

Natural Radioactivity of Drinking Water from Drilled Wells and Its Consequent Radiation Dose in Akure South Local Government Area of Ondo State, Nigeria

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Abstract

Natural radioactivity of water sources from drilled boreholes and its consequent radiation dose in Akure South Local Government, Ondo State, have been investigated. A total of forty (40) drilled borehole water samples were analyzed using a high-purity germanium detector (HPGe) to determine ^{226}Ra , ^{232}Th and ^{40}K activity concentrations in them. The activity concentration values varied from 0.170.02 to 0.440.08 Bq/L, 0.370.03 to 1.510.20 Bq/L and 0.420.02 to 7.050.25 Bq/L for ^{226}Ra , ^{232}Th and ^{40}K respectively. The calculated average total annual effective doses for International Commission on Radiological Protection (ICRP) age group 0–1 y, 1–2 y, 2–7 y, 7–12 y, 12–17 and >17 y from the water samples were 0.64, 0.20, 0.17, 0.18, 0.40 and 0.22 mSv y⁻¹ respectively. The total annual effective dose (AED) received by the six age groups as a result of the ingestion of ^{226}Ra , ^{232}Th and ^{40}K in drilled well water investigated were below 1 mSv y⁻¹ to the general public for prolonged exposure as recommended by ICRP. Therefore, these waters are radiologically safe for drinking.

1.0 Introduction

Water is necessary and one of the most valuable natural resources on the globe [1]. According to statistics, over 140 countries of the world declare water as a limited natural resource and a communal worthy essential to life and health. Access to safe and clean drinking water is important for maintaining the good health and well-being of every member of a community [2]. Safe and clean water has several important roles in the human body, including regulating body temperature, maintaining equal osmotic pressure in cells, maintaining healthy skin and helping with digestion [3]. Drilled wells are a common source of drinking water in Ondo state and natural radioactivity is present in these water sources due to the presence of some radioactive isotopes present in the earth's crust and some others introduced into the atmosphere by technological processes such as mining and fertilizer applications and therefore into drinking water supplies. Drinking any contaminated water can cause a variety of health problems including the development of cancers, genetic mutations, cardiovascular and respiratory diseases and other health problems.[4], [5], [6].

Groundwater sources are the most prevalent and highly used resources for drinking and other domestic purposes [7]. With the growing interest in radioactivity and its applications, the quality of the resources could be jeopardized. As such, there is a need to measure human radiation exposure levels due to the consumption of groundwater resources. Furthermore, natural radioactivity in drinking water from wells is a regular occurrence throughout the world. It is

consequently vital to investigate naturally occurring radioactivity in the environment, particularly in groundwater [8]. Well water derived mostly from groundwater may contain naturally occurring radioactive elements such as uranium, thorium, and even radon, which therefore makes them radiotoxic [9].

Radioactive elements such as potassium-40 and those from the thorium and uranium decay series, specifically radium-226, radium-228, uranium-234, uranium-238, lead-210, and polonium-210, can leach into the water as they move through the aquiferous layers and be introduced through water interactions with the surrounding rocks and sediment [10]. The quantities of radioactivity in well water might vary based on factors such as geology, aquifer depth, and flow rate [11], [12]. Exposure to these radioactive elements in drinking water can increase the chance of developing tumours and genetic disorders. As a result, it is critical to test well water for radioactivity and take appropriate procedures to remove or reduce the amounts of these elements if they exceed the world's safe limits.

The main aim of this present research is to investigate the levels of natural radioactivity in drinking water from drilled wells and evaluate the associated radiation doses for human consumption. The objectives of the research are to measure the activity concentrations of Radium, Thorium and Potassium in drinking water samples from drilled wells, to assess the radiological risk associated with the water samples, to compare the results with the international guidelines and standards for drinking water radioactivity and to provide

recommendations for ensuring the safety of drinking water from drilled wells.

