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ASSESSMENT OF THE LEVEL OF RADIONUCLIDE IN DRINKING WATER IN SELECTED SCHOOLS IN THE NORTHERN PART OF DELTA STATE, NIGERIA

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ABSTRACT
Portable drinking water is crucial in human health discussions. It is no secret that radionuclides are major pollutants of this resource. This study assessed gamma-ray emitting radionuclides in drinking water in selected secondary schools in Eight Local Governments in the northern part of Delta State, Nigeria. Gamma spectrometry having a highly efficient NaI (TI) detector was used for the identification and quantification of these radionuclides. The obtained activity concentrations were then used to calculate the annual effective doses associated with the intake of water for the students between the ages of 12 and 17 years. The result show that ^{238}U, ^{232}Th and ^{40}K are the major radionuclides found in the water samples. The activity concentration ranges from 5.29 ± 0.11 to 10.24 ± 2.05 Bql^{-1}, 1.58 ± 0.03 to 9.06 ± 2.12Bql^{-1}and145.61±12.60 to 345.78±7.99Bql^{-1}, the calculated values for the annual effective doses are 6.836, 0.510 and 0.980 $mSvy^{-1}$for ^{238}U, ^{232}Th and ^{40}K respectively. The measured activity values are relatively high and exceed the recommended respective reference activity limits for drinking water of 1.0, 0.1 and 10 Bql^{-1} by World Health Organisation (WHO). The calculated associated dose values also exceed the 0.1 and 1.0 $mSvy^{-1}$limits of the WHO and the ICRP. Thus drinking water in the studied schools appears to be radiologically unfit. It is suggested that relevant bodies such as Federal Environmental Protection Agency (FEPA) should carry out necessary quality control checks.

Keywords: Activity concentration, Drinking water, Radiological safety, Health risk, Effective dose

INTRODUCTION

The Compulsory, Free Universal Basic Education and Other Related Matters Act of 2004, established the Universal Basic Education Commission (UBEC) with the mission to end illiteracy, ignorance, and poverty as well as to promote and hasten national integration, political consciousness, and development. These objectives align with the national philosophy of education and the aspirations of the nation for social, economic, and political development (UBEC, 2018). Delta State Government in response to the aspirations of UBEC has updated several secondary schools in her domain. The State also ensured that drinking water sources are provided for these schools. Mokobia (2022) indicated that drinking water is contaminated by radionuclides and according to Asiyai (2012), this issue of radioactive contamination is crucial in water quality discussions. This is because natural radionuclides like uranium-238 (^{238}U), thorium-232 (^{232}Th) and potassium -40 (^{40}K) are ubiquitous in the environment (Mokobia 2010). According to the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the populace can be exposed to internal radiation doses through the ingestion of water (UNSCEAR, 2000). This assertion is affirmed by Shanthi et al., (2010) when they indicated that water significantly contributes to the effective internal radiation dosage with serious health ramifications. This concern about radioactivity in drinking has necessitated several investigations both internationally and locally. Some of the local studies include Ajayi and Owolabi (2008), study the determination of natural radioactivity in drinking water in private dug wells in Akure, southwestern Nigeria and concluded that the radionuclides present in dug-well drinking waters in Akure, Southwestern Nigeria such as ^{40}K, ^{226}Ra and ^{228}Ra are identified. These radionuclides' activity concentrations range from 0.35±0.03 to 29.01±2.40, 0.57±0.08 to 26.86±3.42 and 0.20±0.01 to 60.06±3.97 Bq l^{-1}, respectively. The values were discovered to be higher than those discovered in the majority of other nations as reported by other workers. Additionally, it is discovered that the total yearly effective dose exceeds the level advised by the World Health Organization (WHO) and International Commission on Radiological Protection (ICRP). Awodugba and Tchokossa (2008), assessed the radionuclide concentrations in water supplies from boreholes in Ogbomosoland, Western Nigeria. They found that the mean concentrations of the radionuclides in water samples from the boreholes ranged from 3.98 ±0.26, 11.00 ± 2.58, and 17.73 5.04 Bql^{-1} for ^{40}K, ^{232}Th, and ^{238}U, respectively showing that the mean activity of ^{238}U for all the samples is the highest when compared with those of ^{40}K and ^{232}Th. Ugbede and Akpolile (2020), studied the assessment of natural radioactivity in potatoes and the health risk associated with its consumption in Enugu, Nigeria and observed that the activity concentrations of ^{40}K ranged from 327.65 ± 17.49 – 725.30±38.66 $Bq.kg^{-1}$ with mean value 526.39 ± 135.98 $Bq.kg^{-1}$, those of ^{238}U ranged from BDL – 13.94 ± 1.73 $Bq.kg^{-1}$ with mean of 8.55 ± 4.67 $Bq.kg^{-1}$ and those of ^{232}Th ranged from BDL – 3.38 ± 0.20 $Bq.kg^{-1}$ with a mean value of 1.14 ± 1.11 $Bq.kg^{-1}$. The distribution and amounts of the radionuclides were found to be non-uniform in the samples of potatoes that were analyzed, with ^{40}K showing the highest concentration. Additionally, it was found that ^{40}K had the highest daily radionuclide intake. This might be because the farms where they were cultivated used fertilizer that was high in phosphate. It does appear that there is an absence of these investigations in Delta State. The purpose of this work then is to fill this gap by providing baseline data on the radionuclide content of drinking water and their associated annual effective doses for teens between the ages of 12 -17 years

Study Area

The study was carried out in some selected secondary schools in the Northern part of Delta State (Figure 1). It is situated between latitude 5^{o}30.000'N and longitude 7^{o}30.000'E in the Delta-Northern geo-political zone. It has a population of 1,229,371. Table 3.1 shows the sampling locations of drinking water samples.

