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Determination of Radon Concentration in Selected Groundwater Sources in Obajana, Kogi State

***Nakale, J. A., Ayua, K. J., Uloko, F. O., Haruna, B. S.**

Department of Physics, Federal University Lokoja, P.M.B. 1154, Lokoja, Kogi State.

*Corresponding author's email: jonathanrex45@yahoo.co.uk

ABSTRACT

Increasing incidences of Radon concentration in groundwater has gained ascendency as a key challenge for radiation safeguards in recent years, especially as radon is a known carcinogenic gas in humans and is present in some groundwater sources. Obajana as an important industrial town in Kogi state lies in geologic formation that may be sources of radon pollution for groundwater. This study was therefore conducted to appraise the activity concentration of Radon-222 in water accessible from hand-dug wells and boreholes within the study location. Seven (7) samples from hand-dug wells and three (3) from boreholes were obtained from the area using standard sampling collection and preparation methodology and analyzed in the laboratory by means of liquid scintillation counter (LSC). Radon activity concentration and annual effective dose for the study area were evaluated empirically. Findings showed the mean Radon concentration of the well and borehole water to be 24.89 BqL^{-1} and 26.66 BqL^{-1} respectively, which is above the upper tolerable limit of 11.1 BqL^{-1} by USEPA (USEPA, 1991) and the world average value of 10 Bq/L by UNSCEAR and WHO (UNSCEAR, 1998; 2000; WHO, 1993; 2004; 2008; 2009; 2011). Furthermore, the mean Annual Effective Dose (AED) due to human intake of Radon-222 were found to be 0.18 mSv/y and 0.19 mSv/y in well and borehole water respectively. The mean annual effective doses for water samples from both sources were found to be above WHO recommended reference level of 0.10 mSv/y (WHO, 1993; 2004; 2008; 2009; 2011) for intake of radionuclide in water. These results have implication for Obajana residents as they are not safe from radiologic related health hazards and long-term consumption of groundwater without proper prior treatment should be discouraged within the study area.

Keywords:
Radon concentration,
Groundwater,
Scintillation,
Effective dose,
Health hazards.

INTRODUCTION

Water is significant in the daily activities of humans and plays a vital role in the conservation and sustainability of the ecosystem as a whole; it is the major constituent of the earth and covers more than 75 % of the earth surface. Water is so important that it is impossible for living organisms and plants to survive without it. Its importance includes applications for agriculture, transportation and power generation (Oni et al. 2021).

Water has a direct link to every aspect of human activities; therefore it is important to have access to safe and clean water and in sufficient quantity. Accessibility to adequate and good quality water in developing countries such as Nigeria is a great challenge, due to deficient surface water sources and acute pollution of rivers and streams (Falebita and Ayua, 2022) making it necessary for people to depend on unsafe surface and groundwater resources. Pollution of water resources could be from many sources including anthropogenic factors, discharge of industrial effluents and wastes, seepage of contamination plumes from dumpsites and natural radioactivity (Nevas, et al.2000; Umar et al. 2012; Al-alawy and Hassan, 2018; Efenji et al., 2022).

This research work was carried out in order to resolve the activity concentration of radionuclide such as Radon-222 in water accessible from hand-dug wells and boreholes within the study location and thus increase awareness on radon as a significant potential threat to potable water sources. Accumulative incidences of radio hazards has made it obligatory to advance investigations of radon concentration in groundwater as increasing incidences of Radon concentration in water due to natural radioactivity has gained ascendency as a key challenge for radiation safeguards in the recent years. (Al−Masri and Blackburn 1995).

The study location is in Obajana town, Oworo district of

Lokoja Local Government Area, Kogi State. Obajana lies within longitudes 6°24'E and 6°27'E and latitudes 7°54'Nand 7°56'N (Figure 1) and covers an area of approximately 696.81 km^2 (Musa,et al. 2018). The area is characterized by rainy and dry seasons. The vegetation of the study area is guinea savannah consisting of tall grasses, low trees and shrubs.

Geologically, the study area is located within the Benin-Nigeria shield, positioned in the pan –Africa mobile belt sandwiched between the primordial West African basement and the Congo Craton and thought to have originated in the late Precambrian to early Paleozoic orogeny (Musa, et al, 2018). The study location comprises both basement complex rocks particularly the migmatite gneiss complex, banded iron formation, quartzite and marble and sedimentary rocks consisting of sandstones and alluvial deposits to the south (Figure 2).