Up to this period, known literature on the radioactivity of drinking water from drilled wells in Akure South Local Government Area of Ondo state is limited. The primary goal of this research is to evaluate the rate of radioactivity and the potential health risks associated with drinking water from drilled wells in various locations throughout Ondo state's Akure South Local Government Area. In particular, we will determine the activity concentrations of various natural radioisotopes in drinking water, in addition to the effective dose caused by their intake. Hopefully, the outcomes of this research will provide information to ascertain the safe consumption of the resources in Akure South. Akure South municipality is part of the political centre of Ondo state. It is bounded within $7^{\circ} 15'$ N and longitude $5^{\circ} 05'$ E. The areas towards Ado Ekiti and Idanre are hilly and studded with large granitic outcrops rising to 410 m and 496 m above sea level.

Olatunji *et al.* [13] described the results of radiation experiments undertaken in Nigerian surroundings. Most soil samples have radioactivity levels that are contained in the global mean/average of 33 BqKg^{-1} , 45 BqKg^{-1} , and 420 BqKg^{-1} for ^{226}Ra , ^{232}Th , and ^{40}K , respectively. In places around Nigeria, surface and subsurface water resources for consumption and other domestic activities have increased levels of ^{226}Ra that exceed the global permissible level of 0.01 to 0.1 BqL^{-1} and the acceptable standards suggested by the Global Health Agency (WHO) and the United States Environmental Protection Agency.

2.0 Materials and Methods

2.1 Sample collection

Water samples were collected from Forty (40) distinct machine-drilled wells in spread-out locations throughout Ondo State's Akure South Local Government Area. Samples were collected in the following locations: Oke-Aro, New Oke-Aro, Adofure, Isinkan, Fanibi/Airways, Apatapiti, Alagbaka, Ijapo, Oshinle, Oluwatuyi, Oke-Ijebu, Shagari Village, Aule, and Oda Road. Figure 1 is a map of Ondo state that shows Akure South Local Government with a street tour and the locations of water samples gathered. One litre of water sample was collected in plastic containers from each of the machine-drilled wells. Before sample collection, the plastic containers were rinsed with distilled water to eliminate impurities that can cause contaminations.

2.2 Sample preparation

Immediately after sample collection, acidification with two drops of 1 molar (1 M) dilute hydrochloric acid follows to prevent radionuclide adsorption on the containers' walls. The water samples collected in plastics were as well filled to the brim without any headspace to ensure measuring the exact uniform amount of water samples following modified procedures [14]. The water samples were then brought to the laboratory and placed in 1-litre Marinelli beakers for activity concentration assessment. Screw caps were used to close the beakers, which were then wrapped in plastic tape before being stored for measurement. This procedure ensures that the radon gas is contained within the volume and that daughter atoms remain in the sample.

2.3 Radioactivity measurement and analysis of spectra

The activity contents of the samples have been assessed non-destructively utilizing a computerized gamma-ray spectrometry apparatus containing high-purity germanium (HPGe) (Figure 2). The detector is enclosed within a cylindrical lead shield of 5 cm thickness, an interior diameter of 24 cm and a height of 60 cm. In addition, the detector's design involved insulation in a chamber with

four layers of plexiglas, copper, lead and cadmium to mitigate various radiation dangers. The gamma spectrometer was also connected to traditional electronics via a multichannel analyzer card (MCA) mounted on a desktop computer. MAESTRO-32 software was used to collect and evaluate the data manually, and the natural radioactivity concentrations in the sample were calculated using a spreadsheet (Excel). A counting time of 36000 (10 hours) was used to acquire spectra data for each water sample.