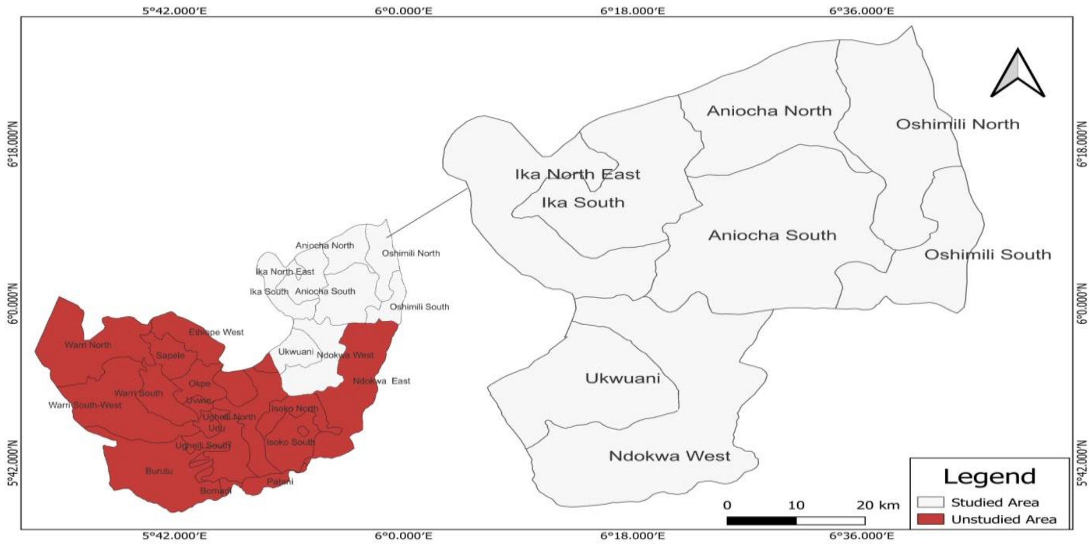

Figure 1: Map of the study area

Methods

Sample preparation

Tap water samples linked to State government sunk boreholes were collected from 36 secondary schools in eight local government areas in the northern part of Delta State. The local government areas where the schools are located are given in Table 1 while the specific schools and local governments where they are located are given in Table 1. The choice of school was mainly based on population density. Before collecting the water samples, the water taps were first turned on to full capacity for several minutes to purge the plumbing system of any water that might have been there for some time in line with standard practice (Avwiri*et al.*, 2007). To minimize turbulence and consequently radioactivity loss, the taps were brought down to a low setting (Avwiri*et al.*, 2007). Containers for the samples were washed with a solution of detergent and then rinsed with freshly dilute hydrochloric acid (HCl) to remove any inorganic material that might have stuck to the walls of the container before the samples were collected, This is to minimize radionuclide adsorption unto their walls(Awodugba and Tchokossa 2008). The container holding each water sample was tightly sealed and wrapped with thick vinyl tape around their screw necks and taken to the gamma counting preparatory laboratory, Preparatory to the radioactivity measurements, 250 ml of each of the water samples was poured into special cylindrical sampling containers which were again tightly sealed and stored for 4 weeks to ensure that a state of secular equilibrium is achieved between the natural radionuclides in the samples and their progenies (IAEA, 1989).

