean of 0.333±0.081 $mSv\,y^{-1}$, which is 4.8 times higher than [21] report. The Okposi Okwu result agreed fairly with the study carried out in Abeokuta in South – western Nigeria and Jos in North – central Nigeria [14]. Furthermore, Uburu salt water lake was in good agreement with 0.45 $mSv\,y^{-1}$ established by [15] in Abeokuta while Okposi Okwu salt lakes agreed favourably with the study carried out by [18] at Rukpokwu International Markert in Rivers State. However, the two salt water lakes were lower than 0.62 $mSv\,y^{-1}$ and 0.92 $mSv\,y^{-1}$ established at Tamilnadu, India [13] and Northern Pakistan [12] respectively.

3.3 Excess Lifetime Cancer Risks ($ELCR$)

Human exposure to ionizing radiation at low levels for a long time can result to stochastic effects like cancer and genetic effects [25]. The excess lifetime cancer risk deals with the probability of developing cancer over a lifetime at a given exposure level [22, 26] and is calculated using equation 3 and the results presented in Table 1 for Okposi Okwu and Uburu respectively.

$$ELCR = AED_{Out}\,(mSv\,y^{-1}) \times DL(y^{-1}) \times RF(Sv^{-1}) \qquad (3)$$

Where ELCR is the excess lifetime cancer risk and the value of 0.290×10^{-3} has been recommended as the average standard [21, 22], AED_{Out} represents the annual effective dose, DL represents for the average duration of life estimated to be 70 years and RF is the risk factor which is the fatal cancer risk per sievert. For stochastic effects, the International Commission on Radiological Protection [27 – 29] publications uses RF as 0.05 for the public exposure [22].

Excess lifetime cancer risk for Okposi Okwu ranged from 0.746×10^{-3} to 1.446×10^{-3} with the mean of 1.007±0.156; while for Uburu, it ranged from 0.700×10^{-3} to 1.915×10^{-3} with the mean value of 1.169×10^{-3}. Both results were 3.5 and 4.0 times higher than the average standard value 0.2×10^{-3} [22]; 25 and 29 times respectively higher than Maiganga coal mining area, Akkok LGA, Gombe, Northeast, Nigeria [19]. In addition, Okposi Okwu and Uburu salt lakes were respectively in favourable agreement with 1.05×10^{-3} (Faroun Zone) and 1.12 $\times 10^{-3}$ (Anabta Zone), both at large scale manufacturing industrial area of Tulkarem Province – Palestine [30]. However, the results of the present study were both lower than 3.21×10^{-3} obtained in Northern Pakistan [12].

3.4 Statistical Analyses

In summarizing a set of data, it is generally desirable not only to record the mean but also to specify the standard deviation, which gives the degree of clustering of the distributions or observations around the mean. The standard deviation was used as an index to indicate the degree to which data set tend to spread or cluster about the meanwhile the ratio of standard deviation to its arithmetic mean describes the coefficient of variation (CV) for a set of data. Though data set recorded at Okposi Okwu and Uburu showed very small deviation (standard deviation less than the mean), however, measurements of exposure rates obtained at Uburu salt lake environ were found more widely dispersed than that of Okposi Okwu salt lake with the CV of 24% and 13.8% respectively.

Distribution of exposure rate at Okposi Okwu saltwater lake environs as observed from Table 1 revealed that 0.0200 $mR\ h^{-1}$ (representing 19.4%) was the most frequent data obtained while the least were found as 0.0170 $mR\ h^{-1}$, 0.0251 $mR\ h^{-1}$ and 0.031 $mR\ h^{-1}$ (representing 3.2%). Likewise in Uburu salt water lake environ as observed from Table 2, the distribution of exposure rate revealed that 0.0210 $mR\ h^{-1}$ (representing 12.9%) was obtained as the most frequent data, while the least frequent data were found as 0.0190 $mR\ h^{-1}$, 0.0200 $mR\ h^{-1}$, 0.0270 $mR\ h^{-1}$, 0.0290 $mR\ h^{-1}$, 0.0310 $mR\ h^{-1}$, 0.0350 $mR\ h^{-1}$ and 0.0410 $mR\ h^{-1}$ (representing 3.2%).

