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Natural Radioactivity and Radiological Risk Estimation of Drinking Water from Okposi and Uburu Salt Lake Area, Ebonyi State, Nigeria

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Authors' contributions

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

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ABSTRACT

Aim: The objectives of this study was to measure the activity concentration of natural radionuclides in different drinking water sources in order to access the associated radiological health risk due to ingestion of such water.
Study Design: The design of this study is purely experimental.
Place and Duration: This study was carried out on drinking water sources around Uburu and Okposi salt lakes areas of Ebony state between April and September, 2016.
Methodology: Sachet waters, borehole water, stream and river waters were collected and chemically treated by adding few drops of nitric acid to each of the samples and then pre-concentrated and kept in a marinelli container for four weeks. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in all the water samples was measured using the High- Purity Germanium detector.

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Results: The specific activity concentration of ^{226}Ra, ^{2321h} and ^{40}K ranged from BDL to 3.66± 0.78 Bql^{-1}, BDL to 7.56 ± 0.0.59 Bql^{-1} and BDL to 23.31 ± 1.65 Bql^{-1} respectively in sachet water. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in borehole water ranges from BDL to 5.65±1.25, 0.45±0.09 to 13.00±0.97 and BDL to 26.45±1.83 Bql^{-1} respectively. Furthermore the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in stream water ranges from BDL to 2.88±1.32 Bql^{-1}, BDL to 8.93±0.66 Bql^{-1} and BDL to 33.32±2.18 Bql^{-1} respectively, while that for river water ranges from 0.03±0.01 to 4.48±1.13 Bql^{-1}, 0.55±0.10 to 8.60±0.65Bql^{-1} and BDL to 13.85 ±0.98 Bql^{-1} respectively. The mean values of annual effective dose obtained for infants, children and adults are within the ICRP and WHO recommended reference values. The life-long cancer risk and hereditary effects due to ingestion of radionuclides by adults show that 16 out of 100,000 may suffer some form of cancer fatality and 9 out of 100,000 may suffer some hereditary effects. Statistical analysis of the data revealed a positively skewed and platokurtic distribution of radionuclides in all the drinking water sources.

Conclusion: All the radiological health risk parameters obtained were within their safe values. Therefore, all the sampled drinking water are radiologically safe for domestic use but infant should not be given any of the studied drinking water since the annual total effective dose for infant exceeded the safe value.

Keywords: Radioactivity; high-purity germanium; effective dose; radiological risk; Uburu and Okposi.

1. INTRODUCTION

Humans have always been exposed to natural radiation arising from the earth as well as from outer space. Terrestrial radiations are given out from natural radioactive elements present in varying amounts in all types of water, soil, rocks, food and other environmental media around us [1]. Radiation exposure through drinking water results from naturally occurring radionuclides in drinking water sources, in particular alpha radiation emitting uranium, radium and their progeny including radon [2]. The occurrence of natural radionuclide in drinking water poses a problem of health hazard, when these radionuclide are taken into the body by ingestion. The radionuclide contributing significantly to the ingestion dose via consumption of water is radium. Radium is a naturally occurring isotope found in the earth's crust, a member of the uranium ^{238}U decay series. The predominant radium isotopes in ground and surface water are ^{226}Ra, an alpha emitter with half-life of 1600 years and ^{228}Ra, a beta emitter with a half-life of 5.8 years [3]. Many salts of radium are soluble in water and therefore surface water may be enriched in radium and its descendant radon. ^{226}Ra is an earth alkaline element sharing the metabolic pathways of calcium in the human body. Due to their radiotoxicity especially those of ^{226}Ra, a contamination hazard for humans exists even at low concentration levels [4].

Ingested radionuclides are absorbed into the blood (International Commission on Radiological Protection, ICRP, 2007) and accumulates in specific tissues that they may damage. Of absorbed uranium, 66% is rapidly eliminated via urine while the rest is distributed and stored in the kidney (12-15%), bone (10-15%) and soft tissues. The internal exposure of humans to ionizing radiation is through inhalation and ingestion. When the radioisotope enters the body, it accumulates in the tissue of body organ. The rate of clearance of such radionuclide from the tissue or organ is dependent on the biological half-life. The retention of radioisotope in the tissue or body organ can be expressed by the relationship given by Onoja and Akpa [5] as:

$$A = A_o e^{-\lambda \varepsilon \tau} \quad (1)$$

Where A is the activity remaining at a time after the depositions of activity A_o and ε is the effective clearance constant. For practical purposes, the limiting values are reached after about half lives. At this steady state condition, the activity deposited will be equal to the activity eliminated. This defines the maximum concentration of any radionuclide type in drinking water. The level of concentrations of radionuclides according to nature in ground waters are mainly due to uranium and thorium bearing soil and rock minerals or with uranium, thorium and radium deposits. Therefore studies has shown that natural radioactivity in water depends on the local geological characteristics of the source, soil or rock [6,7,8].

Natural uranium induces chemical toxicity, especially nephrotoxicity, which is more harmful than radiotoxicity; whereas radium and radon are

thought to induce solely radiotoxicity. Higher concentration of radioactivity in environmental media can cause exposure risk to the general populace which may lead to radiation related sickness such as leukemia, cancer of bladder, kidney, testis and lungs [4,9]. Increased concern for the radiological status of drinking water has led to an increased demand for data on water quality. World Health Organization (WHO) [10], recommended reference dose level (RDL) of committed effective dose of 100 μSv from one year consumption of drinking water. Gamma rays can enter the skin and interact with tissues or organs. Uranium and radium found in water and do not emit strong gamma radiation, so showering with that water will not pose any significant risk. However, if this radionuclide are inhaled or ingested through eating and drinking, the emissions can come into direct contact with sensitive tissues or organs in the body [11,12].

