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Assessment of Natural Radioactivity Hazard in Water Sample in some parts of Delta State, Nigeria

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Abstract

This study evaluated the radioactive activity concentrations (AC) of naturally occurring radionuclides in drinking water sources within the study area and assessed the associated radiological health risks through the estimation of absorbed dose rate, internal hazard index, radium equivalent activity (Raeq), excess lifetime cancer risk (ELCR), and committed effective dose ($mSv\ y^{-1}$). The results revealed relatively elevated activity concentrations across all sampled water sources, with mean values exceeding the permissible limits for drinking water recommended by the World Health Organization (WHO, 2008), namely $10\ BqL^{-1}$ for ^{40}K , $1.0\ BqL^{-1}$ for ^{238}U , $0.1\ BqL^{-1}$ for ^{232}Th , and 1.0 and $0.1\ BqL^{-1}$ for radium equivalent activity indices (^{226}Ra and ^{228}Ra), respectively. The measured activity concentrations ranged from 129.89 ± 11.37 to $345.78 \pm 7.99\ BqL^{-1}$ for ^{40}K , 5.29 ± 0.11 to $10.24 \pm 2.05\ BqL^{-1}$ for ^{238}U , 1.58 ± 0.03 to $9.06 \pm 2.12\ BqL^{-1}$ for ^{232}Th , and 22.33–40.14 BqL^{-1} for Raeq. Samples UKW 5 (Ukwuani LGA), INE 3 (Ika North East LGA), OSN 3 (Oshimili North LGA), and ANS 5 (Aniocha South LGA) recorded the highest concentrations of ^{40}K , ^{238}U , ^{232}Th , and Raeq, respectively, whereas PAT 1 (Patani LGA), INE 5, UKW 4, and ISS 1 (Isoko South LGA) exhibited the lowest values. One-way ANOVA indicated no statistically significant variation ($p \geq 0.05$) among the LGAs, although significant deviations were observed relative to WHO guideline values. Radiological hazard indices ranged from 0.008 to 0.033, with a mean value of 0.014 ± 0.001 . Furthermore, ELCR values across all LGAs exceeded the global average benchmark of 10^{-4} (EPA, 2012), indicating elevated carcinogenic risk. Consequently, all drinking water sources within the study area require appropriate treatment prior to consumption to mitigate potential long-term radiological health implications.

Keywords

Radioactivity Concentration
Radiological Hazard Assessment
Excess Lifetime Cancer Risk
Groundwater Quality
Naturally Occurring Radionuclides

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Introduction

People struggle to have access to safe drinking water due to the huge global demand for potable water caused by population expansion, industrialization, and agricultural development. However, many people lack access to drinkable water, and freshwater access is exceedingly challenging in the majority of poor countries. (Okonkwo and Egbai, 2022). Because of this, the quality of the water is a crucial consideration in environmental studies, and determining the radioactivity content in drinking water can be thought of as one of the main topics in both normal and emergency situations as well as allowing for the estimation of the radioactivity dose that the general public receives from daily water consumption (Amin and Jassim, 2017).

Most water-bearing bodies around the world have had their ecological integrity severely compromised and is now in danger, particularly in developing nations like Nigeria. As byproducts of human daily activities from industrial processes, municipal sewage discharge, agricultural practices, domestic wastewater, effluents, and atmospheric deposits, various amounts of radioactive materials, inorganic contaminants, and organic contaminants have been released either directly or indirectly into water-bearing bodies (Ugbede et al., 2020). Atomic nucleus decay is referred to as radioactivity. It refers to the ability of unstable atoms to shift to a more stable state. Since the earth's formation, radioactivity has been released naturally everywhere, in the air, soil, water, plants, and food (Al-Harmali, 2020).

Radioactive materials may leach into the ground-water system "when groundwater travels through fissures in the bedrock that contain these deposits. Human activities release pollutants into the air, land, and water, which then affect fish crops and other

creatures (Pascal et al., 2011). Radionuclides like K-40 enter the environment by air diffusion and terrestrial soil (Myttenaere et al., 1993; Papp et al., 2002). The presence of ^{226}Ra and ^{228}Ra in water, as well as the potential health hazards associated with them, need special consideration due to their significant radiotoxicities. When consumed or inhaled, radionuclides enter the body and are dispersed across the organs in accordance with the element's metabolism. The organs typically display varied radiation sensitivity, and as a result, varying the organs often display a range of radiation sensitivities, and as a result, consuming or inhaling radiation poses a range of doses and hazards. (UNSCEAR 1993; Pascal et al., 2011).

Accurate evaluation of the presence of radionuclides in drinking water supplies will offer data from which estimates of the public's average radiation exposure from these sources in some Delta State can be established. Therefore, the present study seeks to determine the concentrations of Radium Equivalent Activity Index, and the analysis of some radiological parameter such as Internal Hazard Index, External Hazard Index, , Excess Lifetime Cancer.

Materials and Methods

Samples collection and Preparation

Water samples were taken from a few public and private secondary schools in Delta State's southern and northern region. Sixty-six samples in all were gathered from fourteen LGA, five from each of the following local government areas (LGAs): Warri South (WRS), Warri North (WRN), Patani (PAT), Bomadi (BOM), Isoko South (ISS), Isoko North (ISN), Aniocha North (ANN), Aniocha South (ANS), Ika North East (INE), Ika South (IKS), Ndokwa West (NDW), Oshimili North (OSN), Oshimili South (OSS) and Ukwuani (UKW). (Figure 1).

