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Population Dose Distribution Due to Natural Water Radioactivity Concentration Levels in Ten Local Government Area of Rivers State, Nigeria

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Abstract

This study assessed the natural radionuclide content in water samples collected from twenty communities across ten Local Government Areas of Rivers State, Nigeria. Gamma spectrometry using a NaI (Tl) detector was employed to measure the activity concentrations of ^{40}K, ^{238}U, and ^{232}Th. The obtained results revealed varying levels of radionuclide content within the samples. The activity concentrations ranged from 2.34±1.24 to 12.08±1.97 BqL^{-1} for ^{40}K, 2.00±0.94 to 15.42±1.4 BqL^{-1} for ^{238}U, and 0.32±0.02 to 1.77±0.26 BqL^{-1} for ^{232}Th. The average values were determined as 6.16±1.04 BqL^{-1} for ^{40}K, 11.22±0.83 BqL^{-1} for ^{238}U, and 0.99±0.10 BqL^{-1} for ^{232}Th. The annual collective effective dose resulting from these activity concentrations was calculated, with values ranging from 0.0009 to 0.0227 man-Sv and an average of 0.0082 ± 0.001 man-Sv. Notably, the estimated radiation parameters and activity concentrations of this study were found to be below the global permitted limits. Consequently, the study concludes that there is no significant radiological health impact on the general population based on the analyzed water samples.

Keywords: *Natural radioactivity; Collective effective dose; gamma-ray spectrometry; Absorbed dose;*

1. INTRODUCTION

Typically, drinking water harbours varying degrees of radionuclide concentrations that stem from natural sources (Nuccetelli *et al*., 2012). The activity concentrations of radioactive substances are highly variable, owing to their susceptibility to the characteristics of the aquifer. The dissolution and erosion of radioactive matter from rocks contribute to river water contamination. The significance of water in environmental research is derived from its frequent use for domestic purposes, human consumption, and its ability to transport pollutants. The internal exposure of humans to radioactive elements in potable water is eased by ingesting and inhaling radioisotopes, which indirectly enter the food chain through their radioactive decay. The radioactivity present in ground water is largely attributed to the radionuclides of the natural decay chains of ^{232}Th, ^{238}U, and ^{40}K found in soil and bedrock. The facility with which specific radionuclides break up in water

is dependent on factors like the mineralogical and geochemical makeup of the soil and rock, the current redox condition, and the amount of time groundwater interacts with the soil and bedrock (Asikainen & Kahlos, 1980).

The supply of safe drinking water is not known to present significant health hazards throughout one's lifespan, with due consideration given to any potential variations in sensitivity across different stages of life (WHO, 2017). Lakes, rivers, streams, and wells provide easy access to water. As a universal solvent, it dissolves a wide range of things, including minerals, ores, chemical and radioactive waste products found in the soil through which they run. Surface water sources play a pivotal role in providing drinking water to the populace and their livestock in Africa, primarily in Nigeria. Notably, recent research highlights that surface water sources harbour considerable quantities of naturally occurring radionuclides such as ^{40}K, ^{238}U, and ^{232}Th in addition to their progeny (Avwiri, 2005; Ajayi *et al*., 1995; Ajayi & Ajayi, 1999; Jibiri *et al*., 1999).

The presence of radioactivity in water sources possesses the likelihood of inducing health hazards for both human beings and aquatic ecosystems. The necessity of this study, which aims to gauge the population's exposure to radiation doses due to ingestion of water and assess the natural radioactivity of water in order to estimate the radiological risk related to internal exposure. The study of the radioactivity of water in the designated research area will contribute to the understanding of the intrinsic levels of radiation in the environment. Furthermore, investigating the radioactivity in water in the designated research vicinity affords a more extensive comprehension of the background radiation levels. This is of paramount importance when establishing fundamental benchmarks and differentiating between naturally-occurring and anthropogenic sources of radioactivity.