Measurement of natural radioactivity levels in drinking water is relevant in assessing the radiological risk to humans due to water ingestion [10,11]. Studies of natural radioactivity of bottled water, mineral waters, ground and surface water have been the subject of numerous studies. For instance, the measurement of radium isotopes (^{226}Ra, ^{228}Ra), ^{222}Rn and ^{40}K concentration in bottled water and mineral water for Poland, Austria, Romania and Algeria were presented by Nguyen et al. [12], Wallner et al. [13], Elena Botezatu et al. [14]. Studies on natural radioactivity of different brands of commonly sold bottled drinking water in the federal capital Islamabad and Rawalpindi city of Parkistan revealed that activity concentration of ^{226}Ra, ^{232}Th and ^{40}K were 11.3±2.4, 5.2±0.4 and 140.9±30.6 mBql^{-1} [15]. Activity concentration of ^{40}K was measured using high purity germanium (HPGe) detector in some sachet drinking water samples produced in Nigeria. Activity concentration of ^{40}K obtained in sachet water were within the ICRP safe standard for drinking water. In Nigeria studies related to natural radioactivity monitoring in ground water and surface water has been carried out [16,17] but no work has been done on sachet water, ground water and surface water from Uburu and Okposi salt lake areas of Ebonyi State.

Therefore, the aim of this work is to measure the natural radionuclide concentration in drinking water sources around Uburu and Okposi salt lake in order the quantify its associated health risk parameters for different age groups. The result of this work will serve as the base line radiological data of the study area and also add information to the radiological data base in Nigeria.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is Okposi Okwu and Uburu town located in Ohaozara LGA and are found in Lower Benue Trough which is the southern portion of Benue Trough; others are Upper Benue and Middle Benue Trough. The geology of Lower Benue Trough is associated with tectonic activities that were recorded during the Cenomanian [16]. Lead – zinc – barites mineralization in the Trough is believed to be hydrothermal in origin and it is associated with brine spring [17]. The two towns lie within latitude 06° 02′ N to 6° 07′ N and Longitude 7° 42′ 31″ E to 7° 51′ 37″ E. The bedrock of the area is made up of sedimentry rocks belonging to the Asu – River group of Albian age [18, 19,20,21]. The portable drinking water problem worsened during dry season when water levels and discharge from surface and ground water falls due to the intense drought. Okposi Okwu salt, though believed to be medicinal and relatively expensive than the normal salt and that of Uburu sold in the localities form the bulk of the supply in the local markets. The salt lakes gave Ebonyi State its slogan as the ″Salt of the Nation″. Fig. 1a and 1b shows the map of Okposi Okwu and Uburu salt.

2.2 Sampling and Sample Preparation

In order to measure the natural radioactivity in drinking water sources samples collected from Uburu and Okposi lake environs, a total of thirty–one water samples were randomly collected from borehole water in Okposi Okwu and Uburu, Atta stream and Asu river and also two brand of sachet water mainly distributed in the area were collected for the study. Water samples were collected using 2 litres well labeled homogenous plastic containers. All the water samples were acidified with few drops of concentrated nitric acid (HNO_3) for each 2 litres container to obtain a pH value less than 2 ($pH < 2$) in order to avoid adsorption of radionuclides on the walls of the container and also to prevent microbial activities. Concentration was carried out by gradual evaporation of each water sample in an oven at a temperature of 70°C and 120 ml of the residue was transfer into a 120 ml marinelli