Table 1: Location and codes of the schools where samples were collected

Local Government/location	Secondary School	Code
	Azagba Mixed Secondary School, Azahgba	F1
Aniocha North	Martins College, Issele-Uku	F2
	Pilgrim Baptist Grammar School, Issele-Uku	F3
	Olloh Mixed Secondary School, OllohOgwashi	E1
	Okiti Mixed Secondary School, UbuluOkiti	E2
Aniocha South	Adaigbo Secondary, Ogwashi-Ukwu	E3
	Ejeme Mixed Secondary School, Ejeme-Aniogor	E4
	Ngwu Mixed Secondary School, Ogwashi-Ukwu	E5
	Dynamic Secondary School, Umunede	A1
	Ute-Okpu Grammar School, Ute-Okpu	A2
Ika North East	Mary-mount College, Agbor	A3
	Ute-Ogbeje Secondary School, Ute-Ogbeje	A4
	Mbiri Mixed Secondary School, Mbiri	A5
Ika South	Imeobi Secondary School, Agbor	B1
	Omumu Secondary School, Omumu	B2
	Dien Palace Secondary School, Agbor- Obi	B3
	Abavo Girls Secondary School, Abavo	B4
	Agbor Technical College, Agbor	B5
Ndokwa West	UtagbaOgbe Secondary School Kwale	H1
	Emu Secondary School, Emu-Uno	H2
	Obodeti Commercial Secondary School, Emu-Obodeti	H3
Oshimili North	Ibusa Mixed Secondary School, Ibusa	C1
	St, Thomas' College, Ibusa	C2
	Okpanam High School, Okpanam	C3
	Ibusa Girls Grammar School, Ibusa	C4
	Unity Secondary School Okpanam	C5
Oshimili South	Niger Mixed Secondary School, Asaba	D1
	Government Model Secondary School, Asaba	D2
	Osadenis High School, Asaba	D3
	West End Secondary School Asaba	D4
	Zappa Basic Secondary School, Asaba	D5
Ukwuani	Obiaruku Grammar School, Obiaruku	G1
	Umutu Mixed Secondary School, Umutu	G2
	Ebedei Secondary School, Ebedei	G3
	Umukwata Secondary School, Umukwata	G4
	Boys Secondary School, Obiaruku	G5

Radioactivity Measurement and Quantification

Activity measurements were performed using a NaI (Tl) detector-based gamma-ray spectrometer (Awodugba and Tchokossa, 2007) at the environmental radioactivity laboratory in the department of physics and engineering physics, Obafemi Awolowo University, Ile-Ife, Nigeria. All the samples were counted for 60,000 seconds because of the low gamma counts in the water. The detector was surrounded by a cylindrical Canberra Pb shield, 10 cm thick to screen out the γ-ray background in the laboratory environment. The radioactivity in a sealed but empty cylindrical container similar to the sample containers was also counted at the same time. The displayed gamma-ray spectra for each sample and the empty container (background) were analysed using a 4096-channel Canberra computer analyzer. The analysis and activity of the parent radionuclides depend on those of the daughter energy peaks of the decay products in equilibrium with their parent radionuclides (Ajayi and Owolabi, 2008; Awodugba and Tchokossa, 2008). Therefore, the respective gamma-ray peaks of 911.1 keV and 583.1 keV of ^{228}Ac and ^{208}Tl were used for the identification of ^{232}Th while ^{238}U was identified from the 1120.3 and 609.3 keV gamma peaks of ^{214}Bi and

351.9 keVpeak of ^{214}Pb and the single gamma peak of 1460.8 keV was used ^{40}K. The net activity counts for each of these radionuclides were obtained by subtracting the background count from the respective peak counts. The specific activities of the radionuclides were calculated using the equation (Oyebanjo and Magbagbeola, 2015; IAEA, 2003):

$$A_i = \frac{N_i}{\varepsilon \gamma_i t v} \quad (1)$$

where A_i is the activity (Bql^{-1}) of the particular radionuclide, N_i : the net area under the peak of the particular radionuclide, ε is the efficiency of the detector, γ_i is the branching ratio of the gamma-ray whose peak is being considered (the % intensity), t is the radioactivity counting time (s) and v is the volume of the water sample (l)

The AEDs associated with the ingestion of the identified radionuclides were calculated using the expression (Ugbede et al., 2020)

$$AED = A_{Ri} \times (CR_w)_i \times (D_{cf})_i \quad (2)$$

A_{Ri} is the determined activity of the particular radionuclide in the already defined unit, $(CR_w)_i$: the drinking water consumption rate for the particular age group in (lyr^{-1}) and $(D_{cf})_i$ the dose conversion factor ($mSv(Bq^{-1}$) for the specific age group. The appropriate values of $(CR_w)_i$ and $(D_{cf})_i$ are given in Table 2. The total annual effective dose for an individual in a given age group was computed by summing the contribution of each radionuclide present in the samples.

Table 2: Dose conversion factors and annual water consumption rates for different age groups (WHO, 2011; ICRP, 1996)

Age Group (yrs)	Dose conversion factor (Sv.Bq−1) per age group			Annual water consumption rate (ly^{-1})
	^{40}K	^{238}U	^{232}Th	
0-1	6.2×10^{-8}	4.7×10^{-6}	4.6×10^{-6}	200
1-2	4.2×10^{-8}	9.6×10^{-7}	4.5×10^{-7}	260
2-7	2.1×10^{-8}	6.2×10^{-7}	3.5×10^{-7}	300
7-12	1.3×10^{-8}	8.0×10^{-7}	2.9×10^{-7}	350
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