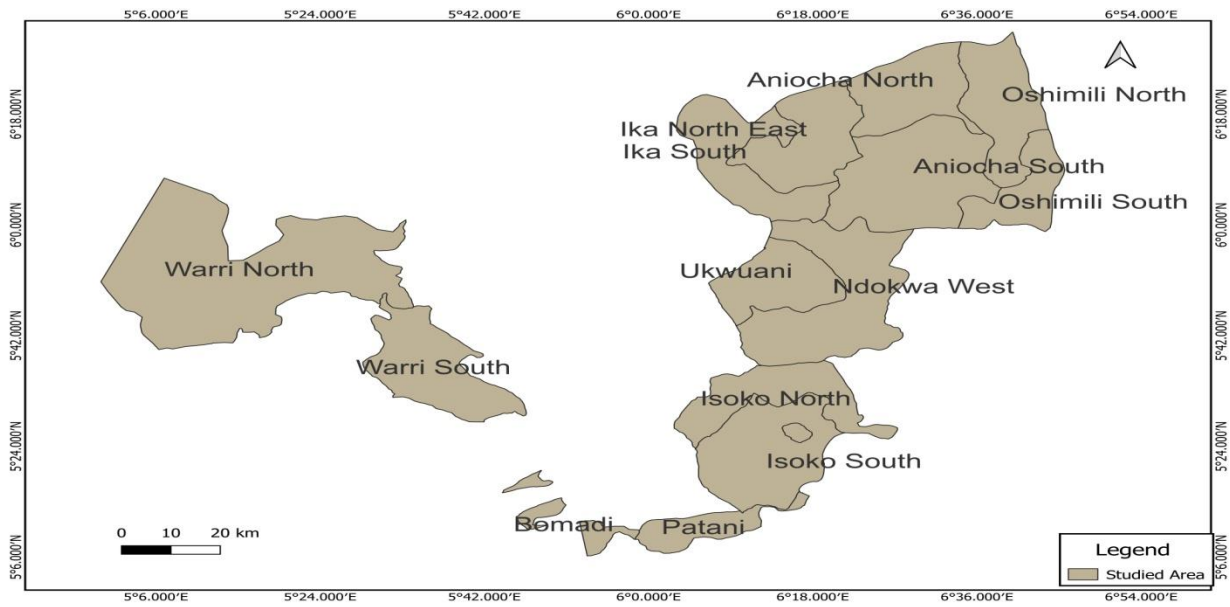


Figure 1: Map of study location

Based on factors like student population density and other factors, the sampling areas were selected. To prevent mixing up, samples were collected into 2-liter plastic containers that were labeled appropriately. Before the samples were collected, the containers holding the samples were cleaned with a detergent solution, and then rinsed with freshly diluted hydrochloric acid (HCl). This was done to get rid of any inorganic debris that might have adhered to the container's walls. (Erhonyota *et al.*, 2022; Sinebe *et al.*, 2022). Each water sample was placed in a container that was carefully sealed, had the screw necks of the container wrapped with thick vinyl tape, and was transported to the gamma counting preparation lab. In order to ensure that the natural radionuclides in the samples and their offspring are in a state of secular equilibrium, 250 ml of each of the water samples was

poured into specialized cylindrical sampling containers before the radioactivity measurements. These containers were once more tightly sealed and stored for 4 weeks (IAEA, 1989).

Gamma spectroscopy

An analytical technique called gamma ray spectrometry allows for the identification and quantification of gamma emitting isotopes in various matrices (Figure 2(b)). Gamma ray spectrometry enables you to identify several gamma emitting radionuclides in the sample in a single measurement and with minimal sample preparation. The measurement produces a spectrum of lines the amplitude of which is related to the radionuclide's activity Figure 2(a)), and whose location on the horizontal axis provides a clue as to the energy of the radionuclide (Nafaa, 2006).

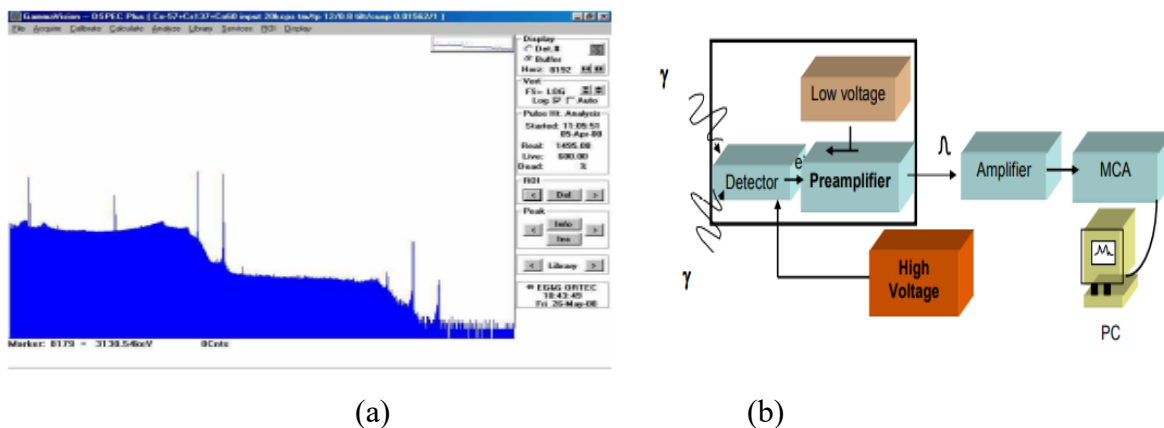


Figure 2: (a) Typical Gamma ray Spectrum output (b) Block diagram of a basic gamma spectrometry system ((Nafaa, 2006).

A NaI(Tl) detector-based gamma-ray spectrometer was used to measure concentrations of the natural radioisotopes (^{40}K , ^{238}U , ^{232}Th) in water samples at the environmental radioactivity laboratory of the Physics and Engineering Physics department at Obafemi Awolowo University in Ile-Ife, Nigeria (Awodugba and Tchokossa, 2007). Due to the low gamma counts in the water, all of the samples were counted for 60,000 seconds. To cut down on background radiation, a 10 cm thick Canberra Pb barrier was utilized to encase the detector. (Erhonyota et al., 2022; Sinebe et al., 2022). Additionally, background spectra were captured for 60,000 seconds per week, and the counts from each region of

interest were deducted (Awodugba & Tchokossab, 2007). Using IAEA reference samples, the efficiency calibration for the various energy peaks was determined. ^{238}U was identified by the energies of 609.3 keV (^{214}Bi), 1120.3 keV (^{214}Bi), and 1764.5 keV (^{214}Bi), whereas ^{232}Th and ^{40}K were identified by the energies of 583.1 keV (^{208}Tl), 911.1 keV (^{232}Ac), and 1460.8 keV (γ -ray), respectively.

Radioactivity Quantification

In order to calculate the activity concentration, Equation 1 (IAEA, 2003) was applied

$$Act = \frac{Net\ Area}{\epsilon \times (BR) \times T \times v} \quad (1)$$

where net area is the net count under the peak, Act (Bq/l) is the activity concentration, ϵ is the energy efficiency for the gamma ray by the detector, BR is the branching ratio of gamma ray intensity (%), T(s) denotes the time of spectra, and v(L) is the volume of the sample.

