Research Article

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Estimation of Radon Levels and Physicochemical Parameters of Groundwater Sources in Benue South Region of Nigeria

Andrew Ichoja* and Emmanuel O Odoh

Department of Medical Physics, Faculty of Science, Federal University of Health Sciences, P.M.B 145, Otukpo, Benue State, Nigeria.

***Correspondence:**
Andrew Ichoja, Department of Medical Physics, Faculty of Science, Federal University of Health Sciences, P.M.B 145, Otukpo, Benue State, Nigeria, ORCID-000-0003-1838-6602.

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ABSTRACT

Groundwater serves as the leading source of freshwater for both agricultural and domestic applications for the inhabitants of the study areas. The present study was conducted to evaluate the radon concentration levels and assess the quality of groundwater samples collected from different locations of the study communities. A total of thirty (30) water samples (boreholes and streams) were analyzed using a liquid scintillation counter (LSC) located at Ahmadu Bello University, Zaria, Nigeria, along with in situ measurements of the physicochemical properties of the water samples. The activity concentration of all the water samples ranged from 4.81 to 54.4 ± 0.10 Bq/L with an average value of 14.58 ± 2.00 Bq/L, Temperature measurements varied from 26.42 ± 28.43°C with a mean value of 27.55 ± 0.10 ±C whereas the mean hydrogen concentration (pH) value of the water samples was found at 7.21 ± 0.10. The Electrical conductivity value ranges from 417 to 840 µS/cm with an average value of 641.33 ± 19.51 µS/cm while the mean concentration of the annual effective dose for ingestion and inhalation of radon gas was found to be 3.06 ± 0.42 ±Sv/y and 19.80 ± 2.96 µSv/y respectively. The risk order of the annual effective dose for ingestion and inhalation for the three categories of people in all the study areas were of the magnitude infants > children > adults suggesting infants' susceptibility to lung cancer than others The average values of temperature, pH, and electrical conductivity were found within the allowable range set by the Nigeria Standard for Drinking Water Quality (NSDWQ) and the WHO. However, the mean radon level was higher than the USEPA reference limit, while the annual effective dose for radionuclide intake in drinking water was lower than the WHO baseline. It could be concluded that the analyzed water samples are relatively safe for both agricultural and domestic purposes, and it does not pose any immediate health concern to the communities.

Keywords
Groundwater, Annual effective dose, Electrical conductivity, Radon gas, pH.

Introduction
Exposure to natural radioactivity is inevitable due to its dominant presence in our environment, water, air, food, etc. The existence of natural radioactive isotopes in drinking water sources poses a significant health concern to the general populace worldwide. Natural radionuclides emanating from Uranium (U-238), Thorium (Th-232), and Radium (Ra-226) decay series in rocks, soils, as well as the continuous increase in human activities, have been identified as the major sources of radioactivity in groundwater [1].

Because uranium is abundant in the earth's crust and because Rn-222 easily penetrates groundwater, well water in Nigeria may include radon (Rn-222) [2]. Concern regarding the potential health risks associated with dissolved Rn-222 in drinking water sources is currently on the rise. Because the residents and animals in the current study communities mostly rely on well water and untreated water sources (both public and private) for household and agricultural uses as well as for consumption, this situation is more complicated and concerning [3]. The over-dependence of the populace on probable radon-infected drinking water sources is attributed to a lack of access to pipe-borne water sources. The presence in utility water of the radioactive gas such as Rn-222 with a half-life of 3.8 days in the Uranium-238 decay chains, presents two pathways for the exposure of consumers to radiological health risks. This includes the direct consumption of radon-infected water and inhalation of the transferred fraction of radon in air, as the trapped Rn-222 gas emanates readily [4]. High concentrations of Rn-222 and its daughter nuclides in drinking water can cause significant health hazards, including lung and stomach cancer, altered respiratory function, and gastrointestinal tract cancer, among other health consequences [5].