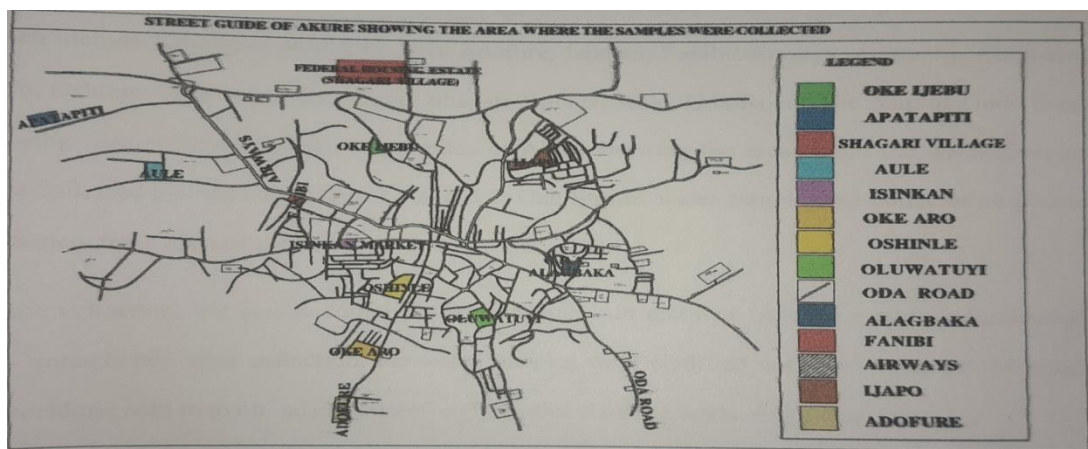


Figure 1: Street guide of Akure showing locations where samples were collected



Figure 2: Diagram of Radioactivity Measuring System

2.4 Calibration of gamma spectrometry system

The detector and its components were calibrated for energy and efficiency so that both qualitative and quantitative investigations could be conducted. The calibrations were accomplished using mixed radionuclide calibration standards following the procedures of [15] in a 1.0 L Marinelli beaker.

Energy calibration was performed by matching the principal gamma-ray peaks observed in the spectrum of the standard to the channel numbers. According to [16], the formula relating the energy and the channel number is expressed as;

$$E = A_0 + A_1 \cdot CN \quad (1)$$

Here, E represents the gamma-ray energy, CN represents the spectral channel number for a given radionuclide, A_0 and A_1 are calibration constants for a given geometry.

2.5 Calculation of activity measurement

The specific activity concentrations (A_{sp}) of ^{226}Ra , ^{232}Th and ^{40}K in BqL^{-1} for water samples were determined using the following expression [17]:

$$A_{sp} = \frac{C_a}{P_r \cdot \varepsilon \cdot T_c \cdot M_s} \quad (2)$$

Where;

A_{sp} – Activity concentration

C_a – Net gamma counting rate (counts per second)

ε – Detector efficiency of the specific gamma-ray

P_r – Probability of gamma emission of energy of the photopeak

M_s – Mass of sample (kg) or volume (L)

2.6 Estimation of Annual Effective Dose

After collection of drinking water samples from 40 distinct machine-drilled wells at strategic locations within the local area of Akure south local government, gamma spectroscopy was used to measure the radiation levels (activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K) in the samples. The annual effective dose (AED) (mSvy^{-1}) was then estimated by taking in account the ingestion of radionuclides in water samples based on the measured activity of the concentration of the radionuclides, the volume of the water intake, which depends on the age of the individual taking the water and the dose conversion factor (SvBq^{-1}) [18]. In this research, the intakes of natural radionuclides were based on the International Commission on Radiological Protection for age groups 0 - 1 year, 1 - 2 years, 2 - 7 years, 7 - 12 years, 12 - 17 years, and > 17 years, with annual average water intake of 200 L, 260 L, 300 L, 350 L, 600 L, and 730 L [19], [20].

The equation used for calculating the annual effective dose (E_d) per person is given by

$$E_d = A_c A_i C_f \quad (4)$$

A_c is the activity concentration of radionuclides in the water samples (BqL^{-1}), A_i is an annual intake of drinking water samples (Ly^{-1}), C_f is the ingestion dose conversion factor for radionuclides (SvBq^{-1}).