Calculation of the radiological hazard Parameters

Radiological hazards parameters calculated are as follows:

i. **Internal Hazard Index (H_{in})**

The internal hazard index gives the internal exposure to Carcinogenic radon and its short-lived progeny and is given by equation 2 (Avwiri *et al.*, 2012)

$$I_{in} = \frac{C_U}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \quad (2)$$

Where C_K , C_U , and C_{Th} are the activity concentration in $Bq\ l^{-1}$ for K, U, and Th respectively

ii. **Radium Equivalent Activity Index (Ra_{eq})**

Allow a single index or number to describe the gamma output from different mixtures of U, Th and K from different local Government Areas is given in equation 3 (UNSCEAR, 2000)

$$Ra_{eq} = C_U + 1.43 C_{Th} + 0.077 C_K \quad (3)$$

Where C_K , C_U , and C_{Th} are the activity concentration in $Bq\ l^{-1}$ for K, U, and Th respectively

iii. **Excess Lifetime Cancer Risk**

This relates to the likelihood of getting cancer over the course of a lifetime at a specific exposure level. It is shown as a value that represents the anticipated number of cancers in a population based on exposure to a carcinogen at a specific dose. It is important to remember that a rise in the ELCR results in a corresponding increase in the likelihood that a person would develop breast, prostate, or even blood cancer. ELCR, or excess lifetime cancer risk, is described in equation 4 (Ononugbo *et al.*, 2013)

$$ELCR = AEDE \times DL \times RF \quad (4)$$

Where, AEDE is the annual committed effective dose,

DL is the average duration of life (estimated to 70 years),

RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public (Ononugbo *et al.*, 2013).

iv. **Estimation of Committed Effective Dose**

To assess the radiological risks to age groups between 12 -17 years and >17, the annual effective dose (AED) resulting from consumption of ^{238}U , ^{232}Th , and ^{40}K in drinking water was estimated. Utilizing the radionuclide's activity concentrations following the relationship shown in equation 5 (Ugbede *et al.*, 2020).

$$AED = A_c \times C_f \times CR_w \quad (5)$$

Where C_f is the dose conversion factor for radionuclides, which is age-dependent, and A_c is the activity concentration of the radionuclides ^{238}U , ^{232}Th , and ^{40}K . The rate at which drinking water is consumed is CR_w . The yearly water consumption rate for the various age groups is provided in table 1 and was taken from a World Health Organization publication. Conversion factors are employed to arrive at the AED (WHO). The total annual effective dosage for an individual in a given age group was determined by summing the contribution of each radionuclide present in the samples.

Table 1: Dose conversion factor and annual water consumption rate for different age groups.

Age Group (yrs)	Dose conversion factor (Sv.Bq ⁻¹) per age group			Annual water consumption rate (ly ⁻¹)
	⁴⁰ K	²³⁸ U	²³² Th	
12-17	7.6×10^{-9}	1.5×10^{-6}	2.5×10^{-7}	600
> 17	6.2×10^{-9}	2.8×10^{-7}	2.3×10^{-7}	730

Results and Discussion

The results of the radioactive activity concentrations (AC) are shown in Table 2, along with radiological parameters including the absorbed dose rate (D), internal hazard index (Hin), radium equivalent activity index (Bq⁻¹), excess lifetime cancer risk, and committed effective dose (mSvy⁻¹). As a result, all water sources in the study area had relatively high activity concentrations, with average activity concentrations exceeding the WHO's recommended permissible drinking water levels of 10, 1.0, and 0.1 Bq⁻¹ for ⁴⁰K, ²³⁸U, and ²³²Th and 1.0, and 0.1 Bq⁻¹ for Radium Equivalent Activity Index (²²⁶Ra, ²²⁸Ra), respectively (WHO,2008).

The descriptive statistical overview of the AC for each location is shown in Table 3. For ⁴⁰K, ²³⁸U, ²³²Th and Ra_{eq}, respectively, the AC of the radionuclides in the water samples ranged from 129.89 ±11.37 to 345.78 ±7.99 Bq⁻¹, 5.29 ± 0.11 to 10.24 ± 2.05 Bq⁻¹, 1.58 ± 0.03 to 9.06

±2.12 Bq⁻¹ and 22.33- 40.14 Bq⁻¹. These results demonstrate that samples UKW 5 (Ukwuani LGA), INE 3 (Ika North East LGA), OSN 3 (Oshimili North LGA) and ANS 5 (Aniocha South) have the highest values for ⁴⁰K, ²³⁸U, ²³²Th and Ra_{eq}, respectively, while samples PAT 1 (Patani LGA), INE 5 (Ika North East LGA), UKW 4 (Ukwuani) and ISS 1(Isoko South LGA) have the lowest for ⁴⁰K, ²³⁸U, ²³²Th and Ra_{eq} respectively.

The activity concentration (Bq⁻¹) and statistics for every local government area in the study region for ⁴⁰K are shown in Figure 3 and Table 4, for ²³⁸U and ²³²Th they are shown in Figure 4 and Table 5, ⁴⁰K they are shown in Figure 5 and Table 6, and for Ra_{eq} they are shown in Figure 6 and Table 7. Test of significance by one-way analysis of variance (ANOVA) shows no significant differences (p ≥ 0.05) exist between the LGA and there exist a significant value with the WHO value.

Table 2: Activity concentration (Bq⁻¹) and Radiological Parameter

LGA	Code	Activity concentration (Bq ⁻¹)			Internal Hazard Index (H _{in})	Radium Equivalent Activity Index (Ra _{eq}) Bq ⁻¹	Excess Lifetime Cancer Risk	Committed Effective Dose (mSv ⁻¹)	
		⁴⁰ K	²³⁸ U	²³² Th				12-17 years	> 17 years
INE	INE 1	213.55±4.35	8.89±1.06	2.24±0.06	0.102	28.53	0.011	0.016	0.011
	INE 2	198.78 ± 5.79	7.25± 2.04	2.19 ±0.11	0.089	25.68	0.010	0.014	0.010
	INE 3	236.45±4.58	10.24±2.05	1.68±0.05	0.111	30.85	0.009	0.015	0.009
	INE 4	199.54 ±3.81	6.28 ±1.30	1.98±0.99	0.084	24.47	0.009	0.012	0.009
	INE 5	212.38 ± 4.87	5.29 ±0.11	3.52±1.08	0.087	26.67	0.014	0.016	0.014
IKS	IKS 1	281.97 ±5.12	7.54 ±1.15	2.46 ±0.09	0.109	32.77	0.011	0.015	0.011
	IKS 2	220.03±4.42	8.92±1.06	2.43±1.05	0.104	29.33	0.011	0.016	0.011
	IKS 3	278.19 ±6.08	8.65±2.00	2.81 ±0.12	0.116	34.08	0.013	0.017	0.013
	IKS 4	301.77 ±5.18	8.12±1.07	3.37±0.09	0.12	36.17	0.015	0.018	0.015
	IKS 5	288.68 ±6.11	6.99 ± 2.08	3.97± 1.21	0.114	34.89	0.016	0.019	0.016
OSN	OSN 1	192.81 ± 5.07	7.08 ±1.12	8.17 ± 2.05	0.110	33.61	0.030	0.030	0.030
	OSN 2	145.61±12.60	7.17±0.77	9.06±2.12	0.105	31.33	0.033	0.032	0.033
	OSN 3	208.58±4.33	6.70±1.06	2.53± 0.63	0.090	26.37	0.011	0.014	0.011
	OSN 4	178.88± 12.86	5.98±1.53	4.72±1.88	0.088	26.50	0.018	0.020	0.018
	OSN 5	211.24±4.33	6.47±1.05	2.59 ±1.84	0.089	26.44	0.011	0.014	0.011
OSS	OSS 1	211.76± 12.20	7.96±2.01	1.76± 0.59	0.094	26.78	0.009	0.013	0.009
	OSS 2	233.96±4.56	7.06± 1.05	1.64±0.09	0.094	27.42	0.008	0.012	0.008
	OSS 3	224.26± 18.20	6.78±0.87	1.99 ±0.07	0.091	26.89	0.009	0.013	0.009
	OSS 4	242.66± 12.66	9.10±2.06	1.81± 0.08	0.107	30.37	0.009	0.015	0.009
	OSS 5	160.14± 8.75	7.50 ±1.80	3.09±0.96	0.086	24.25	0.013	0.016	0.013
ANS	ANS1	195.71±11.17	7.35±1.05	1.81±0.05	0.088	25.01	0.009	0.013	0.009
	ANS2	201.44± 13.61	8.09 ± 2.33	3.11 ±1.05	0.098	28.05	0.013	0.017	0.013
	ANS3	197.48± 9.04	9.24±2.07	2.43±0.03	0.101	27.92	0.011	0.016	0.011
	ANS4	186.92±4.07	6.05±1.05	2.78 ±1.01	0.083	24.42	0.012	0.014	0.012
	ANS5	299.74±46.39	9.23±1.99	5.48± 1.24	0.134	40.14	0.022	0.025	0.022
ANN	ANN 1	208.45 ± 13.61	7.09 ± 2.13	3.19 ± 1.03	0.094	27.70	0.013	0.017	0.013
	ANN 2	214.08 ±17.99	7.58± 1.06	2.45±0.08	0.095	27.56	0.011	0.015	0.011