The United States Environmental Protection Agency (USEPA) states that 11 Bq/L is the permissible maximum concentration limit (MCL) of Rn-222 in drinking water. The inhalation danger effect from the spread of waterborne radon gas serves as the basis for this calculation. Furthermore, the host parent of Radon-222, Radium-226, has chemical characteristics similar to calcium and has been identified as the primordial source of radioactivity in food and water. Radium-226, like other radionuclides, has a long half-life of over 1620 years and can remain in the human body for a very long time with its attendant health implications [6]. A minimal radon level in drinking water has been established by a number of health regulatory agencies as a safeguard against radon exposure via water consumption. For instance, the US Environmental Protection Agency (EPA) had set a reference point of 300 pCi (11 Bq/L) [6]. Similarly, an 11.1 Bq/L baseline had been recommended as the safe limit of radon concentration in drinking water by the Euratom Commission [7]. Whereas the World Health Organization (WHO) had proposed 100 Bq/L as a guideline for drinking water quality [8]. Physicochemical properties such as hydrogen ion concentration (pH), temperature, and electrical conductivity (EC) have the potential to affect the quality of drinking water and need to be investigated. Thus, by using physicochemical analysis of the water samples, the current study aims to provide the radiological evaluation of radon levels and assessment of the quality of drinking water sources in the study regions. This is required to establish a baseline for identifying groundwater that may need additional research about internal radiation exposure and its appropriateness for agricultural and human consumption applications.

Method and Materials

Study Area

Benue State is the study area for this investigation. Benue West, North, and South senatorial districts are its three 3 senatorial districts. It is one of Nigeria's thirty-six (36) states and the Middle Belt region. Between latitudes 6°30° North and 8°15° North and longitudes 7°30° East and 10°00° North is where Benue State is located. Benue state's land area is around 34,059 km2, and its population is roughly 2,780,398 and 4,253,541 according to the national population censuses conducted in 1991 and 2006, respectively. Benue South is the study area for this study. It includes nine (9) of Benue State's twenty-three Local Government Areas (LGAs), including Ado, Agatu, Apa, Obi, Oju, and Ogbadibo. Okpokwu, Ohimini, and Otukpo as represented in (Figure 1). Benue the Savanah region in northern Nigeria, is home to the South Senatorial district. The two primary unique seasonal periods in its equatorial environment are the wet and dry seasons. The dry season lasts from November to March, whereas the rainy season lasts from April to October, with an annual total rainfall of between 1120 to 1500 mm. Southern Benue has a normal climate with high temperatures, averaging between 27 and 38 degrees Celsius per year.

Farmers make up the majority of the local population at the study sites, and there may be a substantial radionuclide migration from soil to plants that calls for routine monitoring.

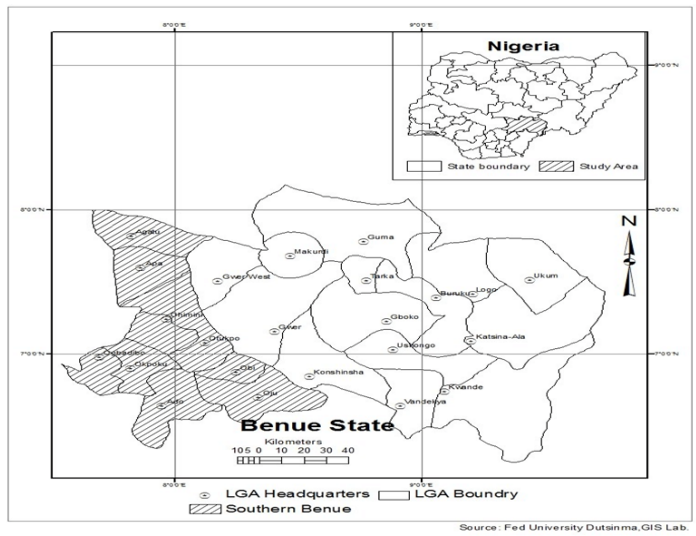

Figure 1: Map of Benue State, adopted from https://idomakingdom.wordpress.com/local-governments/. Showing the various study areas.