The total AED_{eff} to an individual is therefore the sum of each radionuclide. That is;

$$AED_{eff} = \sum(A_c \times C_f \times CR_w) \quad (3)$$

Results and Discussion

The measured activity concentration of ^{238}U, ^{232}Th and ^{40}K, in the investigated water samples of public schools in each LGA of the northern region of Delta State, are presented in Figures 2 to 8 for Ika North East (A). Ika South (B), Oshimili North (C), Oshimili South (D), Aniocha North (E), Aniocha South (F), Ukwani (G), Ndokwa West (H) respectively. Table 2-8 shows the descriptive statistical summary of the AC across all the locations. In all, It was observed that the activity of ^{40}K in the water samples is much higher than that of ^{232}Th and ^{238}U and it ranges from 145.61±12.60 to 345.78 ± 7.99 Bql^{-1}. It was also observed that ^{238}U is higher than ^{232}Th which ranges from 5.29 ±0.11 to 10.24±2.05 Bql^{-1} for ^{238}U and 1.58±0.03 to 9.06±2.12 Bql^{-1} for ^{232}Th. The activities of ^{40}K are found to be higher than ^{232}Th and ^{238}U because ^{238}U and ^{232}Th come from the natural decay series while ^{40}K through a primordial radionuclide does not undergo any decay series. These values as shown in table 5,3 and 9, indicated that C2 (Oshimili North LGA), A5 (Ika North East LGA), and G4 (Ukwani LGA) have the lowest activity concentration in the studied area for ^{40}K, ^{238}U, and ^{232}Th respectively, while G5 (Ukwani LGA), A3 (Ika North East LGA) and C2 (Oshimili North LGA) have the highest concentration in the studied area for ^{40}K, ^{238}U and ^{232}Th respectively. The Average distribution of the radionuclide across the eight LGA revealed that ^{40}K has the highest among the radionuclide detected in the sample in each of the areas and show that Oshimili North LGA has the lowest of 187.424 ±26.764 Bql^{-1} while Ika South LGA has the highest of 274.128±31.545 Bql^{-1}. It also revealed that Ukwani LGA has the lowest value for ^{238}U of 6.448± 0.499 Bql^{-1} and the highest of 8.530± 1.088 Bql^{-1} at Ndokwa West LGA, also for ^{232}Th Oshimili South LGA has the lowest of 2.058 ± 0.590 Bql^{-1} and the highest of 5.414 ±3.069 Bql^{-1} at Oshimili North LGA. The same aquifer properties of the research area may likely be the cause of the small difference in AC between thorium and uranium (Ahmad et al., 2019). The geological characteristics of the Delta region's aquifer environment could be responsible.

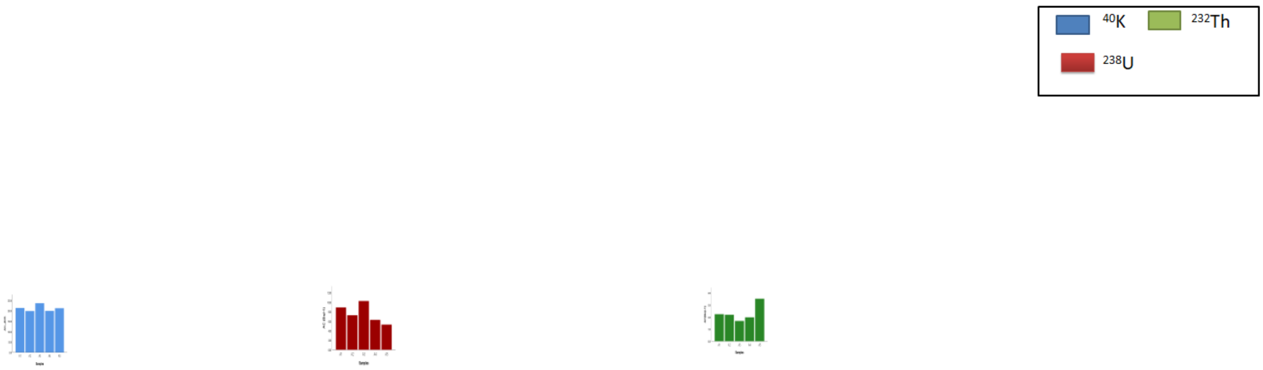

Figure 2: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Ika North East (A).

Table 3: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Ika North East (A)

Statistics	^{40}K	^{238}U	^{232}Th
Mean	212.1400	7.5900	2.3220
Std. Error of Mean	6.82009	0.88978	0.31532
Median	212.3800	7.2500	2.1900
Mode	198.78	5.29^{a}	1.68^{a}
Std. Deviation	15.25018	1.98961	0.70507
Variance	232.568	3.959	0.497
Range	37.67	4.95	1.84
Minimum	198.78	5.29	1.68
Maximum	236.45	10.24	3.52