2. MATERIALS AND METHODS

2.1 Study Area

The study area is ten Local Government Areas of Rivers State in Southern Nigeria. Rivers State lies between latitude 4°45’ North and longitude 6°50’ East, with a total population of 5,198,716 people, as at 2006 census and the projected population for 2022 is 7,476,800. (NPC, 2009). Rivers State is recognized as a diligent region, contributing to 60% of the nation's crude oil production. Additionally, the State boasts of a variety of natural resources. The exploitation of these mineral reserves has the potential to result in environmental contamination, thereby precipitating environmental deterioration and health implications. The release of these minerals into water sources can culminate in the demise of a significant portion of aquatic organisms. The study map of this research is shown in Fig 1.

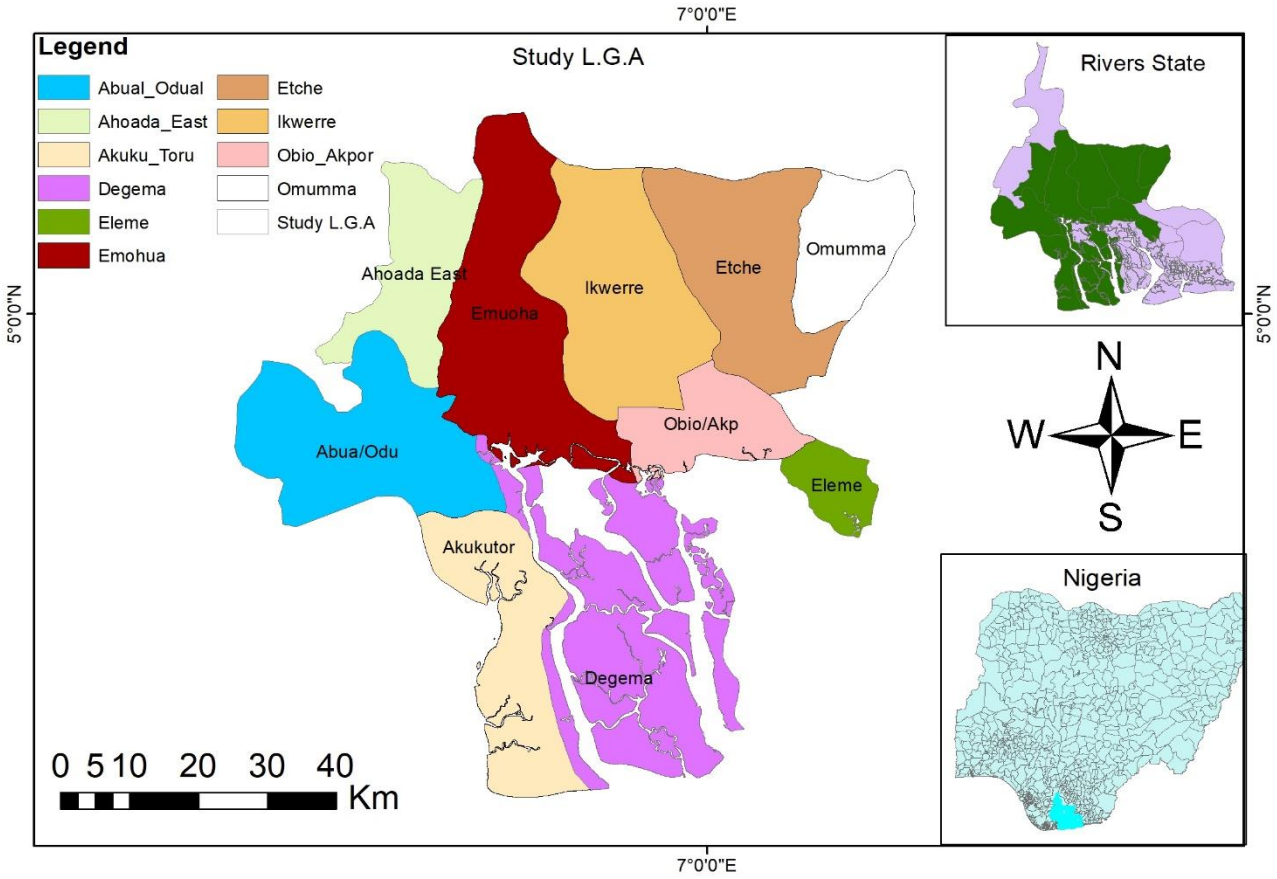

Fig 1. Rivers state map showing research Local Government Areas.