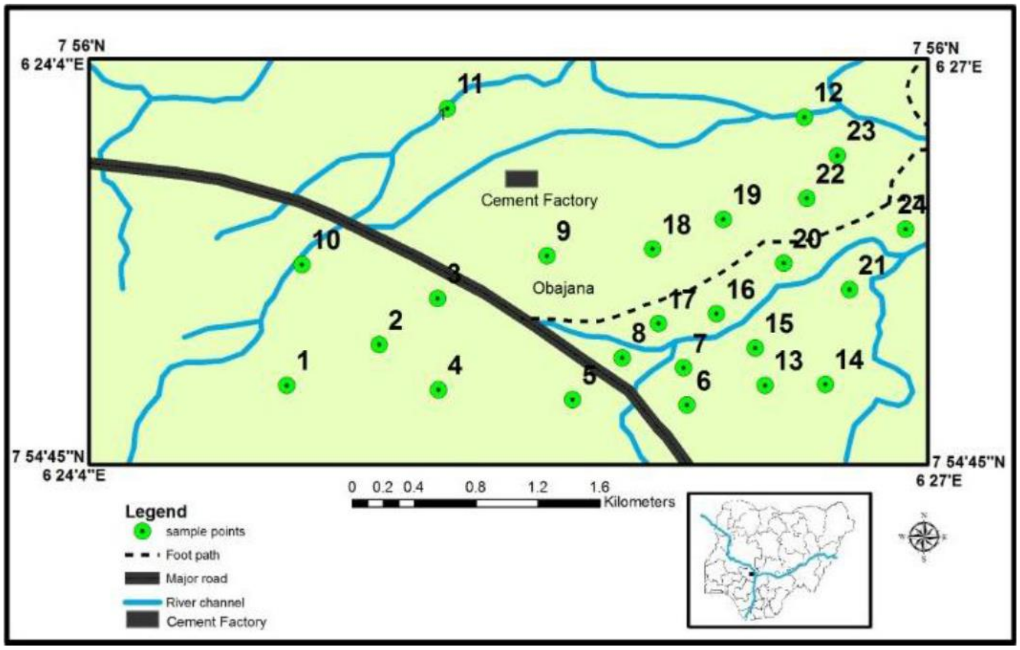

Figure 1: Administrative Map of the Study Area

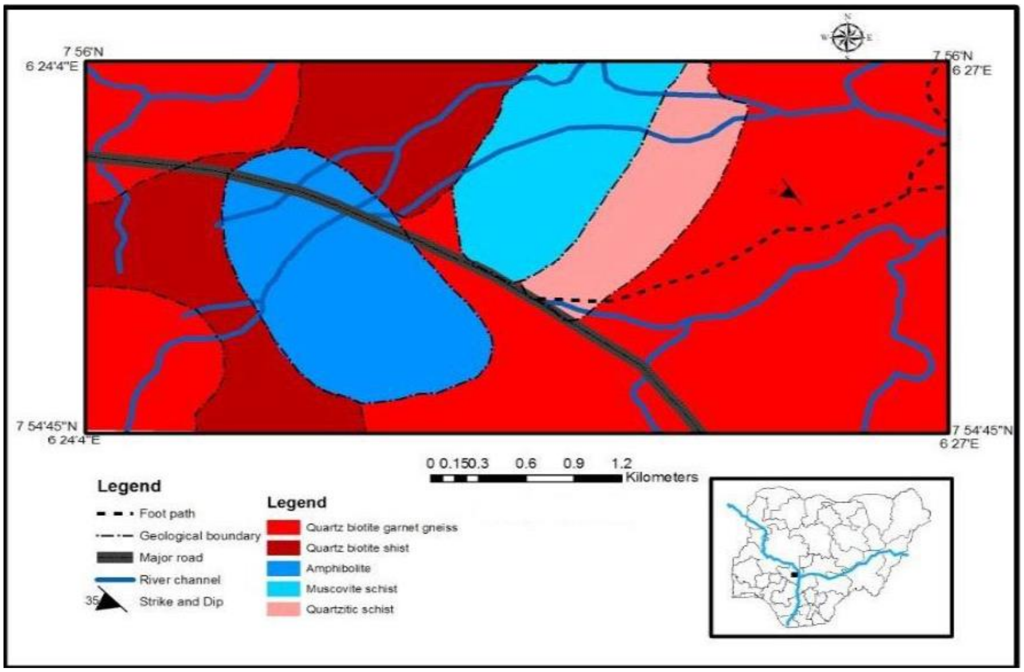

Figure 2: Geologic Map of the Study Area

Obajana is an important industrial hub in Kogi State with industries like the Dangote Cement Factory and has other important commercial activities like mining for limestone and marble; it is an important link to the western parts of Nigeria from North-central Nigeria and this has precipitated an increase in population due to increasing commerce. The population growth has further taxed the limited water resources and the inhabitants have resorted to drilling boreholes and shallow hand dug wells to improve water supply. In sub Saharan Africa, groundwater is the preferred source of drinking water (Falebita and Ayua, 2022; Jika and Mamah, 2014). This is typical because, it is assumed to be cleaner and easier to treat than surface water. Therefore, numerous wells have been dug to that effect.

Groundwater is however not completely safe from pollutants. Anthropogenic activities and elevated concentrations of radioactivity can contaminate groundwater. The radioactivity of groundwater varies greatly in nature and occasions several chemical components that might cause a variety of health issues (Al Masri and Blackburn, 1995; Fasea, 2013; 2015). This has necessitated the International Commission on Radiological Protection (ICRP) to issue recommendations and guidelines on all aspects of ionizing radiation protection (ICRP, 1979), which are published in the Annals of the ICRP, the commission's official scientific magazine.

Although the study area has no specific manufacturing industries that use radioactive materials, natural radioactivity exists in the earth and its contents. Naturally Occurring Radioactive Materials (NORM) is widely distributed throughout many geological formations (Mehade et al. 2014; Adabanija et al, 2020; Efenji et al., 2022) and are a source for the contamination of groundwater resources. The study area, located primarily in a basement complex geology with reported elevated concentrations of natural radioactivity (Adabanija et al, 2020), and with active mining activities is a veritable locality to establish a *prima facie* case for radon concentration in groundwater sources (Ibeanu, 1999; Ifeoluwa and Obed, 2014).