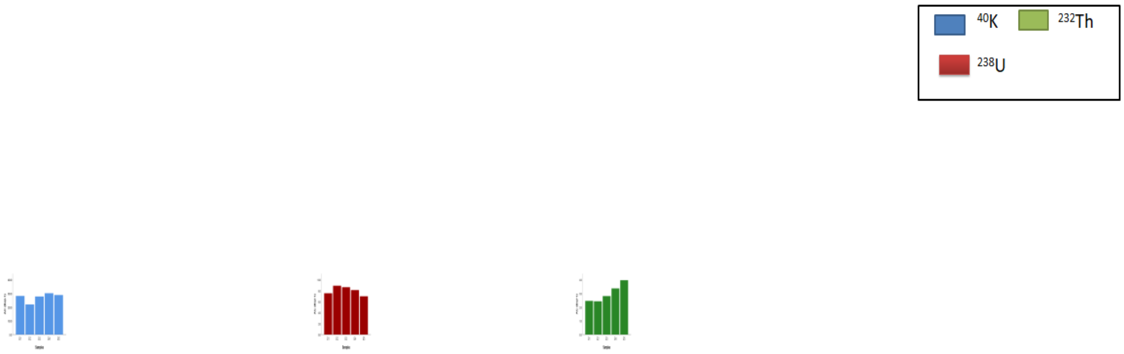

Figure 3: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Ika South (B)

Table 4: Descriptive statistical summary of activity concentration (Bql^{-1}) of natural radionuclides in water samples of Secondary Schools in Ika South (B).

Statistics	^{40}K	^{238}U	^{232}Th
Mean	274.1280	8.0440	3.0080
Std. Error of Mean	14.10750	0.35393	0.29412
Median	281.9700	8.1200	2.8100
Mode	220.03[a]	6.99[a]	2.43[a]
Std. Deviation	31.54533	0.79141	0.65766
Variance	995.108	0.626	0.433
Range	81.74	1.93	1.54
Minimum	220.03	6.99	2.43
Maximum	301.77	8.92	3.97

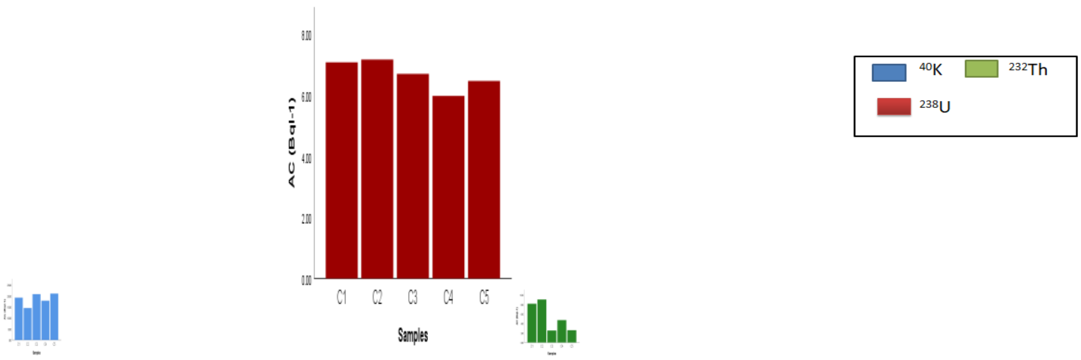

Figure 4: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Oshimili North (C).

Table 5: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Oshimili North (C).

Statistics	^{40}K	^{238}U	^{232}Th
Mean	187.4240	6.6800	7.6800
Std. Error of Mean	11.96912	0.21617	0.40753
Median	192.8100	6.7000	7.5000
Mode	145.61[a]	5.98[a]	6.78[a]
Std. Deviation	26.76377	0.48337	0.91126
Variance	716.299	0.234	0.830
Range	65.63	1.19	2.32
Minimum	145.61	5.98	6.78
Maximum	211.24	7.17	9.10

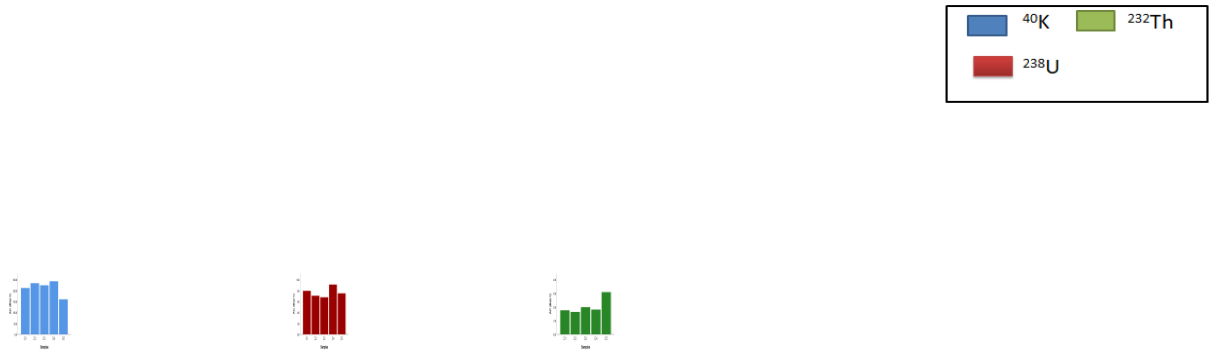

Figure 5: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Oshimili South (D)

Table 6: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Oshimili South (D)