A 20ml scintillation vial with a cap, distilled water, 20ml plastic sample collection bottles, a disposable hypodermic syringe (10ml and 20ml capacity) with a 38mm hypodermic needle, surgical hand gloves, an adjustable scintillation cocktail dispenser, Radium solution, Insta-gel, Indelible mark, and ABRO masking tape, Biro, an exercise book, a digital thermometer, a PH meter, and a conductivity meter are among the supplies used to carry out this study.

Sampling and Samples

Simple random methods were used to choose sampling locations for the groundwater under examination in the study areas. The Global Positioning System (GPS) was used to record the precise coordinates. Thirty (30) water samples (from boreholes and streams) were gathered from various locations within the study communities. In order to preserve the water samples' natural ambient characteristics, physicochemical parameters like pH, temperature, and electrical conductivity (EC) were measured at the points of collection (in situ) using a WTW multimeter. The calibration was performed using three standard reference materials for pH 4, 7, and 10 that were outfitted with an auto-sampler and PC from Orion. The probe was inserted into the plastic sampling container to directly measure electrical conductivity.

In order to reduce any potential contamination, the plastic containers used to collect the samples were typically carefully cleaned with distilled water and then dried before being used to collect borehole water samples. A 100 ml airtight plastic jar with about 1.0% air space left for thermal expansion was used to collect the water samples.

To stop the radionuclides from sticking to the container walls, a few drops of hydrochloric acid were added to the samples. To achieve radioactive equilibrium and stop radon loss, a turbulence-free environment was maintained during the sample collection process. To guarantee that only freshwater samples were taken at a time and utilized for the analysis, water samples from boreholes were only taken after the boreholes had been in operation for roughly two minutes. 15 borehole and stream water samples were gathered for the current study from various Obi and Oju LGA areas and placed in 20 ml vials. To prevent the dissolved radon gas from water samples from outgassing, the plastic vials used for surface water (stream) samples were fully submerged in water up to a depth of 15 to 20 cm, filled, and securely sealed before being removed from the water. In order to apply the decay correction factor (DCF) to samples that were older than three days, the date and time of sample collection were recorded, and records of the sample collection time and its radiometric analysis were appropriately preserved.

Sample Preparation and Analysis

A 20 ml scintillation vial containing toluene was filled with 10 ml of Insta-Gel scintillation cocktail after 10 ml of the water sample had been measured and added for sample analysis. To extract Rn-222 in the water phase into the organic scintillator and prepare it for analysis, the mixture was sealed, shaken vigorously, and left to equilibrate for a while. Toluene is present to facilitate the rapid extraction of Rn-222 gas into the organic scintillator and to stop potential leakage during storage and transit. In the same way, a blank vial used to measure background radiation was cleaned, rinsed with distilled water, and stored so that it could be used for background counting.

Before the actual counting, the prepared samples were left undisturbed for at least three (3) minutes to allow the Rn-222 decay product and its offspring to reach equilibrium. The Center for Energy Research and Training has a liquid scintillation counter (Packard Tri-Card, LSA-1000TR) and other equipment. The activity content of radon in water samples was measured at Ahmadu Bello University in Zaria. A liquid scintillation counting analyzer with energy discrimination for alpha particles was used to measure the actual Rn-222 gas for 60 minutes. Before the actual counting, the IAEA 226Ra standard solution was used to calibrate the efficiency of the radon concentration counting apparatus.

Calculation of Radon Parameters

To determine the activity concentration of radon, the decay correction factor equation represented in equation (1) was used to correct the time elapsed between sample collection and analysis [9]

$$A_0 = A_t exp^{-\lambda T} \; and \quad \lambda = \frac{\ln(2)}{t_{\frac{1}{2}}} \qquad [1]$$

where A_0 is the original activity of the samples in Bq/l; A_t is the activity at the sample analysis time, and T is the decay time in days.