Radon is a radiant naturally occurring odorless, colorless and tasteless radioactive gas. It is formed by decay of uranium (^{238}U) arising directly from decay of radium (^{226}Ra) (Alvarado 1995; Avwiri et al 2016). There are 3 major isotopes of Radon including ^{222}Rn, ^{220}Rn and ^{219}Rn. It has density of about 7.5 times the density of air. Amongst the naturally occurring radionuclide, radon is one of the most highly volatile and it readily dissolves in water and quickly spreads through gases and vapor **(** Ghoshal, 2006; Khattah et al, 2018**).** The concentration of Radon 222 is as a result of radium associated with rock and soil. The radium then decays to form radon and this diffuses through the soil and into groundwater thus contaminating it (Isam, 2003). Also, mining activities for marbles and limestone carried out in Obajana may expose surface waters sources to higher concentrations of radioactive elements which may then percolate into aquifers and shallow hand dug wells (Laith et al. 2011). The water in shallow wells may also be contaminated by radioactivity from surface water run-off from erosions.

The presence of Radon in soils, rocks and waters can be exploited for the determination, identification and prediction of natural hazards, geologic structures, hydrological researchers etc. However, elevated concentration of Radon in drinkable water and indoor spaces pose a major health hazard for humans because of its carcinogenic effects **(**Isam, 2003; Lu et al. 2012). The study is therefore significant in that it evaluates the radon concentration in groundwater within Obajana town with a view to determining the safety of such water sources for drinkability.

MATERIALS AND METHODS

The materials used include: Disposable hypodermic syringe (20 ml, 10 ml capacities), surgical gloves, Scintillation cocktail. Scintillation vials (20 ml capacity) with polyethylene inner seal cap liners, Distilled water, Ink and masking tape, Liquid scintillation counter and GPS (global positioning system)

The most commonly used liquid scintillation vial is 20 ml which is intended to hold 10ml of cocktail. Smaller sizes include 6, 7, 8 ml. There are two major types of LSC vial and they include. Glass (borosilicate) LSC vial: due to its transparency, it allows visual inspection of cocktail for color, in homogeneity, etc. Plastic (polyethylene) LSC vial: they are less expensive, lower background but permeable to toluene, xylene and benzene Liquid scintillation counting (2011)