Frequency histogram distributions for Okposi Okwu and Uburu showed that most of the datasets clustered at the center, with a bell-shaped curve (Figure 3). Linear regression and correlation are two different techniques that are concerned with prediction and strength of the relationship/

association between two variables respectively. The scatter plot as shown in Figure 1 demonstrated negative but very weak correlation coefficient ($\rho = 0.195$) between data sets of Okposi Okwu and Uburu salt lakes. This result is an indication that the contributions of the background ionizing radiation from the environment could be from different sources of radionuclides/radioisotopes in the environment.

Skewness and kurtosis statistics were also estimated for Okposi Okwu and Uburu data sets. The coefficient of skewness is a measure of the degree of symmetry in a variable distribution. While the coefficient of kurtosis measures the degree of tailedness (outliers) in a variable distribution. Dataset for Okposi Okwu (0.603) and Uburu (0.550) are approximately or moderately symmetrical because the results are near zero; which is perfectly symmetrical (normal distribution). A skewness of exactly zero is quite implausible for real – data sets. A normal distribution has a kurtosis of exactly zero called mesokurtic distribution, which is a reference standard. Distribution is platykurtic with thinner tails if kurtosis is less than zero and leptokurtic distribution with fatter tails if kurtosis is greater than zero. While dataset for Okposi Okwu (0.863) is fairly leptokurtic distribution, that of Uburu (– 0.065) is platykurtic distributions.

4. DISCUSSION

Uniformity of readings of exposure rate were observed in some sampling points in both salt lakes, suggesting that the points could be the pathway through which the rural women follow to their respective homes which may have equally been spilled by salt water. The relatively high background radiation obtained in this study for the first time in the locality was considered as sum of the terrestrial and cosmic rays contributions. The mean absorbed dose rate annual effective dose and excess lifetime cancer risks for Uburu salt lake compares favourably well with that of Okposi Okwu which could be attributed to similar local lithology in the localities. Okposi Okwu and Uburu town are geologically located in Lower Benue Trough characterized by lead (Pb) and zinc (Zn) minerals in form of their ores [31]. The area is made up of thick sequence of slightly deformed Cretaceous sedimentary rocks made up of essentially of Abian shales, subordinate siltstones of the Asu River Group [31, 32]. Localities with shale, sandstones and siltstone lithology emit radiation to the environment. Radioisotope of lead (^{210}Po) is alpha and beta emitter, therefore ^{222}Rn and ^{220}Rn gases could possibly dominate the salt lakes environment. Generally, the bedrock of the study area characterised by sedimentary rocks principally accounts for higher gamma dose rate obtained in this work. Furthermore, the results agreed favorably with similar studies while they also differed with some others. Diverse lithology and associated complex tectonic features contributes to environmental radioactivity [33]. It is worthy to mention that the study did not extend to raining season which could have given an interesting results and comparison, however, is the next line of research study to explore.

CONCLUSION

Despite the background ionizing radiation report in different countries of the world including Nigeria, especially in mining areas, market and commercial areas, industrial, agricultural, mountain and rocky areas, the level at salt lake environs of Okposi Okwu and Uburu located in Ohaozara LGA, Ebonyi State had not been determined and reported. The study report that the salt lake environs are locations of higher background ionizing radiation than some studies reported in the literature and as a consequence, the immediate populace may significantly be exposed to high gamma dose emanating from the salt lakes environ. Furthermore, the assessment of excess lifetime cancer risk due to gamma dose rate revealed that the probability of developing cancer over the average lifespan (estimated as 70years) is higher than reported studies in the literature. This study has provided essential baseline information needful and useful to radiation protection and measurement agencies and for future references in the area. Residential houses and farmlands should be sited far away from the salt lakes and also regular monitoring of background ionizing radiation levels within the environment should be encouraged. Since the areas within the salt lakes produce large quantities of food crops and livestock that are distributed within the neighboring localities, there is, therefore, need to examine the radionuclide content and radiological risk indices of food crops and livestock produced within the areas.

