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Natural Radioactivity Levels in Groundwater Sources and Their Health Impact Assessment on the Consumers

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ABSTRACT

Groundwater is one of the significant sources of drinkable water in our society today. Groundwater samples were collected from various locations and then prepared for a coaxial high-purity germanium (HPGe) detector for analysis. These studies measured the activity of 232-Th, 226-Ra, and 40-K in groundwater sources; then estimated the total annual effective radiation dose in groundwater and the lifetime cancer risk to the populace. The results show that the mean activity of 40-K from Egbeda, Ipaja, and Ije Ododo is 2.534, 1.713, and 1.931 Bq/l, respectively. These values were higher than the mean activity of 232-Th, which was 0.342, 0.364, and 0.402 Bq/l for Egbeda, Ipaja, and Ije Ododo, respectively. The mean activity of 226-Ra from Egbeda, Ipaja, and Ije Ododo is 1.191, 0.735, and 0.490 Bq/l, respectively. Hence, the mean total effective doses from Ipaja are 0.218 μSv/year for adults, 0.246 μSv/year for children, and 0.219 μSv/year for infants. In adults, the annual effective radiation doses were highest in EG1, with a value of 0.429 μSv/year, and EG4 had a value of 0.455 μSv/year. PA4 had a value of 0.344 μSv/year, and the lowest was recorded from JE3, with a value of 0.076 μSv/year. The obtained values were lower in Ipaja and Ije Ododo; this may not pose any significant health problems. Samples from Egbeda show significantly higher values of annual effective dose and may pose health problems for the consumers in the long term due to bioaccumulation

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INTRODUCTION

This Water is one of the most essential compounds and mineral sources for all living things in a habitable environment. As a result, there has been an increased reliance on groundwater to meet the growing water resource needs (IAEA, 2004). Most of the drinkable water comes from groundwater; however, it is contaminated mainly through environmental factors, human activities, and natural processes. Groundwater is usually contaminated with naturally occurring radioactive materials and their progeny (USEPA, 2000).

The local geology and geochemistry of an area control the occurrence and distribution of radionuclides in groundwater. The daughter radionuclides that are present in any locality in large concentrations are a function of the parent radionuclide that may be present in the rock material composing the groundwater (Pujol & Sanchez-Cabeza, 2000).

Radionuclides may enter the groundwater by dissolution of minerals or absorption from sediment particle surfaces. The level of toxicity of ^{226}Ra and ^{228}Ra and their progenies in water may require attention due to the health risk Shaban and Shady (2016) associated with drinking such water. The rate of contamination and the amount of contaminants have been worrisome in terms of human health. Similarly, human day-to-day activities have been a significant source of water pollution, including the application of fertilizers to soil and the use of nuclear activities. Abojassim et al. (2017) cause water pollution. Water must be pure for consumption and free from pollution; therefore, the determination of naturally occurring radionuclides in groundwater is helpful as a direct input to our immediate environment and human health assessment (Seiler and Wiemels, 2012).

There are varying rates of radionuclides decay and emit gamma rays, alpha, and beta particles. Since alpha particles cannot penetrate the skin, alpha-emitting radionuclides may be ingested, and these particles emitted can cause damage to cell tissue, potentially leading to cancer.

However, the Th-232 decay series includes Ra-228 progeny, which emits beta radiation that can penetrate the skin and cause internal cell tissue damage when ingested. According to the International Atomic Energy Agency IAEA (2014), the most abundant radioisotopes in nature are 226-Ra, an alpha emitter, and 228-Ra, a beta emitter. They are decay products of the 238-U and 232-Th natural series, respectively, and are the radioisotopes of most significant radiological toxicity due to their relatively long half-lives. The half-lives of Ra-224, Ra-226, and Ra-228 are 3.6 days, 1,600 years, and 5.8 years, respectively. Po-210 has a half-life of approximately 138 days IAEA (2014). Suppose during water drinking or in the course of the food chain (food products from contaminated waters), humans are exposed to low levels of Po-210. In that case, it may have long-term biological effects and possibly cause damage to the tissue (Seiler &Wiemels, 2012).