The annual effective dose (AED) due to ingestion, as well as AED for inhalation by the inhabitants of the study sites, were calculated from the measured radon concentration in water (A_0) using Equations (2) and (3), respectively [10].

$$E_{ing}^{Rn} = C_W^{Rn} \times W_C \times EDC_{ing} \times 10^{-7} \qquad [2]$$

$$E_{inh}^{Rn} = C_W^{Rn} \times R_W \times F \times O \times D_{inh} \times 10^{-6} \qquad [3]$$

where E_{ing}^{Rn} is the annual effective dose for ingestion of radon in drinking water (Sv/y);C_W^{Rn} is the radon concentration in water in (Bq/l); W_C is the weighted estimate of water consumption in Ly^{-1}; EDC_{ing} is the effective dose coefficient per Becquerel of radon concentration for ingestion dose ($3.5x10^{-6}nSvBqL^{-1}$); R_w is the ratio of radon in the air to radon in water (10^{-4}); O is the occupancy factor (7000 hy^{-1}); F is the equilibrium factor (0.4), and D_{inh} is the dose conversion factor for radon inhalation ($9x10^{-9}nSvhr^{-1}BqL^{-1}$).

Results and Discussion

The World Health Organization (WHO) and the United States Environmental Protection Agency (USEPA) have proposed 100 Bq/L and 11.1 Bq/L, respectively, as the acceptable guidelines for drinking water quality (Table 1). Contains the activity concentration of the analyzed water samples from the various locations in the study areas.

The average value of all the water samples with 14.58 ± 2.00 Bq/L showed an increment of 31.35% higher than the 11.1 Bq/L baseline value. The levels of radon concentration, as displayed in Figure 2, show that the highest radon concentration of 54.40 ± 2.00 Bq/L was found at OJ27−Oju LGA location (Borehole) whereas the minimum value of radon concentration, 4.81 ± 1.82 Bq/L was recorded at OB10−Obi LGA for stream water samples, as shown in (Figure 3). The average values of the activity concentration of radon for boreholes in Oju LGAs were found to be higher than the recommended value of 11.1 Bq/L set by the USEPA. Meanwhile, the mean value of stream water samples for Obi is less than the proposed 11.1 Bq/L. However, the average radon concentration for both Obi and Oju LGAs was far below the 100 Bq/L proposed by the WHO, and hence the consumption of the water samples does not pose any immediate health consequences on the health of the inhabitants. The current result is higher than those reported by [11-14].

Table 1: Sample codes, Water sources, Activity concentration levels, Annual effective dose, and Bulk properties of the water samples.

S/NO.	Water Sources	Rn-Concentrations (Bq/L)	Annual Effective dose (Sv/y)		Bulk Properties		
			Ingestion	Inhalation	Temperature (°C)	pH	Conductivity (µS/cm)
1	Stream	8.20 ± 1.05	1.72E-06	2.07E-05	26.42	7.07	620
2	Stream	5.65 ± 1.05	3.29E-06	3.94E-05	26.72	6.74	540
3	Stream	9.73 ± 1.05	2.04E-06	2.45E-05	26.82	6.81	489
4	Stream	6.36 ± 1.05	1.34E-06	1.60E-05	27.22	7.40	417
5	Stream	11.68 ± 1.05	2.45E-06	2.94E-05	28.12	6.77	570
6	Stream	8.99 ± 1.05	1.89E-06	2.26E-05	28.32	7.04	610
7	Stream	11.19 ± 1.05	2.35E-06	2.82E-05	27.52	7.78	770
8	Borehole	6.87 ± 1.82	1.44E-06	1.73E-05	27.92	7.04	520
9	Borehole	5.37 ± 1.82	1.13E-06	1.35E-05	28.02	6.89	700
10	Borehole	4.81 ± 1.82	1.01E-06	1.21E-05	27.42	6.74	730
11	Borehole	12.50 ± 1.82	5.26E-07	6.31E-06	27.62	8.21	596
12	Borehole	14.68 ± 1.82	3.08E-06	3.70E-05	28.42	7.14	660
13	Borehole	15.30 ± 1.82	3.21E-06	3.86E-05	27.32	6.74	633
14	Borehole	14.07 ± 1.82	2.95E-06	3.54E-05	28.02	7.09	840
15	Borehole	5.57 ± 1.82	1.17E-06	1.40E-05	27.42	6.64	670
16	Stream	9.85 ± 2.07	2.07E-06	2.48E-05	27.42	6.84	710
17	Stream	13.69 ± 2.07	2.88E-06	3.45E-05	26.95	7.34	550
18	Stream	15.98 ± 2.07	3.36E-06	4.03E-05	27.42	7.54	685
19	Stream	8.42 ± 2.07	1.77E-06	2.12E-05	27.35	6.94	760
20	Stream	6.09 ± 2.07	1.28E-06	1.54E-05	27.49	7.57	690
21	Stream	23.10 ± 2.07	4.85E-06	5.82E-05	27.42	6.78	540
22	Stream	17.01 ± 2.07	3.57E-06	4.29E-05	26.82	6.94	620
23	Borehole	15.84 ± 5.61	3.33E-06	3.99E-08	27.52	6.64	670
24	Borehole	19.37 ± 5.61	4.07E-06	4.88E-08	28.42	7.74	640
25	Borehole	33.51 ± 5.61	7.04E-06	8.44E-08	28.40	6.85	440
26	Borehole	40.71 ± 5.61	8.55E-06	1.03E-07	27.92	8.34	770
27	Borehole	54.40 ± 5.61	1.14E-05	1.37E-07	27.72	8.43	540
28	Borehole	15.39 ± 5.61	3.23E-06	3.88E-08	26.90	7.19	690
29	Borehole	13.90 ± 5.61	2.92E-06	3.50E-08	27.62	7.94	760
30	Borehole	9.21 ± 5.61	1.93E-06	2.32E-08	27.82	6.98	810
Average		**14.58 ± 2.00**	**3.06E-06±4.23**	**1.98E-05±2.96**	**27.55±0.10**	**7.21±0.09**	**641±19.50**