REFERENCES

1. Bhat AH, Sharma K.C. Physico – chemical analyses of ground water quality of adjoining areas of Sambahar Lake, a Ramsar Wetland of Rajasthan, India. Current World Environment, An International Research Journal of Environmental Science. 2015; 10(3): doi:http://dx.doi.org/10.12944/cWE.10.3.37.

2. Nwaka BU, Enyinna PI. Gross alpha and beta activity concentrations in locally processed salt from Ebonyi State, Nigeria. Physical Science International Journal. 2016; 12 (4): 1 – 12.

3. Okoye EI, Akpan AE, Egboka BCE, Okolo, MC, Okeke HC. Geophysical delineation of sub surface fracture associated with Okposi – Uburu salt lake, Southeastern, Nigeria. International Research Journal of Environmental Sciences. 2015; 4(2): 1 – 6.

4. Turhan ŞÖE, Taşkin H, Varinlioglu A. Determination of natural radioactivity by gross alpha and beta measurements in ground water samples. Water Research. 2013; 47: 3103 – 3108.

5. Isola GA, Oni OM, Olasunkami, SK. Radionuclide concentrations in soil around waste dumpsites and its excess lifetime cancer risks due to gamma radioactivity in Ogbomosho Metropolis, Southwestern Nigeria. International Journal of Humanies, Arts, Medicine and Sciences. 2015; 3(6): 25 – 30.

6. Okaji OO. Salt production in Uburu and Okposi Okwu autonomous community, Ebonyi State. Ebonyi Salt Business Directory. 2009; 11:1 – 3.

7. Petters SW. Central West African Cretaceous – Tertiary Bethic Foraminifera and Stratigraphiy. Paleontographica B. 1982; 179: 1 – 104.

8. Akande SO, Mueke A. Mineralogical and Paragenetic study of Pb/Zn, Cu mineralization in Lower Benue Trough, Nigeria and genetic implications. J. Afr. Sci. 1989; 9: 23 – 29.

9. Mortazavi SMJ, Mozdarani H. Is it time to shed some light on the black box of health policies regarding the inhabitants of the high background radiation area of Ramsar Iran. J. Radiat. Res. 2012; 10: 111 – 116.

10. Aliyu AS, and Ramli AT. The world's high background natural radiation area (HBNRAs) revisited: A broad overview of the dosimetric epidermiological and radiological issues. Radiation Measurements. 2015; 73: 51 – 59.

11. Saher MD, Samia, ME, Amany TS, Najat FA. Natural radioactivity assessment & radiological hazards in soil from Qarun Lake, and Wadi El Rayan in Faiyum, Egypt. Open Journal of Soil Science. 2013; 3(7) 8pages, DOI:104236/ojss.2013.37034

12. Aziz A Q, Shahina T, Kamal Ud Din, Shahid M, Chiara C, Abdul W. Evaluation of excessive lifetime cancer risk due to natural radioactivity in the river sediments of Northern Pakistan. Journal of Radiation Research and Applied Sciences. 2014; 7(4): 438 – 447.

13. SureshGandhi M, Ravisankar R, Rajalakshmi A, Sivakumar S, Chandrasekaran A, Pream AD. Measurement of natural gamma radiation in beach sediments of north east coast of Tamilnadu, India by gamma ray spectrometry with multivariate statistical approach. Journal of Radiation Research and Applied Sciences. 2014; 7: 7 – 17.

14. Farai IP, Jibiri NN. Baseline studies of terrestrial outdoor gamma dose rate levels in Nigeria, Radiation Protection Dosimetry. 2000; 88 (3): 247 – 254.

15. Farai, IP, Vincent UE. Outdoor radiation levels measurement in Abeokuta, Nigeria by thermoluminescent Dosimetry. Nigerian Journal of Physics. 2006; 18 (1): 121 – 126.