All of the naturally occurring radionuclides are Class A human carcinogens, but some pose greater levels of cancer risk than others. Presently, there is no drinking water standards established for Ra-224 or Po-210 by USEPA, even though these radionuclides have significant cancer risk when ingested, nearly equivalent to that of Ra-226 and Ra-228 USEPA (2005). Furthermore, the chemical behavior of radium is similar to that of calcium; therefore, radium is deposited in the human body, mainly in the bones. In fact, little is known of the concentrations of radionuclides in both the public and private water supplies IAEA (2204), which rely heavily on groundwater used for human consumption.

This work aims to determine the concentration of natural radionuclides Uranium-226, Thorium-232, Potassium-40 present in the groundwater samples from different locations within the studied area. Moreover, using the results to estimate the total annual effective doses and evaluate lifetime cancer risk. The data obtained in this work may form part of the baseline information on natural radioactivity in groundwater in that area and provide background information for future research on drinkable water for radiological protection of humans.

METHOD AND MATERIALS

Area of Study

Alimosho is one of the most populous areas, with a population of approximately 11,456,783 in Lagos State, Nigeria (LAGOS MAP, 2022). It is comprised of various towns that are rapidly developing. The populace depends mainly on groundwater as the primary source of consumable water.

Thus, groundwater samples were collected from Ije Ododo, Egbeda, and Ipaja, and samples were coded as in Table 1 below. The three towns were among the most populated towns within the Alimosho local government. These towns are within the geographical locations: Ije Ododo within the Latitude: 6° 27' 11", and Longitude: 3° 23' 44"; Egbeda town within the geographical location Latitude: 6° 35' 32" and Longitude: 3° 19' 22", while Ipaja town is within Latitude: 6° 36' 15", Longitude: 3° 17' 21" with their dense population were all sampled. The map of Alimosho and its environs is shown in Figure 1 below.

Figure 1. *Map of sampling location with Lagos state LAGOS MAP (2022)*

Sample collection and Preparation Techniques

This study is interested in groundwater because it is one of the primary sources of public drinking water. Fifteen groundwater samples per location were collected and grouped according to the locations of the study area. Containers used were washed with dilute HCl to prevent adsorption or loss of radium isotopes around the walls of the sampling containers. Nitric acid was added to the samples collected to eliminate the presence of any organic materials. Then, each sample was filled to a 500 ml capacity polyethylene Marinelli beaker (Abbady, 2004). The counting started after the secular equilibrium was attained by keeping the Marinelli beakers sealed and stored for about 4 weeks. Thereafter, the 226-Ra and 232-Th nuclides (El-Mageed, 2010) and their progenies were assumed to have attained the secular equilibrium for gamma ray measurement. In identifying radionuclides and measuring the concentrations of the samples, a coaxial high-purity germanium (HPGe) detector of serial number 9744, model GC8023, with a relative efficiency of 80% and resolution 2.3 keV full width at half maximum (FWHM) at 1.33 MeV was used. After calibration of the HPGe detector for both efficiency and energy (IAEA, 1989), each sample, after reaching equilibrium, was placed in the detector and counted for 10 hours.

Table 1. *Sampling towns with the coding of samples from different sites*

Towns	Coded
Ije Ododo	JE1 JE2 JE3 JE4 JE5
Egbeda	EG1 EG2 EG3 EG4 EG5
Ipaja	PA1 PA2 PA3 PA4 PA5

Health Risk Assessment Indices

Annual Effective Dose

Doses due to ingestion of waters have been estimated, and this will enable us to assess the contribution of individual radionuclides to public exposure from natural radioactivity. Hence, equation 1 below has been used for the estimation (Gascoyne, 1989; WHO, 2003; WHO, 2017; IAEA, 1996).

$$ED = C_R * I_W * D_C \quad (1)$$

Where *ED* is the effective dose (mSv/year); C_R concentration of radionuclides (Bq/L); I_W intake of water for a person in 1 year and D_C the effective dose conversion factor (mSv/Bq) as in table 2 below

Table 2. *Showing the dose conversion factor of each radionuclide (Sv/Bq) and water consumption*