	ANN 3	227.87 ± 12.60	8.74 ± 2.05	2.65 ± 1.08	0.105	30.07	0.012	0.017	0.012
UKW	UKW1	174.58 ± 3.96	6.80 ± 1.02	4.64 ± 1.43	0.091	26.87	0.018	0.020	0.018
	UKW2	158.51 ± 27.54	7.09 ± 0.76	6.34 ± 2.01	0.096	28.36	0.024	0.025	0.024
	UKW3	175.56 ± 16.07	6.41 ± 1.06	2.60 ± 0.86	0.082	23.64	0.011	0.014	0.011
	UKW4	186.57 ± 13.16	5.94 ± 1.05	1.58 ± 0.03	0.077	22.56	0.008	0.011	0.008
	UKW5	345.78 ± 7.99	6.00 ± 2.04	3.00 ± 1.02	0.116	36.91	0.013	0.016	0.013
NDW	NDW1	187.90 ± 12.07	7.49 ± 2.01	6.85 ± 1.73	0.106	31.75	0.026	0.027	0.026
	NDW2	184.41 ± 10.61	9.66 ± 2.04	4.99 ± 1.21	0.110	30.99	0.02	0.024	0.020
	NDW3	197.84 ± 14.06	8.44 ± 2.08	2.84 ± 1.06	0.098	27.73	0.013	0.017	0.013
WRS	WRS 1	233.34 ± 14.55	6.34 ± 0.06	2.14 ± 0.06	0.092	27.36	0.010	0.013	0.010
	WRS 2	183.22 ± 7.94	8.56 ± 2.04	3.17 ± 1.01	0.097	27.20	0.014	0.018	0.014
	WRS 3	202.69 ± 14.21	6.59 ± 1.21	2.37 ± 0.08	0.087	25.58	0.011	0.014	0.011
	WRS 4	199.54 ± 13.78	7.90 ± 2.08	1.98 ± 0.03	0.092	26.09	0.010	0.014	0.010
	WRS 5	194.83 ± 13.48	6.29 ± 1.31	4.23 ± 1.23	0.091	27.34	0.017	0.019	0.017
WRN	WRN1	188.12 ± 18.37	7.62 ± 0.82	6.14 ± 2.06	0.105	30.88	0.023	0.025	0.023
	WRN2	211.27 ± 15.83	8.01 ± 1.83	5.21 ± 2.03	0.108	31.72	0.020	0.023	0.020
	WRN3	199.76 ± 16.89	9.01 ± 1.87	4.12 ± 1.04	0.107	30.28	0.017	0.021	0.017
	WRN4	227.80 ± 14.16	6.89 ± 2.43	3.42 ± 0.21	0.098	29.32	0.014	0.017	0.014
	WRN5	213.98 ± 18.25	7.22 ± 1.87	5.17 ± 1.65	0.104	31.09	0.020	0.022	0.020
PAT	PAT 1	129.89 ± 11.37	5.67 ± 0.61	7.35 ± 1.87	0.087	26.18	0.027	0.026	0.027
	PAT 2	177.12 ± 9.37	7.36 ± 2.09	3.22 ± 1.74	0.090	25.60	0.013	0.017	0.013
	PAT 3	237.16 ± 14.59	7.04 ± 0.08	1.60 ± 0.02	0.094	27.59	0.008	0.012	0.008
	PAT 4	170.48 ± 24.02	8.07 ± 0.86	3.29 ± 1.12	0.092	25.90	0.014	0.018	0.014
	PAT 5	191.89 ± 11.13	6.89 ± 0.06	2.71 ± 0.06	0.088	25.54	0.012	0.015	0.012
BOM	BOM1	235.29 ± 14.57	6.57 ± 1.06	2.10 ± 0.06	0.093	27.69	0.010	0.013	0.010
	BOM 2	217.89 ± 12.49	5.97 ± 1.17	3.14 ± 1.08	0.090	27.23	0.013	0.015	0.013
	BOM 3	246.12 ± 14.67	5.59 ± 1.06	2.37 ± 0.15	0.091	27.93	0.011	0.013	0.011
	BOM 4	189.01 ± 8.12	6.53 ± 1.27	1.96 ± 0.28	0.083	23.88	0.009	0.013	0.009
	BOM 5	250.87 ± 9.50	5.30 ± 1.06	4.12 ± 1.12	0.097	30.50	0.016	0.018	0.016
ISS	ISS1	145.40 ± 12.82	7.69 ± 1.53	2.41 ± 0.91	0.082	22.33	0.011	0.015	0.011
	ISS 2	221.79 ± 13.21	8.09 ± 2.10	2.12 ± 0.05	0.099	28.20	0.010	0.015	0.010
	ISS 3	198.44 ± 9.90	8.27 ± 1.82	2.44 ± 1.03	0.096	27.04	0.011	0.016	0.011
	ISS 4	199.54 ± 11.33	6.91 ± 2.06	2.17 ± 0.13	0.088	25.38	0.010	0.014	0.010
	ISS 5	256.60 ± 9.60	5.45 ± 0.06	1.99 ± 0.13	0.091	28.05	0.009	0.012	0.009
ISN	ISN1	208.45 ± 12.31	7.09 ± 2.31	2.99 ± 1.02	0.094	27.41	0.013	0.016	0.013