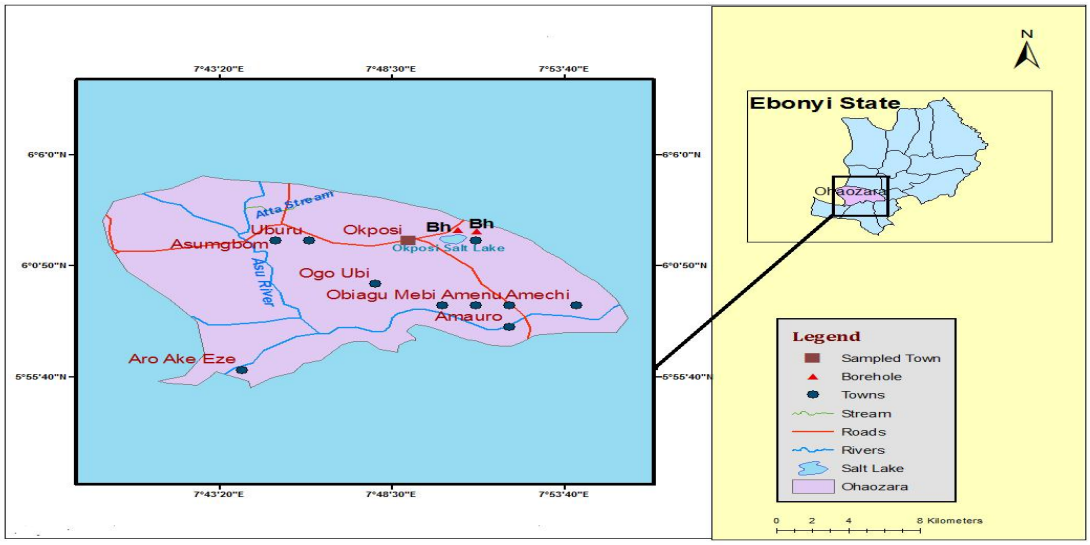


Fig. 1a. Map of Okposi Okwu salt lake in Ohaozara LGA, Ebonyi state Nigeria

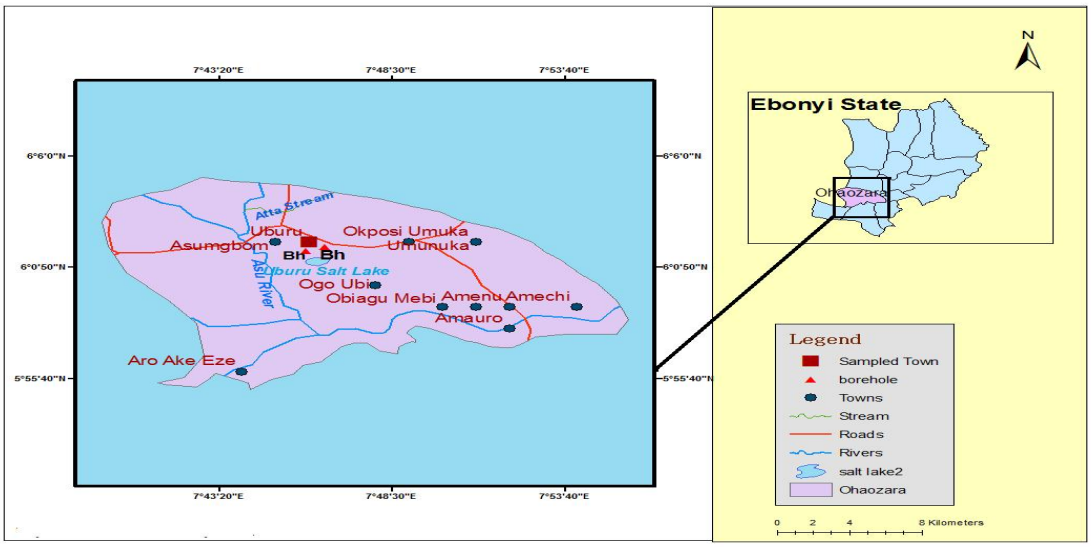


Fig. 1b. Map showing Uburu salt lake in Ohaozara LGA, Ebonyi state Nigeria

bottles and were sealed with thick vinyl tapes around their screw necks. These samples were stored for 4 weeks to reach secular equilibrium between ^{238}U and ^{232}Th and their respective progeny [9,22].

2.3 Experimental Setup

The gamma ray spectrometry analyses for the water samples were carried out at the National Institute of Radiation Protection and Research (NIRPR) in University of Ibadan, Ibadan, Nigeria. After the in-growth period, each water samples was subjected to a low background gamma-ray spectrometer of type; High Purity Germanium (HPGe) P – type detector. The well calibrated, lead shielded HPGe detector (with model number, GC8023) manufactured by CANBERRA Industries Inc, with serial number: 9744 has a length and diameter of 69.8 mm and 78 mm respectively. For the water analysis, the detector was connected through a preamplifier (model number: 2002CSL and serial number 13000742), and a PC – based Multichannel Analyzer (MCA). The gamma spectrum peak area and quantification was carried out using Genie 2K

and 16K software. HPGe detector used in this work has relatively higher energy resolution with relative efficiency of 80%. The standard source used for calibration was CANBERRA Multi Gamma ray Standard (MGS6M315). The energy and efficiency calibrations of the detector was carried out using 1.33MeV gamma line of ^{60}Co resulting to energy resolution of 2.3 KeV Full Width at Half Maximum (FWHM) which is considered adequate to distinguish the gamma ray energies of interest in the present study.

For the purpose of identifying the various radionuclides that may be present in the water samples through the gamma energies they emit, the energy calibration of the detector was performed using standard sources of known radionuclides with well – defined energies. The ^{226}Ra and ^{232}Th (^{228}Ra) activity concentrations were determined indirectly through their activities of their decay products, while ^{40}K content of the water samples was also determined by measuring the 1460.8 KeV gamma rays emitted during the decay of ^{40}K. The detection limits of radionuclides^{226}Ra, ^{232}Th and ^{40}K are given as 0.03, 0.0013 and 0.002 Bql^{-1} respectively.

The background count was determined by counting the empty plastic container volume for 10 hours, thereafter water samples (120 ml) contained in the same container volume were counted in the HPGe detector for a period of 10 hours (36, 000 seconds) each to determine the radionuclides of interest. The net area count under the corresponding photo peaks of each of the radionuclide in the energy spectrum was computed by subtracting counts due to Compton scattering of higher peaks and the background sources from the total area of the peaks. From the measured net counts, the activity concentrations of the radionuclides in the water samples were calculated in Bql^{-1} using equation (2).

$$A(Bql^{-1}) = \frac{C_n}{\varepsilon_\gamma . P_\gamma . t_c . V} \quad (2)$$

Where C_n is the net peak area at gamma ray energy, ε_γ is the efficiency of the detector, P_γ is the emission probability of the radionuclides of interest, t_c is the total count time(s) and V is the sample volume in litres.

2.4 Estimation of Radiation Risk Parameters

The radiation risk parameters (Annual Effective dose and Excess life time cancer risk) was estimated from the activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in drinking water samples, dose coefficient of each of the nuclides and volume of water intake for 3 age brackets (infants, children and adults). In this work, the water intake rates was based on UNSCEAR [23] recommendation of0.5 l/d and 1.0 l/d for infants (0-1 years) and children (10 years) respectively, and 2 l/d for adults (≥ 17 years) were used for calculations.

The annual effective dose due to intake of drinking water sources sampled was computed using the following formula [9,23].

$$H_{ing}\ (mSvy^{-1}) = \sum_{i=1}^{i=3} DCF_{ing}\ (i) \times Ai \times I \quad (3)$$

Where DCF_{ing} (i) is the dose coefficient of a particular radionuclide in Sv/Bq for a particular age categories (Table 1). $A_{i\ is}$ the specific activity concentration of radionuclide in the drinking water sample measured in Bq/l and I, the radionuclide intake in liters per year for each age categories.