Radionuclides	Conversion factors (Sv/Bq)			Consumption rate (L/year)			Ref.
	Adults	Children	Infants	Adults	Children	Infants	
^{226}Ra	2.8×10^{-7}	8×10^{-7}	9.6×10^{-7}				(IAEA,
^{232}Th	2.3×10^{-7}	2.9×10^{-7}	4.5×10^{-7}	730	350	250	2002; IAEA,
^{40}K	5×10^{-9}	5×10^{-9}	5×10^{-9}				2002;ICRP, 1996)

Risk of Radiation

Water is consumed; hence, risk is incurred. However, we are interested in estimating the risk incurred from water consumption. Thus, we assumed a linear dose-effect relationship with no threshold, as stated in the International Commission on Radiological Protection (ICRP, 2007; Tawalbeh et al., 2012) practice. According to ICRP, for low doses, the fatal cancer risk factor is 0.055 Sv^{-1}. Equation 2 is used to estimate the risk.

$$R_k = D * R_f * F \quad (2)$$

Where R_k is the cancer risk, D is the dose in Sv, R_f is the risk factor as given by ICPR, and F is the lifetime exposure (Salonen, 1994).

FINDINGS

The activity of 232-Th, 226-Ra, and 40-K was as shown in Table 3 below, with each of the sampling locations including the lifetime cancer using equation 2, for each of the towns of interest in Alimosho (Egbeda, Ije Ododo, and Ipaja). Groundwater supply sources were located from where five samples were collected and analyzed for the activity of the radionuclides.

In Egbeda town sampling, activity of 232-Th is between ND and 0.783 Bq/l; for 226-Ra activity is between 0.691Bq/l and 1.893 Bq/l, while 40-K activity is in the range of 0.664 Bq/l – 6.163 Bq/l. In Ipaja town, 232-Th activity is in the range of ND and 0.642Bq/l; while for 226-Ra the activity is between of 0.286Bq/l and 2.658Bq/l, and for 40-K the activity range of is between 0.234Bq/l and 4.099Bq/l. Also, in Ije Ododo town, the 232-Th activity is in the table3.

Table 3. *Sampling locations and the activity of 232-Th, 226-Ra, and 40-K*

Sample Locations			Average Activity Concentration (Bq/L)		
	Latitude	Longitude	^{232}Th	^{226}Ra	^{40}K
EG1	6° 35' 31"	3° 17' 22"	0.231±0.04	1.893±0.11	0.767±0.24
EG2	6° 35' 32"	3° 18' 29"	ND	0.836±0.07	3.124±0.73
EG3	6° 36' 33"	3° 18' 27"	0.459±0.13	0.691±0.16	1.952±0.84
EG4	6° 35' 31"	3° 17' 32"	0.783±0.32	1.573±0.27	0.664±0.57
EG5	6° 36' 34"	3° 18' 42"	0.237±0.01	0.962±0.43	6.163±0.83
PA1	6° 36' 35"	3° 19' 26"	0.158±0.16	1.185±0.10	2.658±0.14
PA2	6° 36' 36"	3° 18' 31"	ND	0.579±0.21	0.528±0.16
PA3	6° 36' 38",	3° 19' 34"	0.525±0.23	0.286±0.14	0.234±0.09
PA4	6° 35' 46",	3° 18' 38"	0.642±0.07	1.082±0.81	4.099±0.85
PA5	6° 36' 40",	3° 18' 39"	0.494±0.03	0.541±0.23	1.045±0.19
JE1	6° 28' 19"	3° 24' 51"	0.371±0.19	0.353±0.21	0.767±0.20
JE2	6° 27' 32"	3° 23' 48"	0.736±0.21	0.429±0.05	3.734±0.76
JE3	6° 27' 18"	3° 22' 15"	ND	0.345±0.11	1.542±0.10
JE4	6° 27' 11"	3° 22' 48"	0.673±0.17	0.479±0.20	0.976±0.08
JE5	6° 28' 31"	3° 23' 28"	0.228±0.08	0.843±0.27	2.638±0.17

ND implies not detectable range of ND and 0.736 Bq/l, for 226-Ra, the activity is in the range of 0.345 Bq/l and 0.843 Bq/l then the 40-K activity is in the range of 0.767Bq/l – 3.734 Bq/l. The total effective radiation dose in each of the sampling locations for the adults, children, and the infants was shown in table 4 above. For adults in Egbeda township, samples EG1 and EG4 have the highest values of 0.429 µSv/year and 0.455 µSv/year, respectively; in Ipaja, samples PA2 and PA4 have values 0.120 µSv/year and 0.344 µSv/year, respectively.