The total effective dose D (mSv y^{-1}) to an individual was calculated by adding

contributions from all radionuclides existing in the water samples.

$$D = \sum A_c A_i C_f \quad (5)$$

3.0 Results

3.1 Activity Concentration

The activity concentrations of ^{226}Ra , ^{232}Th and ^{40}K in the water samples are presented in Table 1 and 2. The activity concentration values of ^{226}Ra , ^{232}Th and ^{40}K ranged from 0.17 ± 0.02 to $0.44 \pm 0.08 \text{ BqL}^{-1}$ with an average of $0.28 \pm 0.04 \text{ BqL}^{-1}$, 0.37 ± 0.03 to $1.51 \pm 0.02 \text{ BqL}^{-1}$ with a mean value of $0.39 \pm 0.06 \text{ BqL}^{-1}$, and 0.42 ± 0.03 to $7.05 \pm 0.25 \text{ BqL}^{-1}$ with an average of $2.63 \pm 0.11 \text{ BqL}^{-1}$ respectively. The results showed that the activity concentrations of the radioisotopes in the drinking water samples from drilled wells vary widely.

From the table, ^{226}Ra exhibits a range of $0.17 - 0.44 \text{ BqL}^{-1}$ and with an average of 0.28 BqL^{-1} . Although there are no unique guidelines and regulations for drinking water radium concentration in the country and even in the world. The World Health Organization (WHO) and the Environmental Protection Agency (EPA) had earlier recommended 1000 mBqL^{-1} concentration in drinking water as the safe limit for individuals. This indicates that all the samples are below the recommended limits. ^{232}Th shows a range of $0.37 - 1.51 \text{ BqL}^{-1}$ and with an average of 0.39 BqL^{-1} . These samples are generally higher than those of the ^{226}Ra and some exceed the safe limit recommended by WHO and EPA. Thus, prolonged consumption of samples with higher ^{226}Ra levels may increase the risk of health-related problems. Also, ^{40}K , a primordial radionuclide, exhibits

a range of $0.42 - 7.05 \text{ BqL}^{-1}$ and with an average of 2.61 BqL^{-1} . WHO and EPA suggest that the levels above 1 BqL^{-1} may indicate the presence contaminant but pose no significant health risk itself.

The activity concentration of ^{40}K was the highest, followed by ^{232}Th and ^{226}Ra was the least. The variability in the activity concentration of ^{226}Ra , ^{232}Th and ^{40}K as seen in these water samples could be attributed to well depth, aquifer characteristics, and changes in geological formations within the subsurface that host the aquifers as the locations of these samples are not the same and also depend on the type of activities within the surroundings.

3.2 Annual Effective Dose (AED)

The total AED for the six age groups considered in this study is presented in Table 3 and 4. Using equation 5, the AED results for each age group as obtained from the samples taken from the drilled wells in Akure south local government represent the estimated radiation exposure risk from drinking water for that specific group. The dose conversion factors for the different nuclides and age categories were extracted from the International Atomic Energy Agency (IAEA) basic safety standards. Here's a breakdown of the results for each age group:

Infants (0 - 1 year), the range of AED is $0.36 - 0.96 \text{ mSvy}^{-1}$ with an average of 0.64 mSvy^{-1} . This indicates that infants are exposed to a relatively high radiation dose from drinking water, which is within the safe limits. Children between the ages (of 1 - 2 years and 2 - 7 years) received AED in the range $0.12 - 0.36 \text{ mSvy}^{-1}$ with an average of 0.20 mSvy^{-1} and $0.09 - 0.60 \text{ mSvy}^{-1}$ with

an average of 0.18 mSvy^{-1} respectively. These age groups receive a slightly lower radiation dose than infants and are still within the acceptable range. Adolescents between the ages (of 7 - 12 years and 12 – 17 years) received AED in the range $0.10 - 0.28 \text{ mSvy}^{-1}$ with an average of 0.18 mSvy^{-1} and $0.23 - 0.59 \text{ mSvy}^{-1}$ with an average of 0.408 mSvy^{-1} respectively. Here, the radiation exposure increases slightly but remains relatively low. Adults (> 17 years) and older adults receive a slightly lower radiation dose than children and are still within the safe limits. This observation may be due to decreased level of consumption of water or kidney function by older adults.