Sample Collection

A total of 10 groundwater samples consisting of 7 (seven) samples of hand-dug well water and 3 (three) samples of borehole water were collected from the study area (Obajana) and transferred to Centre for Energy Research and Training (CERT) ABU Zaria for investigation. The samples were collected in 60 ml plastic bottles and not glass bottles because glass bottles undergoes chemical reaction to absorb metals and hence would record high errors in the result. The bottles were brimmed. And a drop of hydrochloric acid was dropped on the water to stop any form of reaction from taking place, and was analyzed within the 4 to 5 days so as to maintain the sample composition (Knoll, 2000).

Sample Preparation/Analysis

The procedures employed for sample preparation and analysis was as reported by Garba et al, (2021). Plastic bottles were employed to collect the samples from the study area because it does not absorb metals unlike glass bottles. The samples were transferred immediately to the laboratory at CERT for analysis. Liquid scintillation vials were prepared containing 10 ml of liquid scintillation solution. 10 ml of each sample was carefully drawn from the sample bottles into a disposable syringe in order to minimize out-grassing the samples by aeration. The samples in the hypodermic syringes were immediately transferred to the liquid scintillation vials containing 10 ml scintillation solution by injecting the sample at the bottom of the vial, beneath the immiscible scintillation solution. The hypodermic needle was thereafter removed carefully from the vial and the cap of the vial was immediately closed tightly. The vial was shaken thoroughly for ^{222}Rn to be extracted from the water phase to the organic scintillator solution due to its greater solubility in organic liquids. The vials were left for about three (3) hours to allow for in-growth of the short lived decay product of ^{222}Rn and also for attainment of secular equilibrium. The background samples were primed by dissolving 10 ml of the scintillation solution in 10 ml of distilled water. The calibration solution was likewise made ready by dissolving 10 ml of IAEA standard ^{226}Rn sample in the 10 ml distilled water.

Liquid scintillation counter (Tri-carb-LSA1000) at CERT was used to analyze the already prepared samples. IAEA ^{226}Ra standard solution was used in calibrating the liquid scintillation counter prior to the analysis.

The calibration sample solutions and the background were measured over the same spectral range and for the same counting period which was 60 minutes and recorded in counts.min^{-1}. ^{222}Radon and its short-lived daughters emit a total of 5 radioactive particles (Three alpha particles and two beta particles) per every dis-integration of ^{222}Rn. All these five emitted particles were used to detect and access the level of radon in water because a secular equilibrium was established between ^{222}Rn and the decay daughters. Hence, the overall efficiency of the detection is 500 %. Considering the sample volume, the total and background count rate, decay time (the time between sample collection and counting) and the detection efficiency, ^{222}Rn activity concentration was evaluated.

The ^{222}Rn concentration in the groundwater samples (Well and Borehole water) was determined using the equation below after Al-alawy and Hassan, (2018):

$$\text{Rn} = \frac{100 \times (N_S - N_B)e^{\lambda t}}{60 \times 5 \times 0.964} \qquad (1)$$

Where;

Rn indicates ^{222}Rn concentration at the time of sample collection (BqL^{-1}); Ns is the sample total count rate (count.min^{-1}), λ is ^{222}Rn decay factor (1.26×10^{-4} min^{-1}), t is the elapsed time between sample collection and counting (4320 minutes), 100 is a conversion factor from per 10 ml to per liter (L^{-1}), 60 is a conversion factor from minutes to seconds, 5 (500%) is the number of emission per disintegration of ^{222}Rn (three alpha and two beta, assuming 100% detection efficiency for each) and 0.964 is the fraction of ^{222}Rn in the cocktail in a vial of 22 ml total capacity, assuming it contains 10 ml cocktail, 10 ml water and 2ml air.

For calculating the annual effective dose of Radon-222 through drinking water, an equation as proposed by the United Nation Scientific Committee on the Effects of Atomic Radiation (Isam, 2003) was used.

$$E = K \times G \times C \times T \times 1000 \qquad (2)$$

Where E = Annual effective dose (mSvy^{-1}); K = Conversion coefficient concentration of Radon-222 (SvBq^{-1}); G = Daily Consumed Water (L/d); C = Concentration of Radon-222 (BqL^{-1}); T = time span of water consumption (365 days); 1000 = conversion coefficient of Sv to mSv

RESULTS AND DISCUSSION

Results

The results for the analysis of ten water samples showing their respective counting time in minutes (sixty minutes 60), count per minute for the various channels and spectral index for the samples is presented as Table 1.