The stochastic effects of radiation in adult citizen that takes water from the various drinking water sources was estimated using the international Commission on effects of protection (ICRP) cancer risk methodology [24]. The health risks to members of the public due to exposure to low dose radiation which is regarded as chronic risk of somatic or hereditary effects were also determined. Cancer risk coefficient and hereditary effect coefficient of 5.5× 10^{-2} Sv^{-1} and 0.2× 10^{-2} respectively of ICRP report and assumed 70 years lifetime of continuous exposure of the population to low level radiation adopted [9,25]. According to ICRP methodology and Ndontchueng et al. [9],

Fatality Cancer Risk = Total annual Effective Dose (Sv) × Cancer risk factor (5.5× 10^{-2}) (4)

Lifetime fatality cancer risk to adult = Total annual effective dose ×70 yrs × 5.5× 10^{-2} (5)

Severe Hereditary Effects = Total annual Effective Dose (Sv) × Hereditary effect factor (0.2× 10^{-2}) (6)

Estimated Lifetime hereditary effect in adult = Total annual Effective Dose (Sv) × 70 yrs × 0.2× 10^{-2} (7)

Table 1. Effective dose coefficients for ingestion of radionuclides for members of the public to 70 years of age (ICRP, 2012; Publication 119)

S/N	Radioisotopes	Infant ≤ 1 year	Children 10 years	Adult ≥ 17 years
1	^{226}Ra	5.7 E-06	8.0E-07	2.8 E-07
2	^{232}Th	1.6 E-06	2.9 E-07	2.3 E-07
3	^{40}K	5.2 E-05	1.3E-08	6.2 E-09
Water intake		0.5 L/day	1.0 L/day	2.0 L/day

3. RESULTS AND DISCUSSION

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K and total annual effective dose for different age groups measured in water samples collected from different locations near Okposi Okwu and Uburu salt lake area are presented in Table 2 while Table 3 gives the estimated cancer risks and the hereditary effects of adult member of the public.

From Table 2, the specific activity concentration of ^{226}Ra, ^{232}Th and ^{40}K ranged from BDL to 3.66± 0.78 Bql^{-1}, BDL to 7.56±0.59 Bql^{-1} and BDL to 23.31 ±1.65 Bql^{-1} respectively in sachet water. The average activity concentration of^{226}Ra and ^{232}Th in sachet water produced in Okposi Okwu and Uburu are found to be higher than 0.02 Bql^{-1} and 0.03 Bql^{-1} in mineral bottled water produced in Cameroon [26] except for ^{40}K.The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in borehole water ranges from BDL to 5.65± 1.24, 0.45±0.09 to 13.00±0.97 and BDL to 26.45± 1.83 Bql^{-1} respectively. Furthermore the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in stream water ranges from BDL to 2.88±1.32, BDL to 8.93±0.66 Bql^{-1} and BDL to 33.32± 2.18 Bql^{-1} respectively, while that for river water ranges from 0.03±0.01 to 4.48±1.13 Bql^{-1}, 0.55±0.10 to 8.60±0.65 Bql^{-1} and BDL to 13.85 ± 0.98 Bql^{-1} respectively. The variations in activity concentrations of these radionuclides are due to the variations in the chemical composition of local geological formations and the aquifer geochemistry from where the drinking water originate. The presence of the salt lake might have contributed to increase concentration of ^{226}Ra, ^{232}Th and ^{40}K in stream water near the salt lakes.

The highest activity concentration value of ^{226}Ra (5.65±1.24) was recorded in borehole water (UgwBH02) which could be due to infiltration from the salt lakes and other activities in the area. The mean activity concentrations of ^{22}Ra, ^{232}Th and ^{40}K obtained in all the different water resources were 1.24, 4.17 and 9.82 Bql^{-1} respectively which is slightly higher than the reference value of 1.0 and 0.1 Bql^{-1} recommended by WHO [6] except for ^{40}K which is within the safe value. The average results of both Okposi Okwu and Uburu borehole water samples were lower than the Tap water results measured by Ononugbo et al. [27] at Ogba/Egbema/Ndoni LGA of Rivers State in oil producing communities, Niger Delta Region of Nigeria due to different geological composition the areas and the oil producing activities in Onelga. However, the obtained results were higher than the results of Osman et al. [28] who studied natural radioactivity levels of ground waters of Kuhliate and Miri Bara in Kadugli, Saudi. The variation in the results is traceable to their local geology and geochemistry of the aquifer as well as the environmental management practices. The levels of gamma radiation in ground water sources could directly be associated with the mineralogical compositions and activity concentrations of radionuclide in aquifer bedrock and the age of the ground water in the aquifer. The result of this study also show that the activity concentration of ^{226}Rais higher in Atta stream than Asu river while activity concentration of ^{232}Th in Asu river is higher than that of Atta Stream and also high than the result obtained by Jibiri et al. [29] from Obafemi – Owode area in Abeokuta, Nigeria.

The annual effective dose due to ingestion of drinking water sources sampled was estimated for three different age groups: Infants, children and adults using equation 3 and presented in Table 2. The calculated annual effective dose for different age groups that drinks sachet water ranges from 0.03 to 0.20 mSvy^{-1} for infants, 0.029 to 0.04 mSvy^{-1} for children and from 0.038 to 0.036 mSvy^{-1} for adult respectively. In borehole water, it ranges from 0.028 mSvy^{-1} to 0.695 mSvy^{-1} in infants, 0.008 to 0.009 mSvy^{-1} for children and 0.0069 to 0.036 mSvy^{-1} in adult. For stream water, total effective dose ranges from 0.0033 to 0.871 mSvy^{-1}, in infant, 0.009 to 0.034 in children and 0.0065 to 0.044 mSvy^{-1} in adult. The total annual effective dose calculated from activity concentration of radionuclides in river water samples for infant, children and adult ranges from, 0.0077 to 0.37 mSvy^{-1}, 0.0027 to 0.051 mSvy^{-1} and 0.0041 to 0.021 mSvy^{-1}

respectively. It can be observed that the radiation dose received by infants is relatively higher than that received by children and adults. The total annual effective dose obtained for infant, children and adults are higher than that obtained by Yussuf et al. [1] but are within the result obtained by Ajayi et al. [30] and WHO [10] and UNSCEAR [23] reference levels of the effective dose for infants, children and adult due to one year continuous ingestion of various drinking water of 0.26, 0.20 and 0.10 $mSvy^{-1}$ respectively. The effective doses obtained are higher than the reference values for infants, children and adults that consume stream water and river water and from the radiation protection point of view, life-long ingestion of these sampled drinking waters may cause significant radiological health risk. It is observed that infants have higher radiation risk than children and adult since the total effective dose calculated for infants exceeded the WHO reference value in all drinking water sources studied.