Statistics	^{40}K	^{238}U	^{232}Th
Mean	214.5560	5.4140	2.0580
Std. Error of Mean	14.54207	1.37228	0.26407
Median	224.2600	4.7200	1.8100
Mode	160.14[a]	2.53[a]	1.64[a]
Std. Deviation	32.51706	3.06851	0.59048
Variance	1057.359	9.416	0.349
Range	82.52	6.53	1.45
Minimum	160.14	2.53	1.64
Maximum	242.66	9.06	3.09

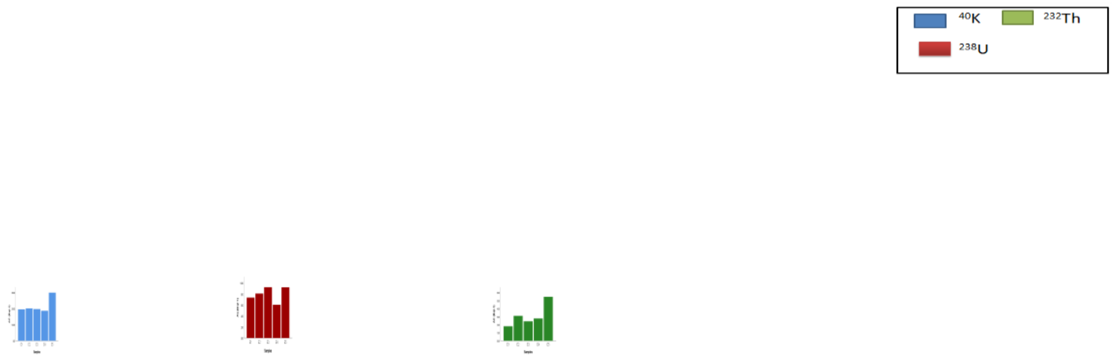

Figure 6: Measured activity concentrations of 40K, 238U and 232Th in water samples of Schools in Aniocha North (E).

Table 7: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Aniocha North (E).

Statistics	^{40}K	^{238}U	^{232}Th
Mean	216.2580	7.9920	3.1220
Std. Error of Mean	21.00520	0.60346	0.62759
Median	197.4800	8.0900	2.7800
Mode	186.92[a]	6.05[a]	1.81[a]
Std. Deviation	46.96906	1.34938	1.40334
Variance	2206.092	1.821	1.969
Range	112.82	3.19	3.67
Minimum	186.92	6.05	1.81
Maximum	299.74	9.24	5.48

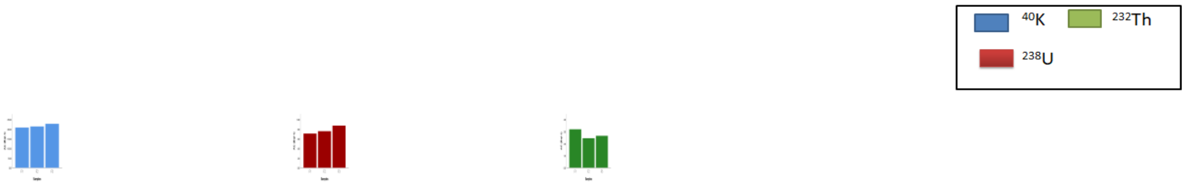

Figure 7: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Aniocha South (F)

Table 8: Descriptive statistical summary of activity concentration (Bql^{-1}) of natural radionuclides in water samples of Secondary Schools in Aniocha South (F)

Statistics	^{40}K	^{238}U	^{232}Th
Mean	216.8000	7.8033	2.7633
Std. Error of Mean	5.76868	0.48923	0.22101
Median	214.0800	7.5800	2.6500
Mode	208.45[a]	7.09[a]	2.45[a]
Std. Deviation	9.99164	0.84737	0.38280
Variance	99.833	0.718	0.147
Range	19.42	1.65	0.74
Minimum	208.45	7.09	2.45
Maximum	227.87	8.74	3.19

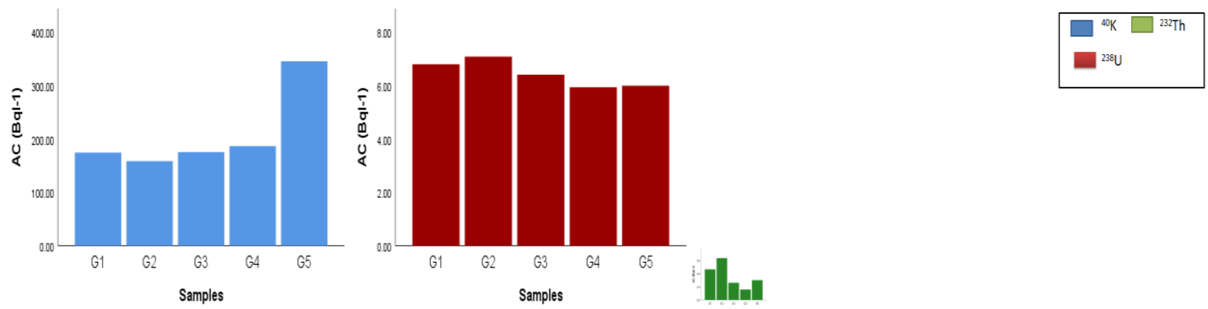

Figure 8: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Ukwani (G).