Table 4. *Total effective radiation dose in each sampling location and the cancer risk*

Sampling locations	Total Effective Radiation Dose (mSv/year)			Annual Cancer Risk	Life Time Cancer Risk
	Adults	Children	Infants	Adult	
EG1	4.285E-04	5.548E-04	4.813E-04	2.357E-08	1.650E-06
EG2	1.823E-04	2.395E-04	2.045E-04	1.003E-08	7.018E-07
EG3	2.254E-04	2.435E-04	2.199E-04	1.240E-08	8.679E-07
EG4	4.554E-04	5.211E-04	4.664E-04	2.505E-08	1.753E-06
EG5	2.589E-04	3.042E-04	2.652E-04	1.424E-08	9.968E-07
PA1	2.784E-04	3.525E-04	3.055E-04	1.531E-08	1.072E-06
PA2	1.203E-04	1.630E-04	1.396E-04	6.615E-09	4.631E-07
PA3	1.475E-04	1.338E-04	1.280E-04	8.110E-09	5.677E-07
PA4	3.439E-04	3.753E-04	3.370E-04	1.892E-08	1.324E-06
PA5	1.973E-04	2.034E-04	1.867E-04	1.085E-08	7.597E-07
JE1	1.372E-04	1.378E-04	1.274E-04	7.548E-09	5.284E-07
JE2	2.249E-04	2.014E-04	1.904E-04	1.237E-08	8.658E-07
JE3	7.615E-05	9.930E-05	8.473E-05	4.188E-09	2.932E-07
JE4	2.145E-04	2.041E-04	1.919E-04	1.180E-08	8.257E-07
JE5	2.202E-04	2.638E-04	2.313E-04	1.211E-08	8.478E-07

Respectively, the Ije Ododo adults' total effective radiation dose is high in samples JE2 and JE5, with values of 0.225 µSv/year and 0.220 µSv/year, respectively.

For Children in Egbeda, the total effective radiation doses were obtained with samples EG1 and EG4 having the highest values of 0.555 µSv/year and 0.521 µSv/year, respectively. In this same group, the children from Ipaja received a total effective dose with the highest values of 0.353 µSv/year and 0.375 µSv/year from samples PA1 and PA4, respectively. However, for the children from Ije Ododo town, the obtained value from sample JE5, at 0.264 µSv/year, is the highest for the town.

The total effective dose of the infants was as in table 4 above, and the highest values obtained from Egbeda, Ipaja, and Ije Ododo sampling locations were from EG4, with a value of 0.466 µSv/year, EG1 value is 0.481 µSv/year, PA1 value is 0.306 µSv/year, PA4 value is 0.337 µSv/year, and for JE4 the value is 0.192 µSv/year, and JE5 is 0.231 µSv/year.

DISCUSSION

The results of the sample activity are comparable with those of the results obtained from other parts of the world as indicated in table 5 below. Thus, the activity of the samples collected are as follows; the mean activity of 40-K from Egbeda, Ipaja and Ije Ododo are 2.534 Bq/l, 1.713 Bq/l and 1.931 Bq/l respectively and these mean values were higher than the mean activity of 232-Th which were 0.342Bq/l, 0.364Bq/l and 0.402Bq/l for Egbeda, Ipaja and Ije Ododo township respectively. 226-Ra mean values from Egbeda, Ipaja and Ije Ododo are 1.191Bq/l, 0.735Bq/l and 0.490Bq/l respectively.