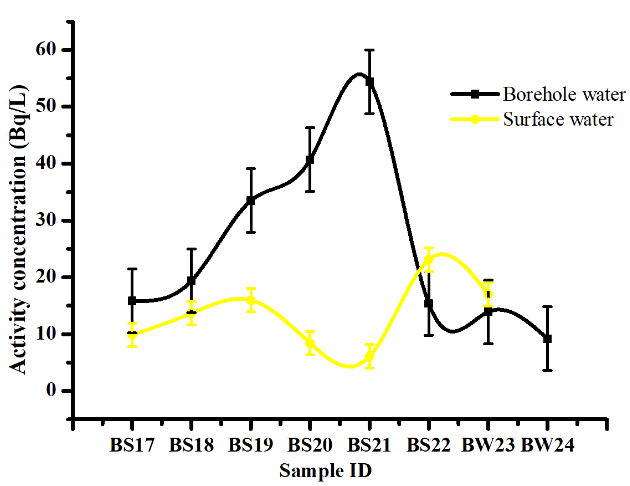

Figure 2: Radon concentration level for Oju LGAs.

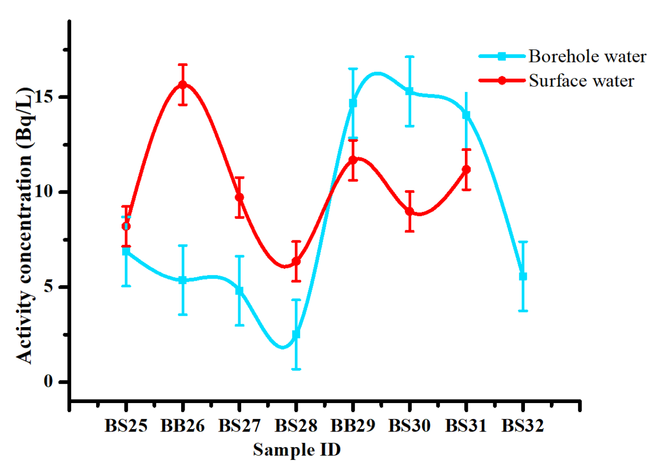

Figure 3: Radon concentration level for Obi LGAs.