ISN 2	198.65±10.79	5.39 ± 1.04	1.67 ±0.04	0.077	23.08	0.008	0.011	0.008
ISN 3	203.61± 14.25	5.97± 1.05	2.52±0.06	0.085	25.25	0.011	0.014	0.011
ISN 4	200.94± 14.22	6.55±1.05	1.77±0.05	0.085	24.55	0.009	0.012	0.009
ISN 5	210.95 ± 13.25	6.09 ±1.27	2.44 ±0.11	0.087	25.82	0.011	0.014	0.011

Table 3: Activity concentration (Bq⁻¹) and Radiological Parameter

	Minimum	Maximum	Mean	Std. Error	Std. Deviation	% Coefficient of Variance
⁴⁰ K (Bq ⁻¹)	129.89	345.78	211.04	4.67	37.96	17.99
²³⁸ U (Bq ⁻¹)	5.29	10.24	7.24	0.14	1.15	15.86
²³² Th (Bq ⁻¹)	1.58	9.06	3.23	0.20	1.64	50.74
Absorbed Dose Rate (D)	8.91	18.85	12.58	0.23	1.85	14.67
Internal Hazard Index (Hin)	0.08	0.13	0.09	0.001	0.010	10.53
Radium Equivalent (Raeq) (Bq ⁻¹)	22.33	40.14	28.11	0.43	3.47	12.35
Excess Lifetime Cancer Risk	0.008	0.033	0.014	0.001	0.005	35.72
Committed Effective Dose (12-17 years) (mSvy ⁻¹)	0.011	0.032	0.017	0.001	0.004	23.53
Committed Effective Dose (>17 years) (mSvy ⁻¹)	0.008	0.033	0.014	0.001	0.005	35.72

This may be explained by the ongoing gas flare activity and the environmental precipitation it causes, as well as the recent frequent oil spills into surface water bodies and arable land and the subsequent leaching of oil into subsurface water beneath these oil fields (Ononugbo et al., 2013).

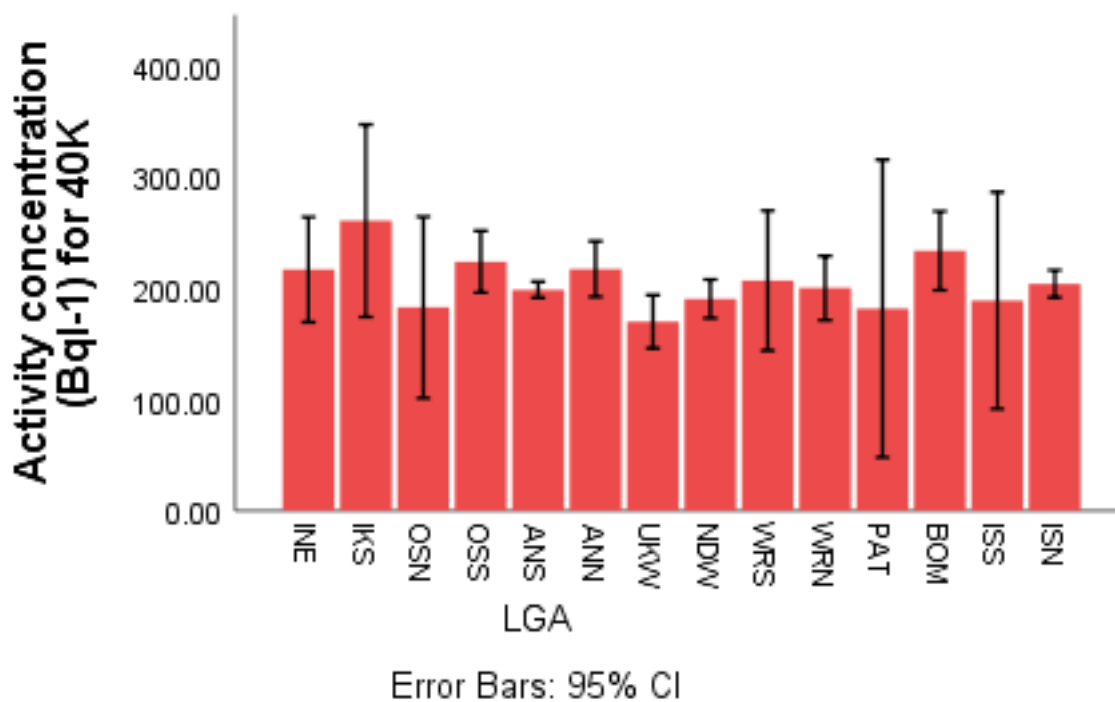
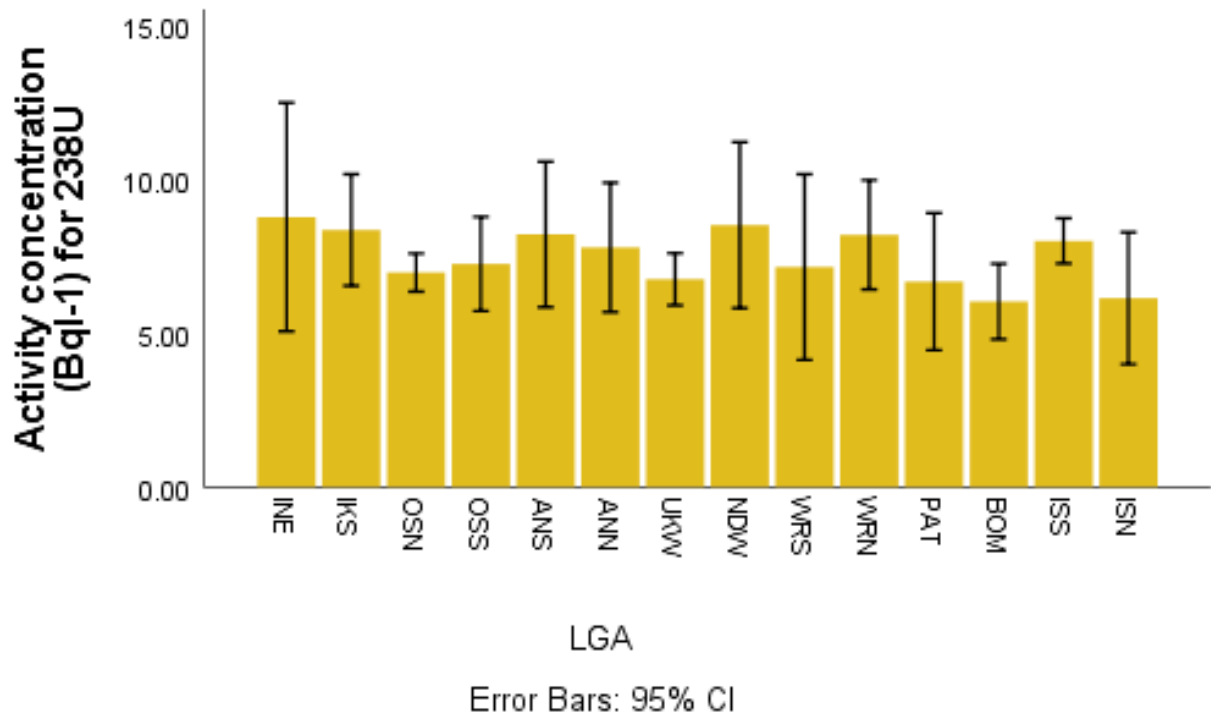