Table 5. *^{232}Th, ^{226}Ra, and ^{40}K activity values in groundwater from other studies in different countries compared to the present study*

Countries	Locations	Average Activity Concentration (Bq/L)			Ref.
		^{232}Th	^{226}Ra	^{40}K	
Present Work (Nigeria)	Egbeda	0.34 - 0.78	0.96 – 1.89	0.66 – 6.16	Present Study
	Ipaja	0.15 – 0.64	0.54 – 1.19	0.23 – 2.66	
	Ije Ododo	0.23 – 0.74	0.35 – 0.84	0.77 – 3.37	
Finland			0.01 - 49		Isam et al. (2002)
Sweden			0.016 – 4.9		Zhuo et al.(2001)
China			0.93 Max		Godoy and Godoy (2006)
Brazil			0.01 – 3.79		Osman et al. (2008)
Sudan			0.007–0.014		(Ahmed, 2004)
Egypt	Qena		0.08		Abd El-Mageed et al. (2013)
	Safaga		0.1 – 0.05		
	Juban	0.3-1.43	2.25-3.45	26.73-43.70	Harb et al. (2013)
	Beer Ahmed	0.15-2.72	0.33-2.67	7.87-19.48	Soto et al. (1988)
Yemen	DaarSaad	0.18-2.31	0.22-2.45	13.07-26.02	
	Ass-Alh	1.07-2.93	2.01-6.55	ND	
Spain			0.02-4		Sgorbati and Forte (1997)
Italy			0.002-1.2		Petitti et al. (2005)

Table 5 above compares the present study of radioactivity in groundwater with similar studies from other parts of the world. Hence, the present study shows that the activity of ^{226}R is greater than that of Italy, Qena, and Safaga, both in Egypt and Sudan, which may be due to the geochemical setting of each region. ^{40}K is lower as reported in this study as compared to the studies from the rest of the world, because of the lower or non-existence of agricultural activities in the area studied. ^{232}Th results show good agreement with the results from the rest of the world (table 5). However, the total annual effective dose has been evaluated, and the results show that in Egbeda, the total effective radiation dose from each sampling site was evaluated for adults, children, and infants because all of them drink and use groundwater every day. Figure 2 below shows the total effective dose due to each sampling site for adults, children, and infants.

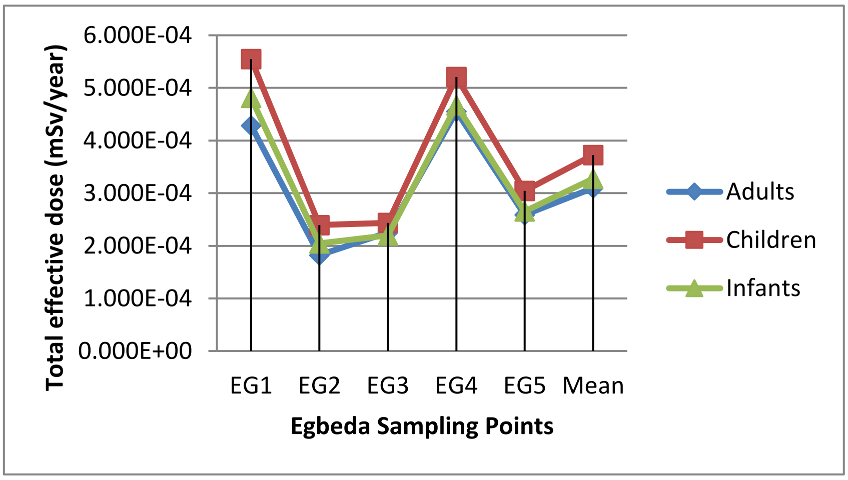

Figure 2. *Total effective dose per sampling of groundwater sources in Egbeda*

The highest values of the effective radiation dose were due to the groundwater from samples EG1 and EG4. Adults receive more from these locations than infants, and infants receive a higher dose than children from these sampling locations. Groundwater samples from location EG2 have the lowest total effective dose in Egbeda. However, the mean value of the individual effective dose is as follows: for adults, the value is 0.317 µSv/year, for children, the value is 0.373 µSv/year, and for infants, the value is 0.328 µSv/year. All other effective doses are below the mean obtained in these sampling locations. Figure 3 below shows the total effective dose from Ije Ododo sampling locations for the adults, children, and infants. Children receive more radiation dose from location JE5 than infants, and the infants have more dose than the adults; however, adults receive more doses from JE2 than the children and the children than in infants.