(Figures 4 and 5) represent the annual effective dose due to ingestion of radon radionuclides for adults, children, and infants in water samples from the study locations. Generally, the annual effective dose for adults from the intake of radon radionuclides in drinking water varied significantly from 0.53 − 11.4 ± 0.42 µSv/y with the average value of 3.06 ± 0.42 µSv/y and 0.02 − 58.2 ± 2.96 µSv/y with an average value of 19.8 ± 2.96 µSv/y due to inhalation of radon gas from the water samples, respectively. The average value of the annual effective dose due to ingestion for Oju and Obi LGAs is of the order: infants > Children > Adults [10,15,16]. This implies that infants consuming water samples in these communities are prone to higher risks of gastrointestinal diseases than children and adults.

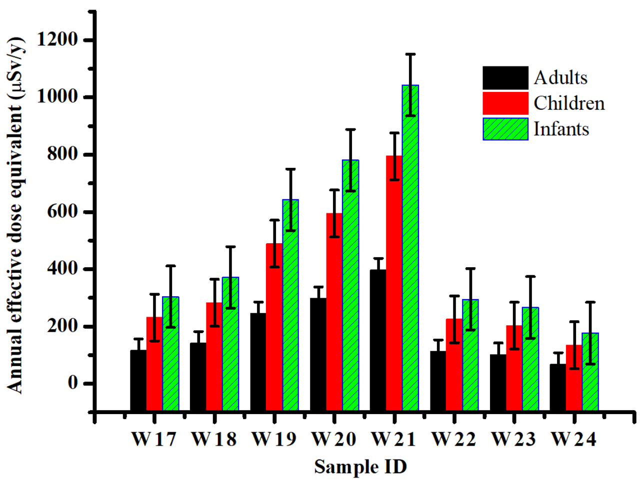

Figure 4: Annual effective dose due to ingestion for Oju LGAs.

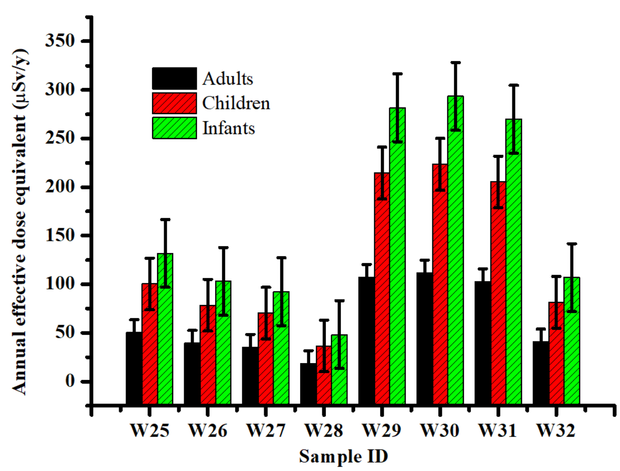

Figure 5: Annual effective dose due to ingestion for Obi LGAs.

Comparing the annual effective dose for ingestion and inhalation, as represented in (Figures 6 and 7), indicates higher values of dose due to inhalation than those of ingestion. This again suggests a higher occurrence of lung cancer compared to stomach cancer arising from the consumption of the water samples. The observed annual effectiveness due to radon intake in water samples was found to be higher than that reported by [17-19].

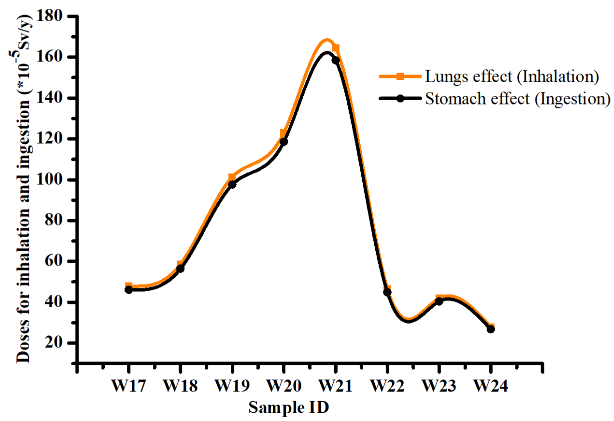

Figure 6: Comparison of annual effective dose due to ingestion and inhalation for Oju LGAs.