In all the water samples, the total AED received as a result of the combined ingestion

of ^{226}Ra , ^{232}Th and ^{40}K from each of the sampled groundwater to the six International Commission on Radiological Protection (ICRP) age groups are below 1 mSvy^{-1} . According to ICRP recommendations, the public should not be exposed to more than an average of 1 mSvy^{-1} of radiation. Therefore, the total populace of Akure South Local Government may be advised to consume these water samples. The water samples are considered safe from a radiological perspective, and the exposure risk may be negligible. The likelihood of cancer due to radiation exposure from drinking water is extremely low. However, the result further shows that age groups 0 – 1 year and 12 – 17 years are most exposed internally to radiation in the water samples.

Table I: Activity Concentration of ^{226}Ra , ^{232}Th and ^{40}K in BqL^{-1} present in water samples at New Okearo, Old Okearo, Isinkan, Apatapiti and Alagbaka Area

Sample Location	Sample ID	Activity Concentration (BqL^{-1})		
		^{226}Ra	^{232}Th	^{40}K
New Okearo	NO1	0.21 ± 0.02	0.87 ± 0.05	0.68 ± 0.04
	NO2	0.29 ± 0.05	0.52 ± 0.03	0.54 ± 0.05
	NO3	0.24 ± 0.02	0.98 ± 0.04	0.62 ± 0.05
	NO4	0.32 ± 0.05	0.50 ± 0.02	0.58 ± 0.03
Old Okearo	OO5	0.30 ± 0.04	0.98 ± 0.05	2.54 ± 0.12
	OO6	0.35 ± 0.05	1.02 ± 0.05	3.04 ± 0.15
	OO7	0.41 ± 0.09	1.08 ± 0.07	5.62 ± 0.20
	OO8	0.38 ± 0.08	0.85 ± 0.02	4.64 ± 0.13
	OO9	0.32 ± 0.08	0.94 ± 0.10	3.24 ± 0.10

Isinkan	IS10	0.19 ± 0.04	0.49 ± 0.03	1.98 ± 0.15
	IS11	0.26 ± 0.03	0.85 ± 0.03	0.85 ± 0.03
	IS12	0.23 ± 0.02	0.52 ± 0.03	3.02 ± 0.15
	IS13	0.28 ± 0.04	0.91 ± 0.07	2.58 ± 0.11
Apatapiti	AP14	0.26 ± 0.02	0.98 ± 0.01	1.95 ± 0.01
	AP15	0.31 ± 0.02	0.82 ± 0.02	2.18 ± 0.02
Alagbaka	AL16	0.22 ± 0.02	0.55 ± 0.05	3.60 ± 0.12
	AL17	0.20 ± 0.01	0.45 ± 0.02	3.40 ± 0.11

The \pm values indicate the variability (standard deviation) in radionuclide activity concentrations.

Table 2: Activity Concentration of ^{226}Ra , ^{232}Th and ^{40}K in BqL^{-1} present in water samples at Ijapo, Oke-Ijebu, Oshinle, Oluwatuyi, Shagari, Aule, Oda-Road, Adofure and F/Airways Area

Sample Location	Sample ID	Activity Concentration (BqL^{-1})		
		^{226}Ra	^{232}Th	^{40}K
Ijapo	IJ18	0.44 ± 0.08	0.93 ± 0.08	3.01 ± 0.08
Oke-Ijebu	OJ19	0.40 ± 0.05	0.95 ± 0.03	3.82 ± 0.12
Oshinle	OS20	0.38 ± 0.05	1.51 ± 0.20	5.20 ± 0.22
	OS21	0.33 ± 0.02	1.14 ± 0.05	3.80 ± 0.11
	OS22	0.30 ± 0.04	1.04 ± 0.04	2.75 ± 0.13
Oluwatuyi	OL23	0.20 ± 0.04	1.39 ± 0.21	0.68 ± 0.05
	OL24	0.23 ± 0.04	0.51 ± 0.10	3.50 ± 0.18
	OL25	0.19 ± 0.06	1.22 ± 0.08	0.85 ± 0.07
	OL26	0.27 ± 0.09	1.05 ± 0.04	1.02 ± 0.08
	OL27	0.18 ± 0.01	0.37 ± 0.03	3.20 ± 0.15
Shagari	SH28	0.30 ± 0.05	0.62 ± 0.08	0.45 ± 0.02
	SH29	0.26 ± 0.02	0.58 ± 0.03	0.46 ± 0.02