Fatality cancer risk and severe hereditary effects of ingestion of the sampled drinking water sources was determined and presented in Table 3. The result showed that cancer risk for adults varies from 0.0068×10^{-6} to $2.41 \times 10^{-6}$and the lifetime hereditary effects varies between 0.046×10^{-5} and $16.83 \times 10^{-5.}$ Whereas the hereditary effect to adult per year calculated varied from $0.025 \times 10^{-8}$to 8.75×10^{-8} and the lifetime hereditary effects hereditary effect in adult varies from 0.017×10^{-6} to 9.64×10^{-6}. This implies that 16 out of 100,000 may likely suffer some form of cancer fatality and the result also shows that 9 out of 100,000 may suffer some hereditary effects. The United States Environmental protection Agency (USEPA) recommended acceptable cancer fatality risk limit of 1.0×10^{-6} to 1.0×10^{-4} (i.e. 1 person out of 1 million to 10,000 persons suffering from some form of cancer fatality) [9,31].

The result of the lifetime cancer risk and the lifetime hereditary effect obtained in this study are in agreement with that obtained by Ndontchueng et al. [9] in mineral waters in Cameroon. The obtained results are within the acceptable risk factor as recommended by USEPA [31].

4. STATISTICS

Statistical analysis of the measured activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in water samples are Presented in Table 4 while the histograms are presented in Fig. 2. When the standard deviation is higher than the mean value, it shows low degree of uniformity and vice versa. In this present study, standard deviation values of activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K are higher than the mean values indicating low degree of uniformity. Skewness refers to asymmetric nature of the shape of frequency distribution. Skewed distribution could either be positively or negatively skewed [32]. From Table 4, the skewness of the activity concentration of ^{226}Ra, ^{232}Th and ^{40}K are positive which shows that their distributions are asymmetric.

Skewness is the extent to which the data are not symmetrical. From Table 4 and Fig. 2, the obtained data are positive skewed or right skewed data since the tail of the distribution points to the right and its skewness value greater than zero. It means that the frequency of positive returns exceeds that of negative returns resulting in the distribution displaying a fat right tail or positive skewness. Kurtosis is a measure of peakedness of the distribution curve. Kurtosis indicates the extent to which the values of the variables fall above or below the mean and manifests itself as a fat tail. With the exception of ^{226}Ra and AEDE children, all the other data had negative kurtosis. The negative value of kurtosis indicates less peaked than normal curve and is called platykurtic [33]. This indicates that returns very high above or below the mean occurred very frequently and the distribution exhibits high kurtosis. It has a flattened shape.^{226}Ra and $AEDE_{children}$ showed a positive kurtosis. This implies that there are lesser returns above or below the mean and the frequency of occurrences increases around the mean and the distribution shows low kurtosis, in order words, it is leptokurtic. This distribution has high peak.

In order to determine the mutual relationships and strength of association between pairs of variables, correlation between them were drawn using SPSS 16.0 software as shown in Table 5. Low positive correlation was observed between ^{226}Ra and ^{40}K and ^{232}Th and ^{40}K. This is due to the fact that ^{226}Ra and ^{232}Th comes natural decay series whereas ^{40}K, though a naturally occurring radionuclide is not part of any such decay series. This indicates that ^{40}K concentrations may not be related with the presence of ^{232}Th and ^{226}Ra bearing minerals. Weak negative correlation coefficient was observed between ^{226}Ra and ^{232}Th shows that their sources in the environment differs.

Table 2. Activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in water samples and annual effective dose for different age categories

S/N	Sample ID	Location	Activity concentration (Bq/l)			Total annual effective dose (μSv/y)		
			^{226}Ra	^{232}Th	^{40}K	Infant	Children	Adult
1	Ubu SA01	N06° 02′ 49 E007°45′20.1	BDL	0.54±0.11	BDL	0.432	0.1566	0.1242
2	UbuSA 02	N06° 02′ 19.0″ E007°46′07.9″	BDL	BDL	BDL	0	0	0
3	UbuSA04	N06° 02′ 17.0″ E007°46′ 09.9″	2.93±0.69	0.28±0.03	7.33±0.57	199.16	2.616	10.86
4	Ubu SA05	N06° 02′ 18.0″ E007°46′ 05.9″	3.66±0.78	7.56±0.59	23.31±1.65	622.54	5.726	34.43
5	UbuBH01	N06° 03′ 12.4″ E007°45′ 14.4″	BDL	2.22±1.35	BDL	1.776	o.6438	1.021
6	UbuBH 02	N06° 03′ 13.7″ E007°45′ 23.9″	0.97±0.27	1.07±0.46	4.22±0.30	113.34	1.196	6.268
7	Ubu BH04	N06° 03′ 13.7″ E007°45′ 24.8″	1.47±0.31	5.58±0.43	8.20±0.55	221.85	3.007	13.56
8	Ubu BH05	N06° 03′ 13.7″ E007°46′ 22.9″	BDL	4.45±0.36	12.61±0.83	331.42	1.618	17.68
9	OkpSA 01	N06° 02′ 02.2″ E007°49′ 06.5″	BDL	BDL	BDL	0	0	0
10	OkpSA 02	N06° 02′ 04.4″ E007°49′ 15.3″	1.11±0.62	0.14±0.03	BDL	3.276	0.9286	0.686
11	Okp SA04	N06° 02′ 04.4″ E007°48′ 15.2	BDL	7.06±0.58	18.49±1.32	486.38	2.528	26.18
12	Okp SA05	N06° 02′ 04.4″ E007°47′ 14.1	BDL	6.98±0.55	12.24±0.89	323.82	2.342	18.39
13	Okp BH 01	N060 02′ 07.5″ E007048′ 4.7″	0.86±0.26	0.45±0.09	BDL	2.811	0.8185	0.6886
14	OKPBH04	N060 03′ 02.4″ E007049′ 8.5″	BDL	2.93±0.25	10.05±0.75	263.64	1.111	13.81
15	Okp BH 05	N060 08′ 02.4″ E007049′ 7.5″	BDL	4.81±0.38	17.83±1.22	467.43	1.858	24.32
16	UgwBH 01	N060 08′ 04.3″ E007049′ 3.5″	4.94±0.99	4.14±0.033	8.91±0.64	249.05	5.384	15.72
17	Ugw BH02	N060 07′ 02.6″ E007048′ 7.5″	5.65±1.24	13.00±0.97	10.65±0.21	303.40	8.567	22.35