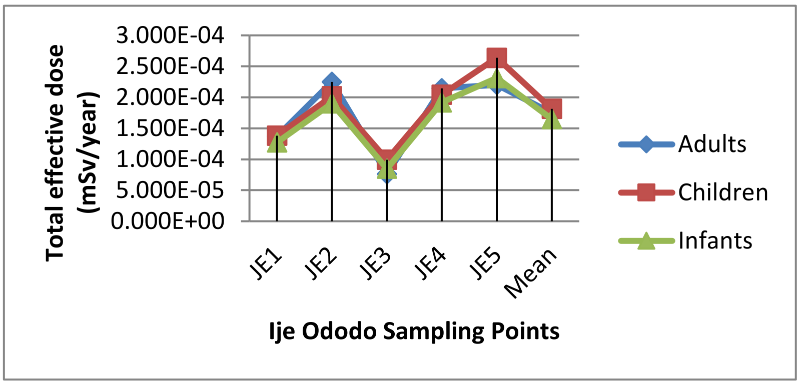

***Figure 3**. Total effective dose per sampling of water sources in Ije Ododo*

The lowest effective dose was received from JE3 in adults, children, and infants. The mean total effective dose received from Ije Ododo by an individual is: adult receives 0.175 µSv/year, children receive 0.181 µSv/year, and infants receive 0.165 µSv/year. Ije Ododo: The total effective dose was generally high in all locations, except for location JE3, which had a lower effective dose compared to the other sampling locations in Ije Ododo. Figure 4 below is the total effective dose from all the sampling locations in Ipaja for adults, children, and the infants.

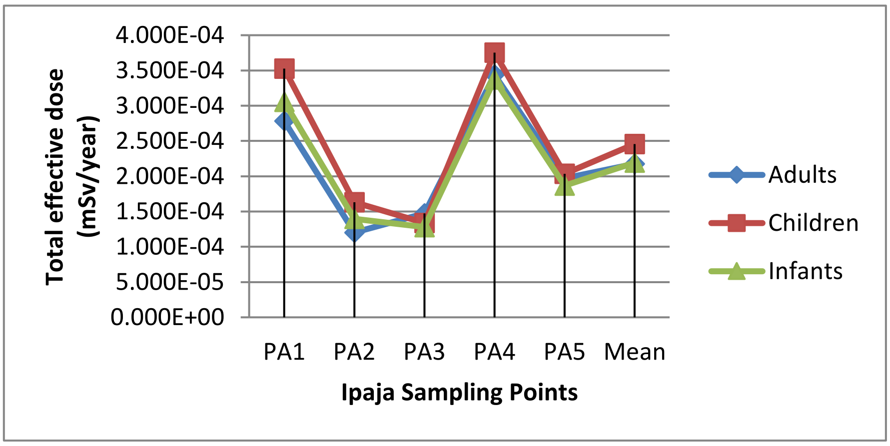

***Figure 4**. Total effective dose per sampling of water sources in Ipaja*

In location PA4, children receive more doses than both adults and infants; this sampling location produces the highest effective dose in Ipaja. Location PA3 produces the lowest effective dose in Ipaja, indicating that infants had the lowest effective dose from this location in Ipaja. The mean total effective dose from Ipaja is 0.218 μSv/year for adults, 0.246 μSv/year for children, and 0.219 μSv/year for infants.

In this study, the total annual effective radiation doses from water consumption for (232Th, 226Ra, and 40K) were highest in EG1, EG4, and PA4, and the lowest was recorded from JE3, PA2, and JE1. For the children, the highest effective radiation dose was obtained from EG1, EG4, and PA4. This trend was also observed in the infants. In addition, just as in the children, the lowest effective radiation doses were from the JE1, JE3, and PA3 sampling locations.