	SH30	0.22 ± 0.03	0.66 ± 0.02	0.42 ± 0.03
	SH31	0.28 ± 0.04	0.70 ± 0.10	0.64 ± 0.05
Aule	AU32	0.36 ± 0.04	1.38 ± 0.12	3.63 ± 0.15
	AU33	0.28 ± 0.03	1.02 ± 0.05	2.92 ± 0.18
Oda-Raod	OD34	0.32 ± 0.04	0.54 ± 0.02	1.44 ± 0.05
	OD35	0.29 ± 0.05	0.95 ± 0.04	1.77 ± 0.10
Adofure	AD36	0.17 ± 0.02	0.98 ± 0.04	4.92 ± 0.20
	AD37	0.29 ± 0.04	1.49 ± 0.24	2.58 ± 0.11
F/Airways	FA38	0.29 ± 0.05	1.45 ± 0.15	7.05 ± 0.25
	FA39	0.25 ± 0.02	1.02 ± 0.03	4.12 ± 0.18
	FA40	0.25 ± 0.02	1.02 ± 0.03	4.12 ± 0.18
Range		0.17 – 0.44	0.37 – 1.51	0.42 – 7.05
Average		0.28 ± 0.04	0.89 ± 0.06	2.63 ± 0.11

The \pm values indicate the variability (standard deviation) in radionuclide activity concentrations

Table 3: Estimated total AED (mSv y^{-1}) to age groups from water samples at New Okearo, Old Okearo, Isinkan, Apatapiti qnd Alagbaka Area

Sample ID	0 – 1 year	1 – 2 years	2 – 7 years	7 – 12 years	12 – 17 years	>17 years
NO1	0.62	0.16	0.13	0.15	0.32	0.19
NO2	0.51	0.14	0.10	0.13	0.34	0.16
NO3	0.59	0.18	0.14	0.17	0.37	0.21
NO4	0.53	0.15	0.11	0.14	0.41	0.15
OO5	0.68	0.21	0.18	0.19	0.43	0.23
OO6	0.75	0.24	0.20	0.23	0.48	0.25
OO7	0.87	0.29	0.23	0.25	0.56	0.29
OO8	0.75	0.24	0.19	0.22	0.49	0.23

OO9	0.69	0.23	0.18	0.20	0.44	0.24
IS10	0.40	0.13	0.10	0.11	0.25	0.13
IS11	0.60	0.19	0.31	0.15	0.37	0.20
IS12	0.46	0.15	0.11	0.12	0.30	0.14
IS13	0.64	0.18	0.17	0.19	0.40	0.22
AP14	0.62	0.19	0.16	0.18	0.39	0.22
AP15	0.63	0.20	0.16	0.18	0.41	0.21
AL16	0.47	0.15	0.12	0.14	0.30	0.15
AL17	0.40	0.14	0.11	0.13	0.27	0.14

Table 4: Estimated total AED (mSv y^{-1}) to age groups from water samples at Ijapo, Oke-Ijebu, Oshinle, Oluwatuyi, Shagari, Aule, Oda-Road, Adofure and F/Airways Area

Sample ID	0 – 1 year	1 – 2 years	2 – 7 years	7 – 12 years	12 – 17 years	>17 years
IJ18	0.83	0.26	0.20	0.22	0.55	0.26
OJ19	0.79	0.25	0.19	0.23	0.52	0.26
OS20	0.96	0.33	0.27	0.15	0.59	0.35
OS21	0.74	0.25	0.23	0.23	0.49	0.28
OS22	0.70	0.22	0.19	0.21	0.44	0.24
OL23	0.68	0.22	0.60	0.20	0.39	0.27
OL24	0.62	0.20	0.18	0.17	0.35	0.24
OL25	0.66	0.20	0.17	0.20	0.41	0.20
OL26	0.46	0.16	0.11	0.13	0.30	0.16
OL27	0.36	0.12	0.09	0.10	0.23	0.11
SH28	0.55	0.15	0.13	0.14	0.36	0.16
SH29	0.50	0.14	0.11	0.13	0.32	0.15