S/N	Sample ID	Location	Activity concentration (Bq/l)			Total annual effective dose (μSv/y)		
			^{226}Ra	^{232}Th	^{40}K	Infant	Children	Adult
18	Ugw BH03	N060 06′ 02.3″ E007047′ 6.5″	BDL	3.50±1.24	12.05±0.84	316.1	1.328	16.55
19	Ugw BH04	N060 08′ 07.5″ E007048′ 6.2″	BDL	11.50±0.8	11.17±0.84	299.62	3.625	19.14
20	Ugw BH05	N060 08′ 02.4″ E007049′ 7.5″	BDL	8.88±0.71	21.30±1.50	560.90	3.129	30.5
21	Ugw BH06	N060 08′ 02.4″ E007049 7.5″	1.32±0.29	5.64±0.44	26.45±1.83	695.97	3.379	36.13
22	AttaST 01	N06° 01′ 56.4″ E007°48′30.7″	1.16±0.57	BDL	BDL	0.3306	0.928	0.6496
23	Atta ST 02	N06° 01′ 58.5″ E007°48′28.2″	2.88±1.32	0.25±0.04	BDL	8.408	2.377	1.728
24	Atta ST04	N06° 01′ 57.6″ E007°47 28.4″	BDL	8.93±0.66	11.67±1.02	310.56	2.893	18.58
25	Atta ST05	N06° 01′ 57.4″ E007°48′27.2″	BDL	5.23±0.41	33.32±2.18	870.50	2.383	43.72
26	Atta ST06	N06° 01′ 58.5″ E007°48′28.2″	BDL	4.34±0.34	26.94±1.80	703.91	1.959	3.54
27	AsuRv 01	N06° 03′ 59.4″ E007°44′32.1″	0.03±0.01	0.86±0.44	BDL	0.7735	0.2734	0.4124
28	AsuRv 02	N06° 04′ 59.4″ E007°44′ 2.1″	2.0±0.61	0.55±0.10	BDL	614.0	1.76	1.373
29	Asu Rv04	N06° 04′ 57.5″ E007°44′ 33.2	4.48±1.13	4.32± 0.36	11.20±0.81	307.42	5.128	18.38
30	AsuRV 05	N06° 04′ 56.4″ E007°44′ 35.2	2.05±0.46	8.60±0.65	2.76±0.03	8.4482	4.206	8.526
31	Asu Rv06	N06° 04′ 59.4″ E007°44′ 30.9	2.39±0.55	5.67±0.45	13.85±0.98	372.56	4.228	21.34

Ubu SA: Uburu sachet water samples, Ubu BH:Uburu borehole water samples, Okp SA: Okposi Okwu sachet water samples, Okp BH: Okposi Okwu borehole water samples, Atta ST: Atta stream water samples, AsuRv: Asu River water samples, BDL = Below Detection Limit

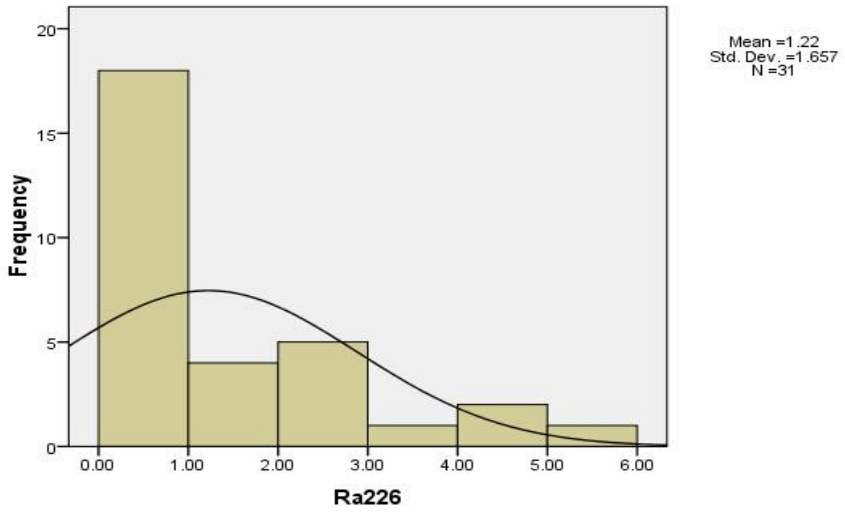
Table 3. Estimated cancer risks and hereditary effects of adult member of the public