16. Ademola, JA. Exposure to high background radiation level in the tin mining area of Jos Plateau, Nigeria. Journal of Radiological Protection. 2008; 28 (1): 93 – 99.

17. Jibiri NN, Alausa SK, Owofolaju AE, Adeniran AA. Terrestrial gamma dose rates and physical – chemical properties of farm soil from ex – tin mining locations in Jos – Plateau, Nigeria. African Journal of Environmental Science and Technology. 2011; 5(12):1039 – 1049.

18. Ononugbo CP, Oduware SC. Baseline studies of terrestrial outdoor gamma doses rates of ten selected markets in Port Harcourt Metropolis. Archives of Current Research International. 2017; 10(2): 1 -13.

19. Kolo MT, Khandakar MU, Amin YM. Abdullahi WHB. Quantification and radiological risk estimation due to the presence of natural radionuclides in Maiganga Coal, Nigeria. PLOS ONE. 2016; 11(6) e0158100.doi.101371/journal.phone.0158100.

20. Muhammad R, Saeed UR, Muhammad B, Wajid A, Iftikhar A, Khursheed A L, et al. Evaluation of excess lifetime cancer risk from gamma dose rates in Jhelum Valley. Journal of Radiation Research and Applied Sciences. 2014; 7(1): 29 – 35.

21. UNSCEAR. United Nations Scientific Committee on the Effects of Atomic Radiation. Sources, Effects and Risks of Ionizing Radiation. Report to General Assembly with Scientific Annexes, United Nations, New York; 2000.

22. Taskin H, Karavus M, Topuzoglu A, Hindiroglu S, Karahan G. Radionuclide concentrations in soil and lifetime cancer risk due to gamma radioactivityin Kirklareli, Turkey J. Environ. Rad. 2009; 100: 49 – 53.

23. Knoll GF. Radiation Detection and Measurement. 3rd edition, John Wiley and Sons Inc. Printed in United State of America, 2000; Chapter 2: 57 – 58.

24. Ademola AK, Bello AZ, Adejumobi AC. Determination of natural radioactivity and hazard in soil samples in and around gold mining area in Itagunmodi, Southwestern Nigeria. Journal of radiation Research and Applied Sciences. 2014; 7: 249 – 255.

25. Farai IP. Physics in radiation application and safety for national technological advancement. A Plenary Lecture delivered at the 37th Annual Conference of the Nigerian Institute of Physics at Oduduwa University, Ipetumodu, 27 – 31 October, 2014; 23 pages.

26. Emelue HU, Nwaka BU, Amanze K, Nwosu CO. Radiological Health hazard indices and excess lifetime cancer risk of oil producing communities in Nigeria. British Journal of Medicine and Medical Research 2014; 4(36): 5853 – 5865

27. ICRP. The Recommendation of the International Commission on Radiological Protection, Publication 60, 1990; Pergamon Press.

28. ICRP. The Recommendation of the International Commission on Radiological Protection, Publication 76, 1999; Pergamon Press.

29. ICRP. Annals of the ICRP, International Commission on Radiological Protection Publication 119, Compendium of Dose Coefficient based on ICRP Publication 60, 2012.

30. Kaleel MT, Mohanad MJ. Natural radioactivity levels and estimations of radiation exposure in environmental soil samples from Turkarem Province – Palestine. Open Journal of Soil Science. 2012; 2: 7 – 16.

31. Onyewuchi RA, Opara AI, Ahiarakwem CA, Oko FU. Geological Interpretations inferred from Airborne Magnetic and Landsat data: Case study of Nkalagu Area, Southeastern Nigeria. International Journala of Science and Technology. 2012; 2(4): 178 – 191.

32. Fatoye FB, Gideon YB. Geology and mineral resources of the Lower Benue Trough, Nigeria. Advances in Applied Research. 2013; 4(6): 21 – 28.

33. Ramola RC, Choubey VM, Ganash P, Gusain, GS, Tosheva, Z, Kies A. Radionuclide analysis in the soil of Kumaun Himalaya, Indian, Using gamma ray spectrometry. Current Science 2011; 100(6):906 – 914.