Figure 3: Activity concentration (BqL⁻¹) for ⁴⁰K

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	212.14	274.12	187.42	214.55	216.25	216.80	208.20
Std. Error of Mean	6.82	14.10	11.96	14.54	21.01	5.77	34.68
Std. Deviation	15.25	31.54	26.76	32.51	46.96	9.99	77.56
Variance	232.56	995.10	716.29	1057.36	2206.09	99.83	6015.22
Minimum	198.78	220.03	145.61	160.14	186.92	208.45	158.51
Maximum	236.45	301.77	211.24	242.66	299.74	227.87	345.78

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	190.05	202.72	208.18	181.31	227.83	204.35	204.52
Std. Error of Mean	4.02	8.33	6.71	17.33	11.24	18.12	2.29
Std. Deviation	6.96	18.64	15.01	38.76	25.13	40.52	5.12

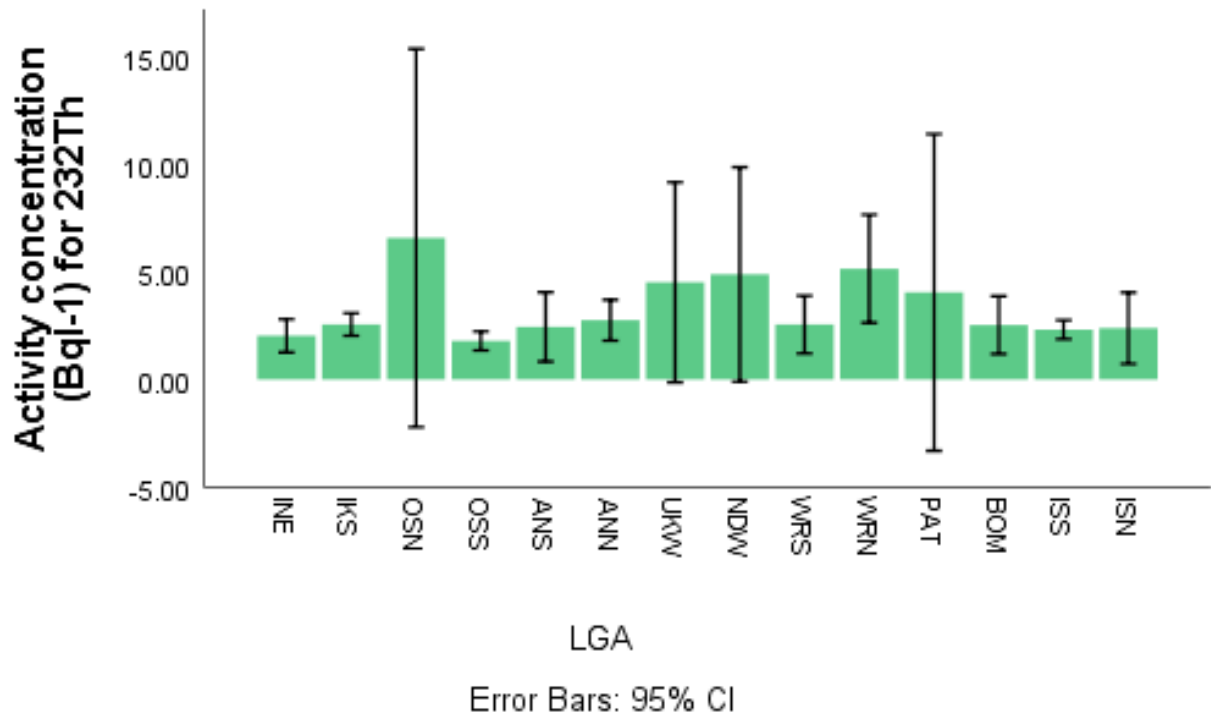
Variance	48.55	347.55	225.35	1502.50	631.70	1641.85	26.22
Minimum	184.41	183.22	188.12	129.89	189.01	145.40	198.65
Maximum	197.84	233.34	227.80	237.16	250.87	256.60	210.95

Figure 4: Activity concentration (BqL⁻¹) for ²³⁸U

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	7.59	8.04	6.68	7.68	7.99	7.80	6.44
Std. Error of Mean	0.89	0.35	0.21	0.41	0.60	0.49	0.22
Std. Deviation	1.99	0.79	0.48	0.91	1.34	0.84	0.49
Variance	3.97	0.63	0.23	0.83	1.82	0.72	0.25
Minimum	5.29	6.99	5.98	6.78	6.05	7.09	5.94
Maximum	10.24	8.92	7.17	9.10	9.24	8.74	7.09

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	8.53	7.13	7.75	7.01	5.99	7.28	6.22
Std. Error of	0.62	0.46	0.37	0.39	0.25	0.51	0.28

Mean							
Std. Deviation	1.08	1.03	0.82	0.87	0.56	1.15	0.63
Variance	1.18	1.07	0.67	0.76	0.31	1.32	0.41
Minimum	7.49	6.29	6.89	5.67	5.30	5.45	5.39
Maximum	9.66	8.56	9.01	8.07	6.57	8.27	7.09

Figure 5: Activity concentration (BqL⁻¹) for ²³²Th

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	2.32	3.00	5.41	2.05	3.12	2.76	3.63
Std. Error of Mean	0.32	0.29	1.37	0.26	0.62	0.22	0.83
Std. Deviation	0.70	0.66	3.06	0.59	1.40	0.38	1.87
Variance	0.49	0.43	9.42	0.35	1.96	0.14	3.50
Minimum	1.68	2.43	2.53	1.64	1.81	2.45	1.58
Maximum	3.52	3.97	9.06	3.09	5.48	3.19	6.34

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	4.89	2.78	4.81	3.63	2.73	2.23	2.28

Std. Error of Mean	1.16	0.42	0.47	0.97	0.40	0.09	0.25
Std. Deviation	2.01	0.93	1.05	2.18	0.89	0.19	0.55
Variance	4.03	0.86	1.11	4.77	0.80	0.04	0.31
Minimum	2.84	1.98	3.42	1.60	1.96	1.99	1.67
Maximum	6.85	4.23	6.14	7.35	4.12	2.44	2.99