2.2 Sample Collection and Preparation

Twenty (20) water samples were collected from rivers in twenty communities across ten Local Government Areas of the state. All water samples were collected into one (1) liter linear polypropylene bottles that had been thoroughly cleaned. To prevent radionuclide absorption into the container's walls, the collected samples were acidified with concentrated hydrochloric acid (HCl) (Jibiri *et al*., 2010). Before analysis, each water sample was sealed and kept for 28 days to allow ^{238}U and ^{232}Th and their respective offspring to reach secular equilibrium (Fasunwon *et al*., 2010).

2.3 Gamma Spectrometry

The α-spectrometry of samples was conducted at the National Institute of Radiation Protection and Research, University of Ibadan, Ibadan, using a gamma ray spectrometric system connected with a NaI (Tl) model 802 detector. The detector is mounted in a sizable lead shield to lower the system background. It is positioned vertically connected to an 8 KPC based Multi-channel

Analyzer (MCA). The energy calibration of the detector was performed using point sources Co-60, Cs-137, Am-241, and Na-22; the efficiency calibration was carried out using volume source IAEA-385. The gamma analysis was carried out as previously reported (Faanu *et al*., 2011; Ononugbo & Tutumeni, 2016). At the conclusion of the measurement, a specialized template that included the energy, percentage error, count, uncertainty, Activity concentration, and uncertainty in activity was used to compute the various region of interest. The radionuclide concentration in each sample was calculated using the gamma probability, efficiency, and efficiency uncertainty functions (Ononugbo & Tutumeni, 2016).

The activity concentration (A) for the detected radionuclides were computed using (Farai & Ademola, 2005);

$$A_s\,(Bq/L) = \frac{N}{\varepsilon + t + \gamma + M} \quad (1)$$

Where;

A_s is the Sample Activity Concentration in $Bqkg^{-1}$ or BqL^{-1}. N is the radionuclide's net peak-area. ε is the energy-dependent efficiency of the detector. t is the Counting time in seconds. γ is the yield of gamma ray per disintegration. M is the samples' mass, measured in litters.

2.4 Radiological Parameters

The following radiological parameters were calculated to estimate the level of health hazards associated with radionuclides in water.

A. Absorbed Dose Rates

Absorbed dose rate (D) is a radiological parameter that measures the rate at which ionizing radiation is deposited or absorbed in a material or organism per unit of time. The absorbed dose was calculated using the relation (Beck *et al*., 1972; Obed *et al*., 2005):

$$D(nGy^{-1}) = 0.429A_U + 0.666A_{Th} + 0.042A_K \quad (2)$$

B. Annual Collective Effective Dose (S_E)

The size of the population involved is crucial to any population-based study because it establishes the actual number of people who are anticipated to experience a particular health impact. E which is the Effective dose is multiplied by N the population size to produce collective effective dose (S_E). The formula below was used to calculate the collective effective dose (Obed *et al*., 2005):

$$S_E = E \times N \quad (3)$$

C. Annual Effective Dose Equivalent (AEDE)

The Annual Effective Dose Equivalent (AEDE) is a radiological parameter used to calculate the overall radiation dose an individual received over the course of one year. AEDE was computed from absorbed

dose (D) taking into cognizance two principal conversion factors. They are 0.7Sv Gy^{-1} and the occupancy factors of 0.8 (19/24) and 0.2 (5/24) for indoors and outdoors (Samreh *et al*., 2014; UNSCEAR, 2000). The following formulae were used to compute the outdoor doses, D_{out}; the indoor doses, D_{in}; and the total annual effective doses, D_{tot}. (Sombo *et al*., 2018; Veiga *et al*., 2006):

$$D_{out}\ (\mu Svy^{-1}) = D_r(nGh^{-1}) \times 24h \times 365.25d \times 0.2 \times 0.7SvGy^{-1} \times 10^{-3} \quad (3a)$$

$$D_{in}\ (\mu Svy^{-1}) = D_r(nGh^{-1}) \times 24h \times 365.25d \times 1.4 \times 0.8 \times 0.7SvGy^{-1} \times 10^{-3} \quad (3b)$$

$$D_{tot}\ (\mu Svy^{-1}) = D_{out} + D_{in} \quad (3c)$$

3 Result and Discussion

The results for the analysis are presented in Table 1-4.