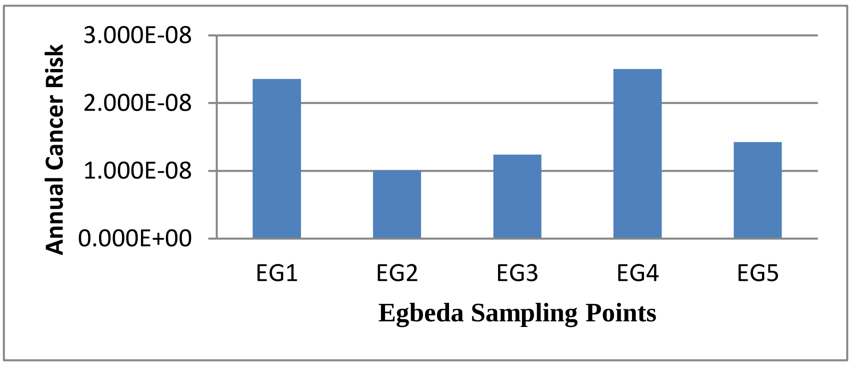

Figure 5. *Annual Cancer risk estimated in each sampling sites from Egbeda*

The annual cancer risks from Egbeda, Ije Ododo, and Ipaja have been evaluated as in figures 5, 6, and 7, respectively. The annual cancer risk in adults from Egbeda township resulting from groundwater consumption is illustrated in Figure 5 above. The groundwater from locations EG4 and EG1 has the highest annual cancer risk compared to locations EG2, EG3, and EG5. More adults are prone to cancer problems in locations EG4 and EG1 annually in Egbeda Township than in locations EG2 and EG3. This also implies that the lifetime cancer risk is higher at these locations with higher annual cancer risk, as indicated in Table 4 above.

The annual cancer risk for Ije Ododo Township is as shown in Figure 6 above. Three locations, JE2, JE4, and JE5, are at a higher annual cancer risk in Ije Ododo, while location JE3 has the lowest annual cancer risk, as shown in Figure 6 above.

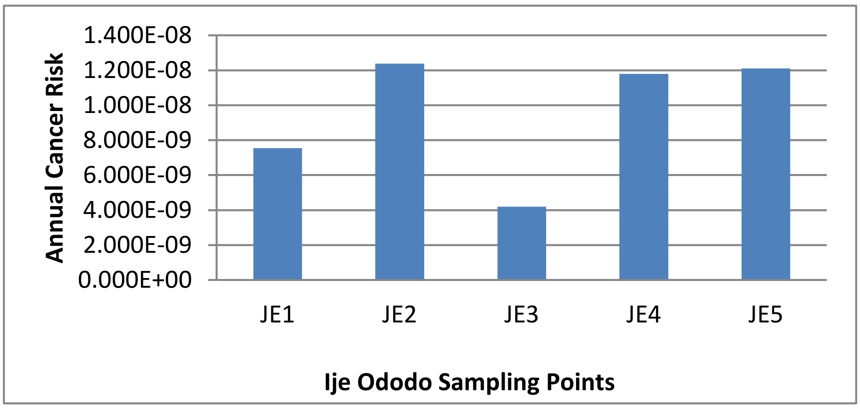

Figure 6. *Annual Cancer risk estimated in each sampling site from Ije Ododo*

The lifetime cancer risk from this town, Ije Ododo, is evaluated in Table 4. These values are for locations JE1, JE2, JE3, JE4, and JE5, with values of 5.284E-07, 8.658E-07, 2.932E-07, and 8.257E-07 and 8.478E-07, respectively.