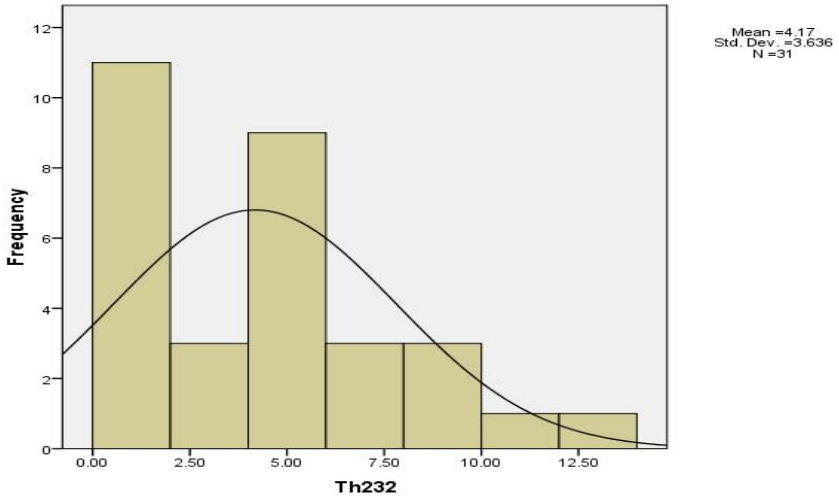
S/N	Sample code	GPS	Total annual effective dose (μSvy^{-1})			Fatality cancer risk to Adult per year	Lifetime fatality cancer risk	Severe hereditary effects in adult per year	Estimated lifetime hereditary effects
			Infant	Children	Adult	$\times 10^{-6}$	$\times 10^{-5}$	$\times 10^{-8}$	$\times 10^{-6}$
1	Ubu SA01	N06° 02′ 49 E007°45′20.1	0.432	0.156	0.1242	0.0068	0.048	0.0248	0.0174
2	UbuSA 02	N06° 02′ 19.0″ E007°46′07.9″	0	0	0	0	0	0	0
3	UbuSA04	N06° 02′ 17.0″ E007°46′ 09.9″	199.16	2.62	10.86	0.597	4.181	2.172	1.520
4	Ubu SA05	N06° 02′ 18.0″ E007°46′ 05.9″	622.5	5.73	34.43	1.89	13.256	6.886	4.82
5	UbuBH01	N06° 03′ 12.4″ E007°45′ 14.4″	1.78	0.64	1.021	0.056	0.393	0.204	0.143
6	UbuBH 02	N06° 03′ 13.7″ E007°45′ 23.9″	113.34	1.20	6.27	0.345	2.413	1.254	0.878
7	Ubu BH04	N06° 03′ 13.7″ E007°45′ 24.8″	221.85	3.01	13.56	0.746	5.219	2.712	1.898
8	Ubu BH05	N06° 03′ 13.7″ E007°46′ 22.9″	331.42	1.62	17.68	0.973	6.808	3.537	2.476
9	OkpSA 01	N06° 02′ 02.2″ E007°49′ 06.5″	0	0	0	0	0	0	0
10	OkpSA 02	N06° 02′ 04.4″ E007°49′ 15.3″	3.28	9.29	0.69	0.0377	0.264	0.137	0.0960
11	Okp SA04	N06° 02′ 04.4″ E007°48′ 15.2	486.39	2.53	26.18	1.44	10.077	5.235	3.66
12	Okp SA05	N06° 02′ 04.4″ E007°47′ 14.1	323.82	2.34	18.39	1.011	7.080	3.678	2.574
13	Okp BH 01	N060 02′ 07.5″ E007048′ 4.7″	2.81	0.82	0.69	0.028	0.265	0.138	9.640
14	OKPBH04	N060 03′ 02.4″ E007049′ 8.5″	263.64	1.11	13.81	0.759	5.317	2.762	0.0193
15	Okp BH 05	N060 08′ 02.4″ E007049′ 7.5″	467.43	1.86	24.32	1.34	9.364	4.864	3.41
16	UgwBH 01	N060 08′ 04.3″ E007049′ 3.5″	249.05	5.38	15.72	0.865	6.052	3.144	2.20

S/N	Sample code	GPS	Total annual effective dose (μSvy^{-1})			Fatality cancer risk to Adult per year	Lifetime fatality cancer risk	Severe hereditary effects in adult per year	Estimated lifetime hereditary effects
			Infant	Children	Adult	$\times 10^{-6}$	$\times 10^{-5}$	$\times 10^{-8}$	$\times 10^{-6}$
17	Ugw BH02	N060 07′ 02.6″ E007048′ 7.5″	303.40	8.57	22.35	1.229	8.605	4.47	3.13
18	Ugw BH03	N060 06′ 02.3″ E007047′ 6.5″	316.1	1.33	16.55	0.910	6.373	3.31	2.317
19	Ugw BH04	N060 08′ 07.5″ E007048′ 6.2″	299.62	3.63	19.14	1.053	7.369	3.828	2.679
20	Ugw BH05	N060 08′ 02.4″ E007049′ 7.5″	560.90	3.13	30.5	1.677	11.741	6.099	4.270
21	Ugw BH06	N060 08′ 02.4″ E007049 7.5″	695.97	3.38	36.13	1.987	13.911	7.226	5.058
22	AttaST 01	N06° 01′ 56.4″ E007°48′30.7″	3.31	0.93	0.65	0.036	0.250	0.130	0.091
23	Atta ST 02	N06° 01′ 58.5″ E007°48′28.2″	8.41	2.38	1.73	0.095	0.665	0.346	0.242
24	Atta ST04	N06° 01′ 57.6″ E007°47 28.4″	310.56	2.89	18.58	1.022	7.153	3.716	2.601
25	Atta ST05	N06° 01′ 57.4″ E007°48′27.2″	870.50	2.38	43.72	2.405	16.833	8.745	6.12
26	Atta ST06	N06° 01′ 58.5″ E007°48′28.2″	703.91	1.96	35.4	1.947	13.63	7.08	4.956
27	AsuRv 01	N06° 03′ 59.4″ E007°44′32.1″	0.77	0.27	0.41	0.023	0.158	0.0083	0.058
28	AsuRv 02	N06° 04′ 59.4″ E007°44′ 2.1″	6.14	1.76	1.37	0.076	0.529	0.275	0.192
29	Asu Rv04	N06° 04′ 57.5″ E007°44′ 33.2	307.42	5.13	18.38	1.011	7.078	3.677	2.574
30	AsuRV 05	N06° 04′ 56.4″ E007°44′ 35.2	84.45	4.21	8.53	0.469	3.283	1.705	1.194
31	Asu Rv06	N06° 04′ 59.4″ E007°44′ 30.9	372.56	4.23	21.34	1.174	8.216	4.268	2.988
			13.0076	7.610E-05	472.30	2.59E-05	18.185E-04	9.447E-07	6.613E-05
	WHO, 2004; IAEA, 2000		0.26	0.20	0.10				