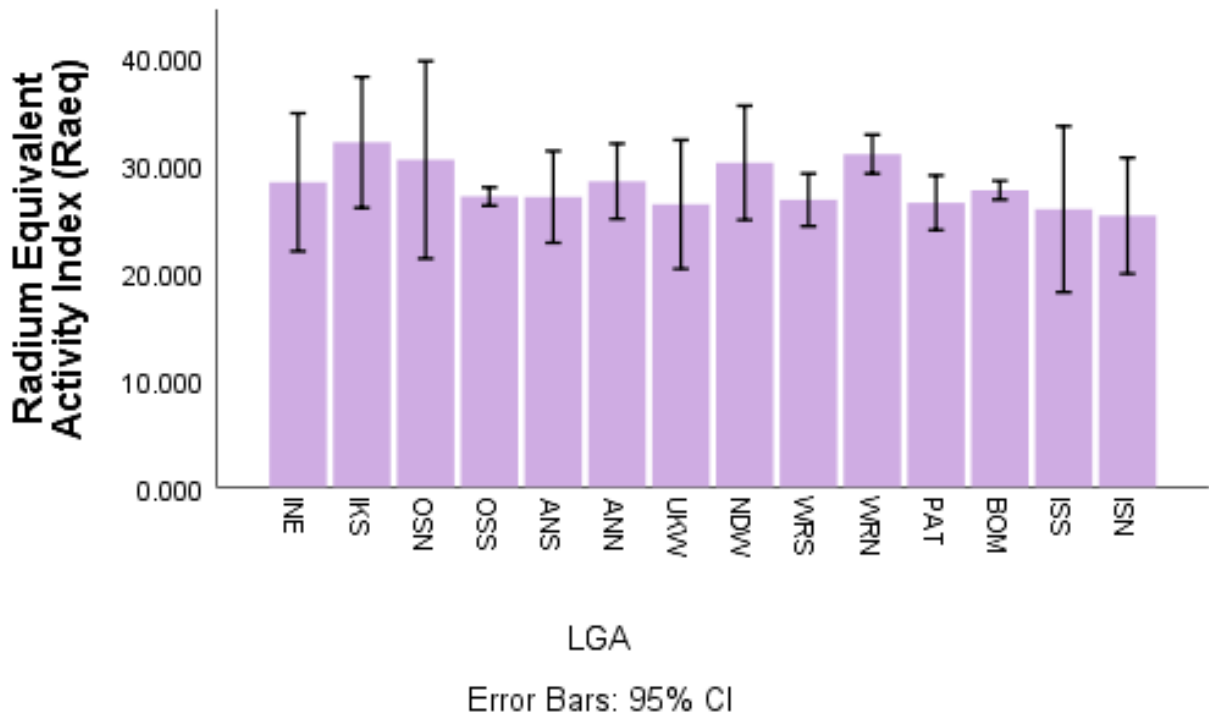


Figure 6: Radium Equivalent Activity index

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	27.24	33.45	28.85	27.14	29.11	28.45	27.67
Std. Error of Mean	1.12	1.16	1.52	0.97	2.86	0.81	2.53
Std. Deviation	2.50	2.61	3.40	2.18	6.39	1.41	5.68
Variance	6.27	6.83	11.57	4.77	40.79	1.99	32.20
Minimum	24.48	29.34	26.37	24.25	24.42	27.56	22.56
Maximum	30.85	36.18	33.61	30.37	40.15	30.08	36.91

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	30.16	26.71	30.66	26.16	27.45	26.20	25.22

Std. Error of Mean	1.23	0.36	0.41	0.37	1.06	1.09	0.71
Std. Deviation	2.13	0.82	0.91	0.83	2.36	2.43	1.59
Variance	4.56	0.67	0.83	0.70	5.59	5.94	2.55
Minimum	27.73	25.58	29.32	25.54	23.88	22.33	23.08
Maximum	31.75	27.36	31.73	27.59	30.51	28.20	27.41

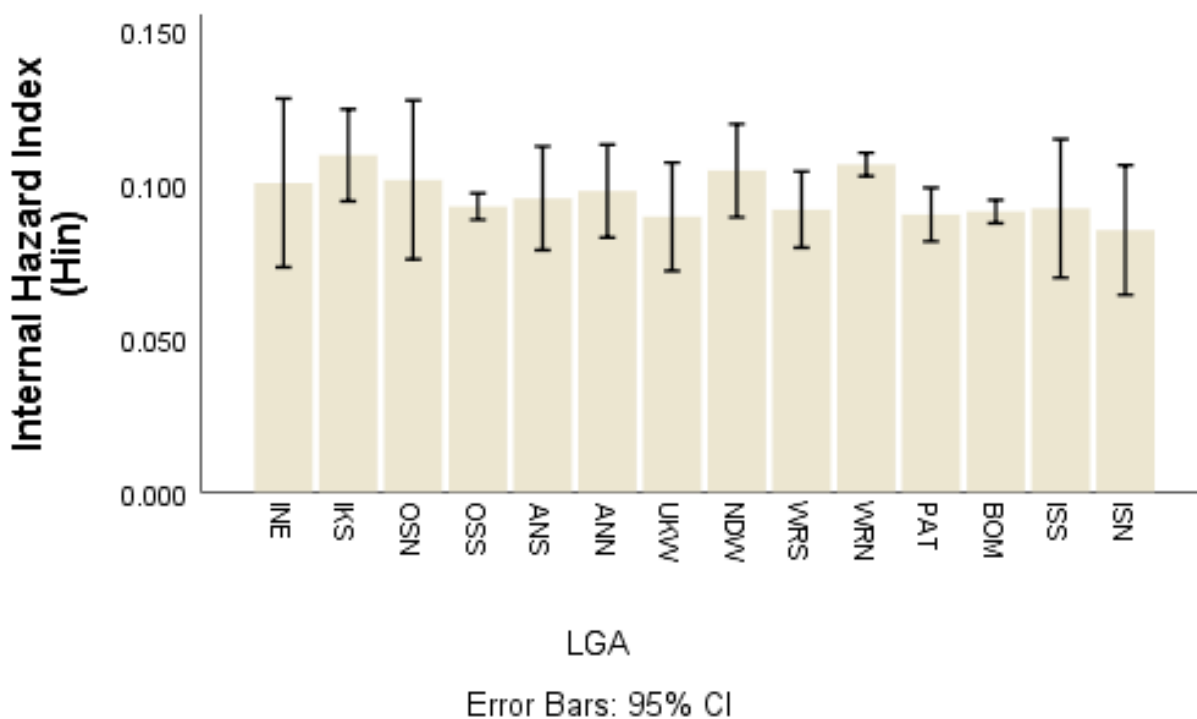


Figure 5: Internal Hazard Index (H_{in})

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	0.094	0.112	0.096	0.094	0.100	0.098	0.092
Std. Error of Mean	0.005	0.003	0.005	0.003	0.008	0.003	0.006
Std. Deviation	0.011	0.006	0.010	0.008	0.019	0.006	0.015
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.084	0.104	0.088	0.086	0.083	0.094	0.077
Maximum	0.111	0.120	0.110	0.107	0.134	0.105	0.116