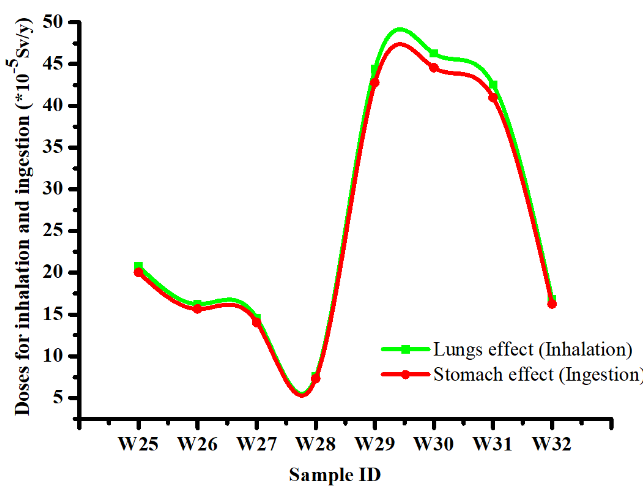

Figure 7: Comparison of annual effective dose due to ingestion and inhalation for Obi LGAs

Physicochemical parameters such as temperature, pH, and electrical conductivity of the water samples were analyzed and reported in (Table 1). The temperature ranged from 26.42 to 28.43 ± 0.1°C with an average value of 27.55 ± 0.1°C. The Nigeria Standard for Drinking Water Quality (NSDWQ) recommends a temperature value of about 27 °C [20]. The pH, as a measure of ion concentration of the water samples, indicates whether the water is acidic or alkaline. In the present study, the pH ranges from 6.64 to 60 8.43 ± 0.09 with an average value of 7.21 ± 0.09. The recommended pH range according to the Nigerian Standard for Drinking Water Quality is 6.5 − 8.5. This study indicates that the pH values of the water samples are within the acceptable limit set by the NSDWQ and WHO, and therefore, the analyzed water samples were neither acidic nor alkaline and safe for consumption.

The electrical conductivity (EC) of the analyzed water samples varied from 417 to 840 ± 19.50 S/cm with an average value of 641.33 ± 19.50. An average value of 640 µS/cm is recommended by the NSDWQ and WHO.

Electrical conductivity is a measure of the water salinity, where a high value of EC in drinking water influences the water taste and could be injurious to human health. Approximately 47% of the water samples have their EC values lower than 640 µS/cm and 53% had an EC value higher than the recommended average EC value.

Electrical conductivity is a valuable determinant for the classification of all underground water for drinking and irrigation purposes. All water samples with an EC value in the range of 250 µS/cm) to 750 µS/cm are classified as good water, while water samples with an EC content between 750 µS/cm and 2,250 µS/cm are permissible water. The result of the physicochemical analysis revealed that the analyzed water samples are suitable for drinking [21,22].

Conclusion

The activity concentration levels and the physicochemical properties of 30 water samples collected from different locations in Obi and Oju LGAs, Nigeria, were determined. The average values were 14.58 ± 2.00 Bq/L, 3.06 ± 0.42 µS/y, 19.8 ± 2.96 µS/y, 27.55 ± 0.1°C, 7.21 ± 0.42 0.09 and 641.33 ± 19.51 µS/cm for radon levels, radon activities for ingestion and inhalation, temperature, pH and electrical conductivity respectively. Approximately 43% of the water samples have their radon levels below 11.1 Bq/L, and 53% higher than the guideline proposed by USEPA. The risk order of activity concentration for ingestion and inhalation for the three categories of people was of the magnitude infants > children > adults, suggesting infants' susceptibility to lung cancer than others.

Physicochemical analysis of the water samples revealed that the mean temperature, pH, and electrical conductivity values were within the limits specified by the NSDWQ and WHO, respectively. In conclusion, therefore, the preliminary results showed that the water samples could be considered safe for consumption and do not pose any immediate public health concerns to the people of the study locations.

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