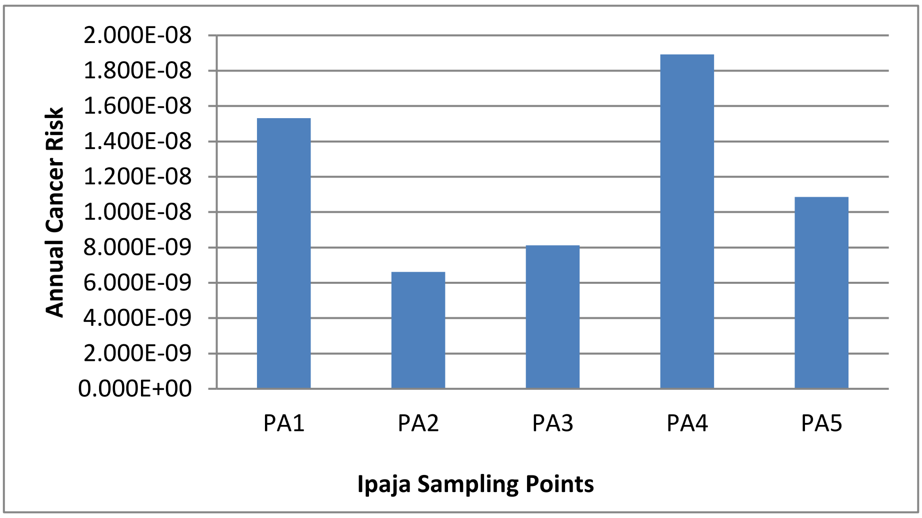

Figure 7. *Annual Cancer risk estimated in each sampling site from Ipaja*

PA4 has the highest annual cancer risk from Ipaja township, as shown in Figure 7 above. PA1 has the second-highest value of annual cancer risk from this location, while the lowest comes from PA2 in Ipaja township. This shows that the lifetime cancer risk is high at locations PA4 and PA1.

CONCLUSION

The Concentration levels of 232-Th, 226-Ra, and 40-K have been determined in groundwater samples collected from different locations in the Alimosho area of Lagos in southwest Nigeria. The contributions of each radionuclide to the estimated total annual effective radiation dose are very significant; however, the mean values obtained from each town (Egbeda, Ipaja, and Ije Ododo) are comparable with similar works from other parts of the world. 40-K may not be relevant for the dose (but it is of interest to determine the concentration as a result of high farming with the use of fertilizer in the area) because the body's potassium content is in homeostatic balance. Hence, the concentration of 40-K in the body is already almost constant, and the diet cannot influence the dose of 40-K.

The estimated total annual practical dose contributions from each location of sampling in adults are: 0.310 µSv/year, 0.218 µSv/year, and 0.175 µSv/year, then for children are: 0.373 µSv/year, 0.246 µSv/year, and 0.182 µSv/year, while for infants: 0.328 µSv/year, 0.219 µSv/year, 0.165 µSv/year, which so that these values are relatively compared to other studies; nevertheless, they are very significant.

Excess lifetime cancer risks for adults have been evaluated for each township, and the mean values obtained are as follows: Egbeda, 1.194E-06; Ipaja, 8.373E-07; and Ije Ododo, 6.722E-07. This means that, per million population, the risks are Egbeda, 1.194E-06; Ipaja, 8.373E-07; and Ije Ododo, 6.722E-07. Therefore, the variations in radiological risk assessments may be due to the geophysical morphology of each location; hence, they are very significant in terms of health issues over a long period for the residents of those areas.

The total effective radiation dose in each of the sampling locations for the adults, children, and the infants was shown in table 4 above. For adults in Egbeda township, samples EG1 and EG4 have the highest values of 0.429 µSv/year and 0.455 µSv/year, respectively; in Ipaja, samples PA2 and PA4 have values 0.120 µSv/year and 0.344 µSv/year, respectively, and the Ije Ododo adults' total effective radiation dose is high in samples JE2 and JE5 with values of 0.225 µSv/year and 0.220 µSv/year, respectively. Children from Egbeda obtained the total effective radiation doses, with samples EG1 and EG4 having the highest values of 0.555 µSv/year and 0.521 µSv/year, respectively. In this same group, the children from Ipaja received a total effective dose with the highest values of 0.353 µSv/year and 0.375 µSv/year from samples PA1 and PA4, respectively. However, for the children from Ije Ododo town, the obtained value from sample JE5, at 0.264 µSv/year, is the highest for the town.

The total effective dose of the infants was as in table 4 above, and the highest values obtained from Egbeda, Ipaja, and Ije Ododo sampling locations were from EG4, with a value of 0.466 µSv/year, EG1, with a value of 0.481 µSv/year, PA1, with a value of 0.306 µSv/year, PA4, with a value of 0.337 µSv/year, and for JE4, the value is 0.192 µSv/year, and JE5 is 0.231 µSv/year.

RECOMMENDATIONS

The areas with high radionuclide activities should be monitored periodically and studied to determine the causes of the activity variation. The water supplied from this area of high effective dose may be stopped for the infants. More data is required for policy making in those areas with high effective annual doses.

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CONFLICT OF INTEREST STATEMENT

It should be on record that there is no conflict of interest.

DATA AVAILABILITY STATEMENT

All data generated or analysed during this study are included in this published article.

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