Table 4. Descriptive statistics

Statistics							
		Ra226	**Th232**	**K40**	**AEDEinfant**	**AEDEchildren**	**AEDEadult**
N	Valid	31	31	31	31	30	31
	Missing	32	32	32	32	33	32
Mean		1.2226	4.1742	9.8242	279.3492	2.5151	13.7631
Std. error of mean		.29768	.65303	1.69532	45.34643	.35395	2.20893
Median		.0300	4.3200	10.0500	299.6200	2.3595	13.8100
Mode		.00	.00	.00	.00	.00	.00
Std. deviation		1.65743	3.63594	9.43915	252.47822	1.93866	12.29880
Variance		2.747	13.220	89.098	63745.249	3.758	151.261
Skewness		1.332	.625	.754	.565	1.172	.614
Std. Error of Skewness		.421	.421	.421	.421	.427	.421
Kurtosis		.870	-.298	-.123	-.518	1.913	-.342
Std. error of kurtosis		.821	.821	.821	.821	.833	.821
Range		5.65	13.00	33.32	870.50	8.57	43.72
Minimum		.00	.00	.00	.00	.00	.00
Maximum		5.65	13.00	33.32	870.50	8.57	43.72
Sum		37.90	129.40	304.55	8659.83	75.45	426.66





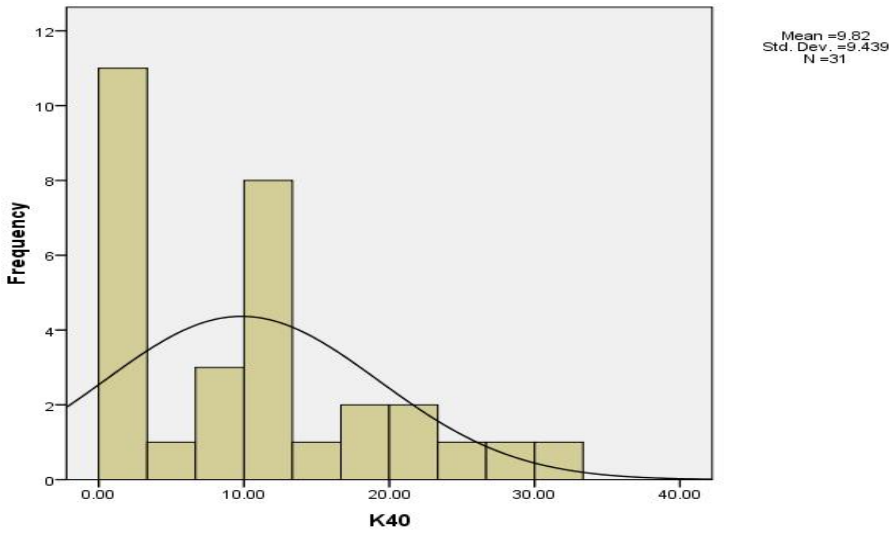


Fig. 2. Frequency distributions of ^{226}Ra, ^{232}Th and ^{40}K in drinking water sources

Table 5. Pearson's correlation coefficient analysis

Correlations							
		Ra226	**Th232**	**K40**	**AEDEinfant**	**AEDEchildren**	**AEDEadult**
Ra226	Pearson Correlation	1	.187	-.046	.009	.780**	.122
	Sig. (2-tailed)		.314	.808	.960	.000	.514
Th232	Pearson Correlation	.187	1	.557**	.464**	.744**	.677**
	Sig. (2-tailed)	.314		.001	.008	.000	.000
K40	Pearson Correlation	-.046	.557**	1	.902**	.381*	.868**
	Sig. (2-tailed)	.808	.001		.000	.038	.000
AEDEinfant	Pearson Correlation	.009	.464**	.902**	1	.354	.778**
	Sig. (2-tailed)	.960	.008	.000		.055	.000
AEDEchildren	Pearson Correlation	.780**	.744**	.381*	.354	1	.551**
	Sig. (2-tailed)	.000	.000	.038	.055		.002
AEDEadult	Pearson Correlation	.122	.677**	.868**	.778**	.551**	1
	Sig. (2-tailed)	.514	.000	.000	.000	.002	
	N	31	31	31	31	30	31

***. Correlation is significant at the 0.01 level (2-tailed), *. Correlation is significant at the 0.05 level (2-tailed)*

5. CONCLUSION

The natural radioactivity level of ^{226}Ra, ^{232}Th and ^{40}K have been estimated in various water resources of Uburu and Okposi salt lake area of Ebonyi state using high purity Germanium based gamma spectroscopy. This study showed slight elevation of activity concentration of ^{225}Ra, ^{232}Th and ^{40}K in all the water samples. ^{232}Th contributed the largest activity concentration and ^{40}K the least compared to their respective reference values.

The use of water samples that have been investigated in this study show much lower internal exposure than the WHO and ICRP reference limits of 0.10 mSvy^{-1} and 1.0 mSvy^{-1} respectively for children and adult but slightly higher in infants. Fatality risk and hereditary risk analysis showed that only 16 out of 100,000 adult persons exposed to these water studied might develop cancer in their lifetime and 9 out of 100,000 may suffer some hereditary effects. Therefore all the water sources sampled are safe to be used by children and adult humans either

as drinking or daily routine activities but not suitable for infants. This study provided a data base on environmental radioactivity burden of the water resources of the study area.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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