Table 9: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Ukwani (G)

Statistics	^{40}K	^{238}U	^{232}Th
Mean	208.2000	6.4480	3.6320
Std. Error of Mean	34.68493	0.22319	0.83739
Median	175.5600	6.4100	3.0000
Mode	158.51[a]	5.94[a]	1.58[a]
Std. Deviation	77.55785	0.49907	1.87246
Variance	6015.221	0.249	3.506
Range	187.27	1.15	4.76
Minimum	158.51	5.94	1.58
Maximum	345.78	7.09	6.34

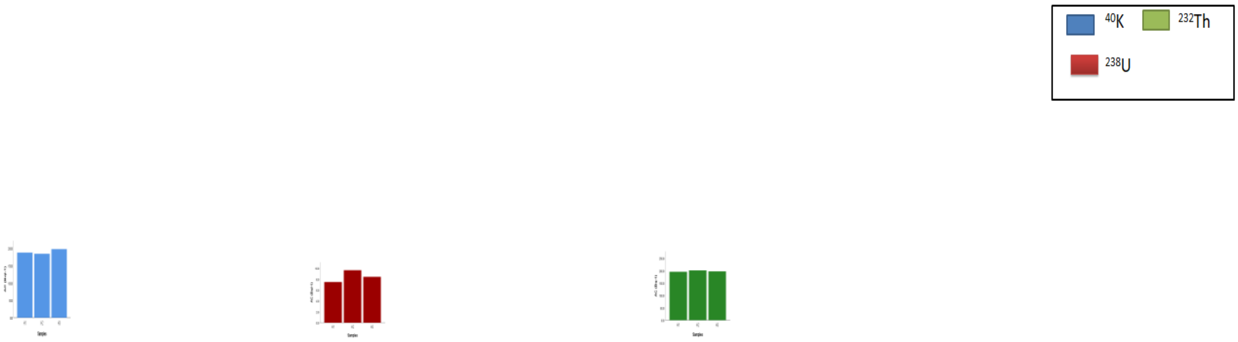

Figure 9: Measured activity concentrations of ^{40}K, ^{238}U and ^{232}Th in water samples of Schools in Ndokwa West (H)

Table 10: Descriptive statistical summary of activity concentration (Bql^{-1}) natural radionuclides in water samples of Secondary Schools in Ndokwa West (H).

Statistics	^{40}K	^{238}U	^{232}Th
Mean	190.05	8.53	4.89
Std. Error of Mean	4.023	0.62804	1.15860
Median	187.90	8.4400	4.9900
Mode	184.41[a]	7.49[a]	2.84[a]
Std. Deviation	6.97	1.08780	2.00675
Variance	48.558	1.183	4.027
Range	13.43	2.17	4.01
Minimum	184.41	7.49	2.84
Maximum	197.84	9.66	6.85

Test of significance by one-way analysis of variance (ANOVA) shows that no significant differences ($p \geq 0.05$) exist between each of the LGA and there exist significant differences between the LGA and that of WHO average limits of 10, 1.0, and 0.1 Bql^{-1} for ^{40}K and ^{238}U and ^{232}Th respectively. It was observed that ^{238}U concentrations were higher than ^{232}Th concentrations in all samples. This observation may be explained by the presence of limestone, which is widespread in some schools, and uranium-bearing minerals associated with granite rocks. (Akpanowo*et al*, 2021)Different radionuclides' solubility and mobility may be to blame for the observed broad variance in activity concentrations. One naturally occurring radionuclide that is abundant in the earth's crust is potassium-40. Its elevated concentration in the study area's drinking water may be the result of topsoil seeping from surrounding farms that use inorganic potassium fertilizers to increase soil nutrients. A large number of radionuclides that have collected in agricultural soil can percolate and seep into neighbouring aquifers. One crucial aspect of water quality that warrants attention is the radiological safety of drinking water. The WHO limits and UNSCEAR reports served as the foundation for the majority of countries' radiation risk regulations and drinking water guidelines (Ugbede et al., 2020). The activity concentrations of ^{40}K and ^{238}U and ^{232}Th obtained in this present study are higher than WHO average limits of 10, 1.0, and 0.1 Bql^{-1} respectively for drinking water. This demonstrates that the water at these study sites is not within the WHO drinking water radiological safety limit, which is a significant criterion of concern. As a result, drinking the research water can cause radionuclides to build up in various body organs, which could irradiate the organs due to released gamma photons, resulting in radiation damage. Any organ's extent of damage is linearly connected with the AC of the radionuclides present in those organs (Jibiri et al., 2007). Uranium may be absorbed in the blood, growing bone, and other soft tissues, making the kidney and lungs the ideal places for it to collect. Thorium can also be absorbed in the bones, liver, and lungs (Akhter et al., 2007; Nahar et al., 2018; Ahmad et al., 2019). Potassium is a necessary intracellular cation that is widely distributed throughout the body and carries little risk (Hassan et al., 2021). Given its minimal danger, specific guideline levels for 40K are typically not provided; nonetheless, children and other vulnerable people with conditions like hypertension, diabetes, renal failure, etc. may be susceptible to its presence (Portuphy et al., 2018). These observations highlight the radiologically contaminated drinking water found in secondary schools in the northern part of Delta State. The maximum annual effective dosage for students between the ages of 12 and 17 as shown in Table 11indicates that ^{40}K, ^{238}U, and ^{232}Th were 0.980, 6.836, and 0.510 mSvy-1, respectively (students). In all the samples and locations, it was observed that the average $AED_{eff}$of ^{238}U was higher than that of ^{40}K and ^{232}Th, in the following order: ^{238}U >^{40}K >^{232}Th. This demonstrates both the radiotoxic properties of uranium, which are greater than those of potassium and thorium, as well as its solubility and mobility in water (Ahmad et al., 2019; Khandaker et al., 2019). Additionally, the research locations' combined average yearly effective dosage of ^{40}K, ^{238}U, and ^{232}Th ranges from 7.298 to 9.277$mSvy^{-1}$These statistics demonstrate that the annual effective dose resulting from the ingestion of radionuclides from water and food exceeds the reference limits of 0.1 mSvy-1 set by the World Health Organization (WHO, 2011) for drinking water and 1.0 mSvy-1 by the ICRP (ICRP,1991, 1996) and IAEA (IAEA, 2014) for ingestion of radionuclides from water and food. Furthermore, the readings were higher than the 0.29 mSv UNSCEAR (2000) projected global average yearly effective dosage for all countries. These findings highlight the radiological hazard of the drinking water in the study area.