Table 1: The Range and Average Water Radioactivity Concentrations due to ^{40}K, ^{238}U and ^{232}Th in 10 Local Government Areas (in Bq/l).

L.G.A.	^{40}K		^{238}U		^{232}Th	
	Range	Mean± σ	Range	Mean± σ	Range	Mean± σ
Abua/Odua	4.82-12.73	8.78 ± 0.87	8.51-15.04	11.78 ± 0.19	0.56-1.98	1.27 ± 0.09
Ahoada East	1.03-13.27	7.15 ± 0.33	12.24-14.15	13.20 ± 0.66	1.04-2.49	1.77 ± 0.26
Akuku Toru	1.45-22.70	12.08 ± 1.97	12.23-17.60	14.92 ± 1.23	0.45-2.06	1.26 ± 0.09
Degema	0.32-5.77	3.05 ± 1.04	6.75-13.93	10.34 ± 0.29	0.26-0.75	0.51 ± 0.16
Eleme	5.61-16.15	10.88 ± 1.57	8.58-18.93	13.76 ± 0.85	0.03-1.65	0.80 ± 0.06
Emohua	5.43-9.59	7.51 ± 0.45	12.61-13.74	13.18 ± 0.65	0.89-1.27	1.08 ± 0.03
Etche	1.56-4.94	3.25 ± 0.97	10.02-14.12	12.07 ± 0.28	0.18-0.45	0.32 ± 0.02
Ikwerre	0.38-4.47	2.43 ± 1.24	0.35-10.67	5.51 ± 1.9	0.97-1.04	1.01 ± 0.01
Obio/Akpor	2.47-3.95	3.21 ± 1.05	11.30-19.54	15.42 ± 1.4	0.23-1.92	1.08 ± 0.03
Omuma	2.60-3.87	3.24 ± 0.14	BDL-4.00	2.00 ± 0.94	0.66-0.87	0.77 ± 0.07

Table 2: The Range and Average Absorbed Dose Rate (in $nGyh^{-1}$) in air due to ^{232}Th, ^{238}U, and ^{40}K.

L.G.A	Range ($nGyh^{-1}$)	Absorbed Dose Rate ($nGyh^{-1}$)
Abua/Odua	4.3-8.29	6.26
Ahoada East	5.99-8.29	7.13
Akuku Toru	5.61-9.88	7.74
Degema	3.08-6.72	4.90
Eleme	3.94-9.84	6.88
Emohua	6.23-7.14	6.68
Etche	4.48-6.75	5.52
Ikwerre	0.81-5.46	3.13
Obio/Akpor	5.11-9.83	7.46
Omuma	0.55-2.46	1.51
Mean		**5.72 ± 1.9**

Table 3: Population Percentage in each of the Dose Rate Bands (μGyh^{-1}) in the study area.

Table 4: The Average annual effective (for indoor and outdoor) dose, population and collective dose in each Local Government Areas

L.G.A.	**Population ($\times 10^6$)**	**Total population (%)**	**Absorbed Dose Rate (μGyh^{-1})**
Abua/Odual	0.4062	12.54	0.00626
Ahoada East	0.2392	7.38	0.00713
Akuku Toru	0.2317	7.15	0.00774
Degema	0.3588	11.08	0.00490
Eleme	0.2735	8.44	0.00688
Emohua	0.2892	8.93	0.00668
Etche	0.3595	11.10	0.00552
Ikwerre	0.2717	8.39	0.00313
Obio Akpor	0.6650	20.53	0.00746
Omuma	0.1444	4.46	0.00151
Mean			**0.00572 ± 0.0019**
Total	**3.2392**	**100**	**0.05721**

