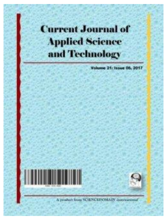

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Outdoor Gamma Dose Rates and Excess Lifetime Cancer Risks Due to Exposure Rates at Salt Water Lakes, Ebonyi State, Nigeria

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Authors' contributions

This work was carried out in collaboration between all authors. Author BUN designed the study, performed the statistical analysis, wrote the protocol and wrote the first draft of the manuscript. Authors BUN, GOA and PIE managed the analyses of the study. Author BUN managed the literature searches. All authors read and approved the final manuscript.

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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

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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 (3 g/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 more 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 METHODS

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.

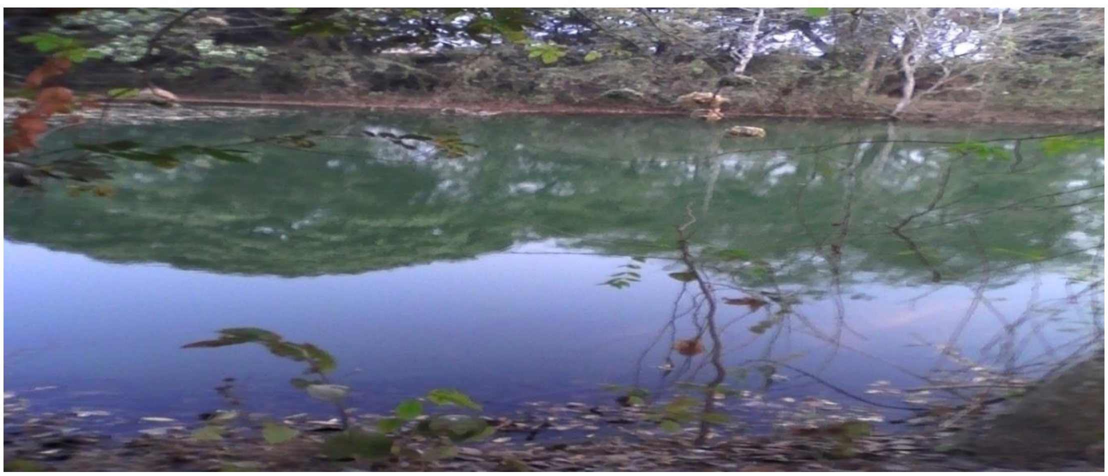

Plate 1. Okposi Okwu salt water lake in Ohaozara LGA, Ebonyi State, Nigeria

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. Fig. 1 shows the frequency distribution histogram of the exposure rates at Okposi Okwu salt lakes while Fig. 2 shows the frequency distribution histogram of the exposure rates at Uburu salt lakes. Fig. 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.

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 [20,21], 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.

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

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 [22].

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
[22]			0.013*	60	0.07	
[23]						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**	

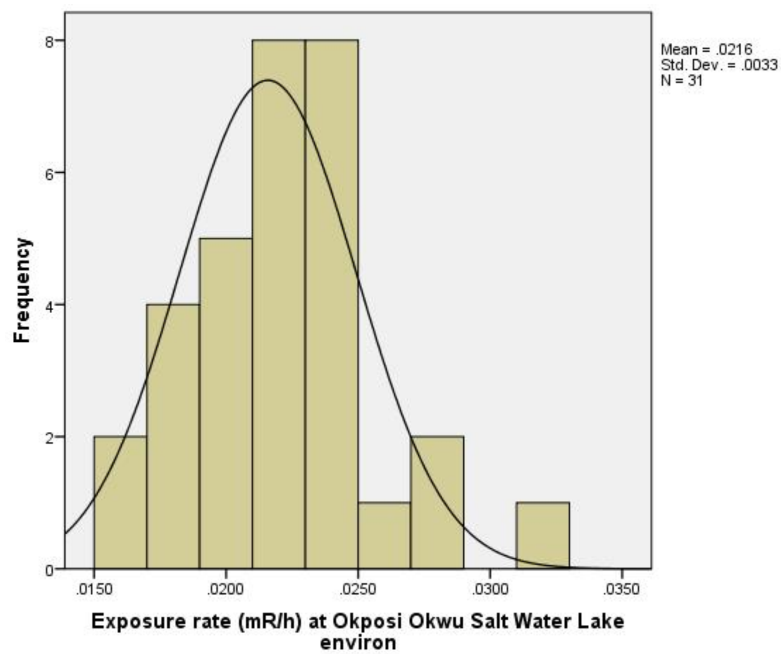

Fig. 1. Frequency histogram distribution for Okposi Okwu salt water lake environs

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 [23]; 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 [22] 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.