Table 11: Summary of estimated annual effective dose (AEDeff) of natural radionuclides in water samples

LGA		AEDeff for 12 – 17 years(mSvy–1)						
		Range	Minimum	Maximum	Mean	Mean Std. Error	Std. Deviation	Variance
Ika North East	40K	0.17	0.91	1.08	0.967	0.032	0.07	0.005
	238U	4.46	4.76	9.22	6.831	0.801	1.791	3.206
	232Th	0.28	0.25	0.53	0.349	0.048	0.106	0.011
	Total	4.91	5.92	10.83	8.147			
Ika South	40K	0.37	1.00	1.38	1.25	0.065	0.144	0.021
	238U	1.74	6.29	8.03	7.24	0.319	0.713	0.507
	232Th	0.23	0.36	0.60	0.451	0.045	0.099	0.010
	Total	2.34	7.65	10.01	8.941			
Oshimili North	40K	0.30	0.66	0.96	0.855	0.055	0.123	0.015
	238U	1.07	5.38	6.45	6.012	0.195	0.436	0.189
	232Th	0.98	0.38	1.36	0.812	0.206	0.461	0.212
	Total	2.35	6.42	8.77	7.679			
Oshimili South	40K	0.38	0.73	1.11	0.978	0.067	0.149	0.022
	238U	2.09	6.10	8.19	6.912	0.367	0.821	0.673
	232Th	0.22	0.25	0.46	0.309	0.04	0.089	0.008
	Total	2.69	7.08	9.76	8.199			
Aniocha South	40K	0.51	0.85	1.37	0.986	0.096	0.215	0.046
	238U	2.87	5.45	8.32	7.193	0.544	1.215	1.475
	232Th	0.55	0.27	0.82	0.468	0.095	0.211	0.044
	Total	3.93	6.57	10.51	8.647			
Aniocha North	40K	0.09	0.95	1.04	0.989	0.027	0.046	0.002
	238U	1.49	6.38	7.87	7.023	0.441	0.763	0.582
	232Th	0.11	0.37	0.48	0.414	0.034	0.058	0.003
	Total	1.69	7.7	9.39	8.426			
Ukwani	40K	0.85	0.72	1.58	0.949	0.159	0.354	0.125
	238U	1.04	5.35	6.38	5.804	0.201	0.45	0.202
	232Th	0.71	0.24	0.95	0.545	0.126	0.281	0.079
	Total	2.6	6.31	8.91	7.298	0	0	
Ndokwa West	40K	0.06	0.84	0.90	0.866	0.019	0.033	0.001
	238U	1.95	6.74	8.69	7.677	0.566	0.98	0.958
	232Th	0.60	0.43	1.03	0.734	0.174	0.301	0.090

Conclusion

This research was done to assess the water quality, radionuclide activity concentrations, and health hazard indicators of drinking water samples in the studied area. Thirty-Six drinking water samples from selected secondary schools were collected from the study region and radionuclide studies were performed on them. Typically, the ^{40}K activity concentration is more prominent than the levels of ^{238}U or ^{232}Th. The findings demonstrated that all mean activity concentration values of drinking water samples are above WHO recommended ranges of 10, 1.0,0.1 Bql^{-1} for ^{40}K,^{238}U, and ^{232}Th respectively. Further consumption of water in schools without alternative portable sources may soon pose serious health challenges to the students. This, therefore, calls for urgent attention from relevant government agencies and school officials to make available portable water.

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