L.G.A	Average annual effective dose E (μSv)	Population N (10^6)	Annual collective effective dose S_E (man-Sv)
Abua/Odual	0.0254	0.4062	0.0103
Ahoada East	0.0288	0.2392	0.0069
Akuku Toru	0.0313	0.2317	0.0073
Degema	0.0199	0.3588	0.0071
Eleme	0.0279	0.2735	0.0076
Emohua	0.0271	0.2892	0.0078
Etche	0.0224	0.3595	0.0081
Ikwerre	0.0127	0.2717	0.0035
Obio Akpor	0.0342	0.6650	0.0227
Omuma	0.0062	0.1444	0.0009
Mean	**0.0465**		**0.0082 ± 0.001**

3.2 Discussion

Table 1 showed the range and average water radioactivity concentrations due to ^{40}K, ^{238}U and ^{232}Th (in Bq/L). For ^{40}K was from 2.43 ± 1.24 BqL^{-1} to 12.08 ± 1.97 BqL^{-1} with an average value of 6.16 ± 1.04 BqL^{-1}, for ^{238}U was from 2.00 ± 0.94 BqL^{-1} to 15.42 ± 1.4 BqL^{-1} with a mean value of 11.22 ± 0.84 BqL^{-1}, for ^{232}Th was from 0.32 ± 0.02 BqL^{-1} to 1.77 ± 0.26 BqL^{-1} with an average value of 0.99 ± 0.10 BqL^{-1}. The slight variations in the activity concentration of radionuclide (^{232}Th, ^{238}U, and ^{40}K) in the surface water could be the result of the water's passage through bedrock cracks that are home to radioactive material deposits; these deposits could then leak into the water supply (Sombo *et al*., 2018). ^{238}U has the highest number of concentrations in this study's water samples for all LGA, which may be as a result to the amount of uranium in surface soils or bed rocks that could be leached into the water or rivers system (Kinyua R. *et al*., 2011). The ^{40}K readings could be the result of radioactive elements from fertilizer use on farmlands seeping into the water body. The amount of monazite present in the water body as well as

the geological structure of the subterranean rocks in the sea bed may be related to the ^{232}Th concentration. The results of this study, in accordance to Sombo *et al*., (2018) demonstrate that the concentration discovered in the river water samples is within the authorized safety restrictions of 100 Bql^{-1} established by the Radiological Protection Advisors (RPA, 2000).

Table 2 showed the range and average absorbed dose rate calculated in nGy/h across the ten Local Government Area. Different regions exhibit varying rates of radionuclide absorption from river water. The absorbed dose rate varies from 1.51 $nGyh^{-1}$ to 7.74 $nGyh^{-1}$ and has an average value of 5.72 $nGyh^{-1}$. The population dose is therefore considered to be low because these values fell below the advised limits and, when compared to the results of Oyebanjo & Magbagbeola, (2015) and Jibiri & Esen, (2011).

Table 3 showed the population percentage in each of the dose rate bands in μGyh^{-1}. Any epidemiological study needs to know how big the population is because this determines how many people will actually experience a certain health effect (Obed *et al*., 2005). The ten Local Government Areas under study in this research have a combined population of about three (3) million. The absorbed dose rate varies from 0.00151 to 0.00774 μGyh^{-1} with an arithmetic mean value of 0.00572 μGyh^{-1} which falls within limits as compared with Oyebanjo & Magbagbeola, (2015).

Table 4 showed the projected population number N and the annual collective dose S_E (man-Sv). The gross mean of the annual outdoor collective effective dose, varies from 0.0019 to 0.0095 µSv/y, is 0.0070 µSv/y. while taking into account the Local Government Areas' combined population of 3.2392 million and the assumption that each receives an average annual outdoor effective dose of 0.0070 µSv/y, then 2.3×10^{-2} man-Sv is the annual collective effective dose.

4 Conclusion

Gamma spectrometry was employed for the purpose of ascertaining the concentrations of radioactivity in water pertaining to ^{40}K, ^{238}U, and ^{232}Th within a set of 20 water samples collected from 10 distinct Local Government Areas. The concentrations of radioactivity in water were subsequently utilized for the calculation of the absorbed dose rate of gamma radiation in the atmosphere resulting from the presence of the aforementioned three primordial radionuclides in water. This study shows that an individual in the population received a collective effective dose (S_E) of 0.0075 (7.5×10^{-2}) man-Sv and an absorbed dose of 0.00572 μGyh^{-1}.

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