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

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 [22] 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 [22] 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 Market 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 [23,26] and is calculated using equation 3 and the results presented in Table 1 for Okposi Okwu and Uburu respectively.

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

Where ELCR is the excess lifetime cancer risk and the value of 0.290×10^{-3} has been recommended as the average standard [22,23], 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 [23].

Excess lifetime cancer risk for Okposi Okwu ranged from 0.746 $\times 10^{-3}$ to 1.446$\times 10^{-3}$ with the mean of 1.007±0.156; while for Uburu, it ranged from 0.700 $\times 10^{-3}$ to 1.915$\times 10^{-3}$ with the mean value of 1.169 $\times 10^{-3}$. Both results were 3.5 and 4.0 times higher than the average standard value 0.2$\times 10^{-3}$ [23]; 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$\times 10^{-3}$ (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 $\times 10^{-3}$ obtained in Northern Pakistan [12].

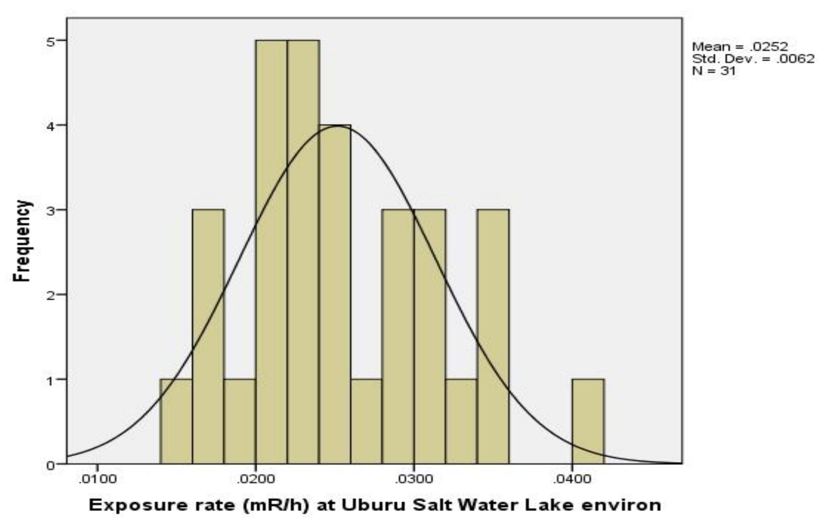

Fig. 2. Frequency histogram distribution for Uburu salt water lake environs

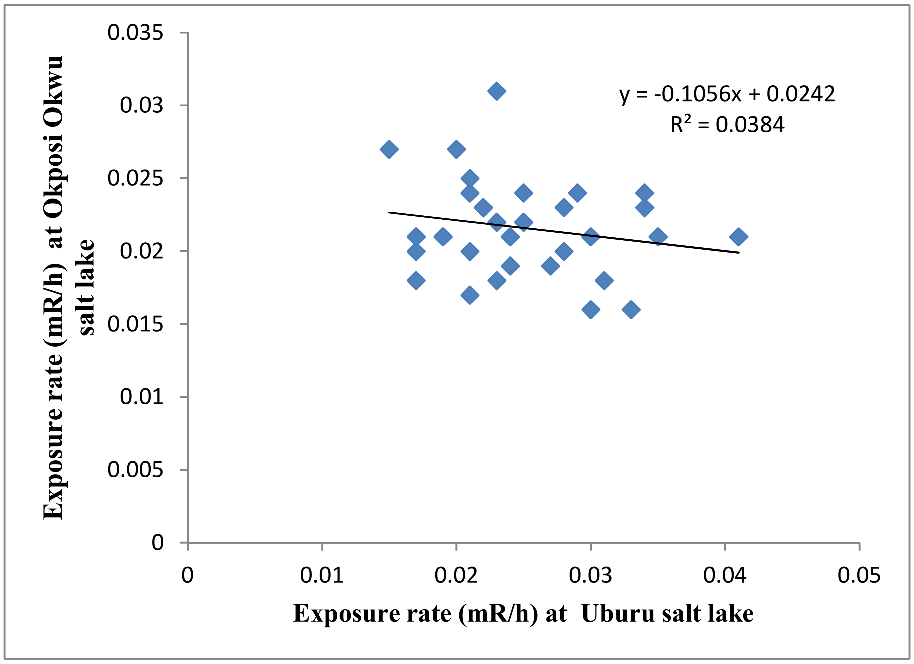

Fig. 3. Regression plot between exposure rate in Okposi Okwu and Uburu salt lakes ($\rho = 0.195$)

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 (Fig. 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 Fig. 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.

5. 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 70 years) 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.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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