Table 8 Continues

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	0.104	0.091	0.104	0.090	0.090	0.091	0.085
Std. Error of Mean	0.003	0.001	0.001	0.001	0.002	0.002	0.002
Std. Deviation	0.006	0.003	0.003	0.002	0.005	0.006	0.006
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.098	0.087	0.098	0.087	0.083	0.082	0.077
Maximum	0.110	0.097	0.108	0.094	0.097	0.099	0.094

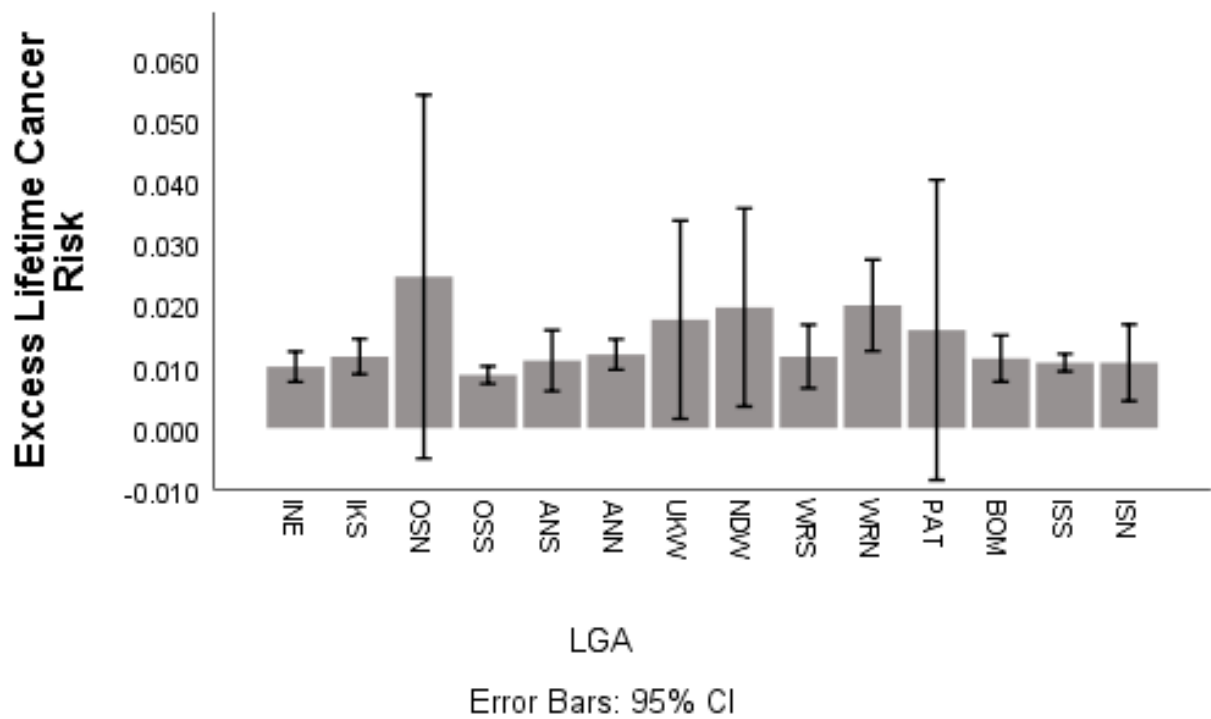


Figure 7: Excess Lifetime Cancer Risk

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	0.011	0.013	0.021	0.010	0.013	0.012	0.015
Std. Error of Mean	0.001	0.001	0.005	0.001	0.002	0.001	0.003
Std. Deviation	0.002	0.002	0.010	0.002	0.005	0.001	0.006
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.009	0.011	0.011	0.008	0.009	0.011	0.008

Maximum	0.014	0.016	0.033	0.013	0.022	0.013	0.024
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Table 9 Continues

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	0.019	0.012	0.019	0.015	0.012	0.010	0.010
Std. Error of Mean	0.004	0.001	0.002	0.003	0.001	0.001	0.001
Std. Deviation	0.007	0.003	0.003	0.007	0.003	0.001	0.001
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.013	0.010	0.014	0.008	0.009	0.009	0.008
Maximum	0.026	0.017	0.023	0.027	0.016	0.011	0.013



Figure 8: Committed Effective Dose

Table 10: Committed Effective Dose (12-17 years)

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	0.014	0.017	0.022	0.014	0.017	0.016	0.015
Std. Error of Mean	0.001	0.001	0.004	0.001	0.002	0.001	0.001
Std. Deviation	0.002	0.002	0.009	0.002	0.005	0.001	0.001
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.012	0.015	0.014	0.012	0.013	0.015	0.012
Maximum	0.016	0.019	0.032	0.016	0.025	0.017	0.016

Table 10 Continues

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
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Mean	0.017	0.022	0.016	0.021	0.017	0.014	0.017
Std. Error of Mean	0.002	0.003	0.001	0.001	0.002	0.001	0.002
Std. Deviation	0.005	0.005	0.003	0.002	0.005	0.002	0.005
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.011	0.017	0.013	0.017	0.012	0.013	0.011
Maximum	0.025	0.027	0.019	0.025	0.026	0.018	0.025

Table 11: Committed Effective Dose (>17 years)

	INE	IKS	OSN	OSS	ANS	ANN	UKW
Mean	0.011	0.013	0.021	0.009	0.013	0.012	0.015
Std. Error of Mean	0.001	0.001	0.005	0.001	0.002	0.001	0.003
Std. Deviation	0.002	0.002	0.010	0.002	0.005	0.001	0.006
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.009	0.011	0.011	0.008	0.009	0.011	0.008
Maximum	0.014	0.016	0.033	0.013	0.022	0.013	0.024

Table 11 Continues

	NDW	WRS	WRN	PAT	BOM	ISS	ISN
Mean	0.020	0.012	0.019	0.015	0.012	0.010	0.010
Std. Error of Mean	0.004	0.001	0.002	0.003	0.001	0.000	0.001
Std. Deviation	0.007	0.003	0.003	0.007	0.003	0.001	0.002
Variance	0.000	0.000	0.000	0.000	0.000	0.000	0.000
Minimum	0.013	0.010	0.014	0.008	0.009	0.009	0.008
Maximum	0.026	0.017	0.023	0.027	0.016	0.011	0.013

Conclusion

The results of Excess Lifetime cancer Risk are shown in table 2 for each of the LGA, table 3 shown the statistics of the radiological parameter which ranges from 0.008 - 0.033 where OSS 2, UKW 4, PAT 3, ISN 2 has the lowest value of 0.008 while OSN 2 has the highest value of 0.033 with a mean of 0.014 ± 0.001 . The excess lifetime cancer risk and statistics for every local government area in the study region are shown in Figure 7 and

Table 9 were above the world average value of 10^{-4} (EPA, 2012). This implies that the chances of having cancer in the study area is significant. Therefore, all the sources of drinking water in this area of study must be treated before consumption to avert the likely health implications.

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