SH30	0.46	0.14	0.11	0.13	0.30	0.15
SH31	0.55	0.22	0.12	0.15	0.36	0.18
AU32	0.89	0.29	0.23	0.26	0.55	0.32
AU33	0.68	0.22	0.18	0.19	0.41	0.24
OD34	0.54	0.16	0.21	0.15	0.38	0.17
OD35	0.65	0.20	0.15	0.19	0.41	0.23
AD36	0.55	0.20	0.16	0.17	0.32	0.21
AD37	0.84	0.27	0.23	0.24	0.49	0.32
FA38	0.68	0.22	0.17	0.20	0.43	0.24
FA39	0.91	0.33	0.25	0.28	0.56	0.34
FA40	0.65	0.22	0.19	0.19	0.41	0.24
Range	0.36 – 0.96	0.12 – 0.36	0.09 – 0.60	0.10 – 0.28	0.23 – 0.59	0.11 – 0.35
Mean	0.64	0.20	0.18	0.18	0.40	0.22

4.0 Discussion

The activity concentrations of radionuclides ^{226}Ra , ^{232}Th , and ^{40}K in drinking water samples were below the WHO, EPA, and ICRP recommended limits [21]. This means that the water is safe to drink, and the risk of radiation-induced health impacts is low. The total AED was found to be within the suggested acceptable limit of 1 mSv y^{-1} [22]. The consumption of water samples poses a modest risk of cancer, and the radiation dose is insufficient to induce any other negative health impacts, such as genetic mutations and other biological effects. It can also be argued that the water samples adhere to the criteria and standards established by international health organizations such as the WHO, EPA, and ICRP.

The greatest mean activity concentration of ^{40}K can be a result of radionuclides washed/leached into the groundwater through the excessive application of inorganic fertilizers as the locations have a history of farming activities [23]. High concentrations of ^{232}Th were also detected in the water samples from Shagari and New Okearo. ^{232}Th has the highest activity concentrations in the water samples at these two locations except for samples OL2 and OL5 which have a high concentration of ^{40}K . This could be attributed to geology (the presence of sedimentary rock), mineralogy (diagenesis) and probably hydrothermal activities in the areas [24]. Locations of wells OL2 and OL5 were both presumed to have been used as dumpsites in the past and

therefore the higher activity concentration due to ^{40}K .

The findings of the total AED of drinking water from drilled wells in the Akure South local government area of Ondo state have important implications for radiation safety and, in fact, for public health for all six age groups. The findings aid in determining whether the water samples adhere to radiation safety regulations and drinking water standards. The results further enable age-specification risk assessment, as different age groups has variation in radiation sensitivities.

In general, the total populace of Akure South Local Government may be advised to consume these water samples. However, the result further shows that age groups 0 – 1 year and 12 – 17 years are most exposed internally to radiation in the water samples.

5.0 Conclusion

Gamma-ray spectroscopy was used to determine the activity concentrations of ^{226}Ra , ^{232}Th , and ^{40}K in drinking water from dug wells in Akure South municipality, Ondo State. This study discovered that ^{40}K supplied the greatest activity concentration and ^{226}Ra gave the least activity in drinking water samples. The use of water samples examined in this study resulted in lower internal exposures than the ICRP recommended limit. As a result, drinking water samples from drilled wells in these selected locations in Akure South municipality of Ondo State are radiologically safe for humans of all ages. Also, these water samples are radiologically safe for everyday routine activities such as cooking, bathing, gardening, teeth brushing as well as washing clothes.

Declarations

Ethical approval and consent to participate

Not applicable.

Consent for publication

Not applicable

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

TTA, AA and IOA conceptualized and designed the study. WAA drafted the manuscript and organized it into journal format. OFA and HBA contributed to literature review and grammar check. All authors performed the analysis, analyzed and interpreted the data. All authors read and approved the final manuscript

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