Table 2 and Figure 3 shows the evaluated radon activity concentration and the annual effective dose rate for groundwater obtained from hand-dug wells while Table 3 and Figure 4 shows the same results for groundwater obtained from drilled boreholes. A comparison of the annual effective dose for boreholes and hand dug wells is presented in Figure 5 below.

Table 1: count per minute for the various channels and spectral index for the samples

S/N	Sample Description	CPMA/K	CPMB/K	CPMC	SIS
1.	A Well	72.95	21.58	94.63	35.930
2.	B Well	69.37	26.53	96.05	38.622
3.	C Well	62.30	18.15	80.50	34.828
4.	D Well	65.70	22.02	87.87	39.331
5.	E Well	64.57	20.53	85.23	38.192
6.	F Well	72.43	26.78	99.38	41.757
7.	G Well	68.75	26.17	95.23	41.972
8.	H BH	71.57	22.22	93.88	37.454
9.	I BH	70.75	22.97	93.87	36.904
10.	J BH	68.83	21.63	90.48	38.024

Table 2: Results of Analysis of count rate, Radon Concentrations in (Bq/L) and their corresponding Annual Effective Doses (AED) in (mSv/y), for groundwater (well-water)

/N	Sample Description	Sample (WW)	Long.	Lat.	Rn (BqL^{-1})	AED (msvy^{-1})
1	A	WW	6.245350	7.546570	24.47	0.2078
2	B	WW	6.253454	7.566850	23.74	0.1733
3	C	WW	6.246968	7.547965	24.47	0.1786
4	D	WW	6.276523	7.56321	24.21	0.1767
5	E	WW	6.241223	7.542375	24.41	0.1782
6	F	WW	6.273428	7.566875	25.30	0.1847
7	G	WW	6.277141	7.546883	23.60	0.1723

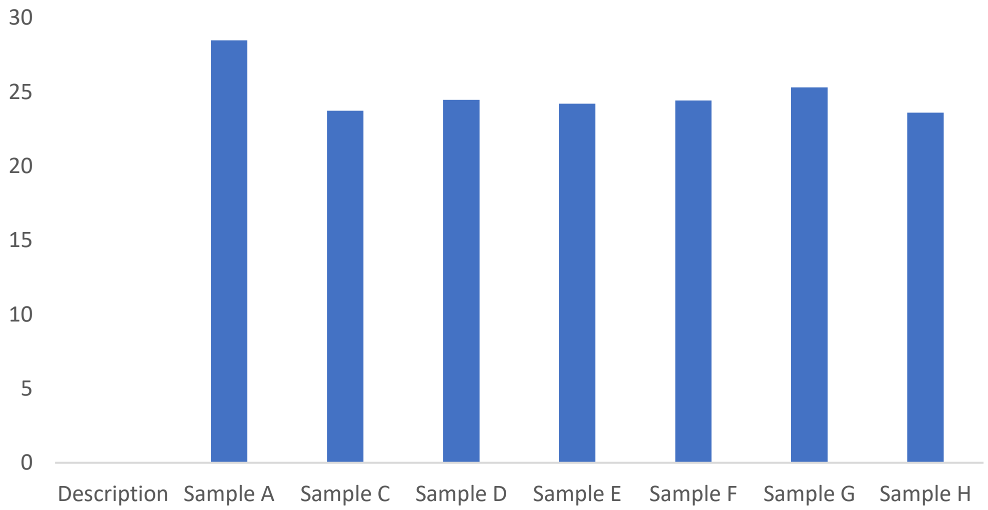

Figure 3: Radon Concentration in well water

Table 3: Results of Radon Concentrations in (BqL^{-}) and their corresponding Annual Effective dose (AED) for groundwater (Borehole-water)

S/N	Sample Description	Sample Source (BW)	Longitude	Latitude	Rn (Bq/L)	AED (mSv/y)
1	H	BW	6.241830	7.546875	26.16	0.1910
2	I	BW	6.267194	7.561416	27.35	0.1997
3	J	BW	6.241830	7.541 055	26.48	0.1933

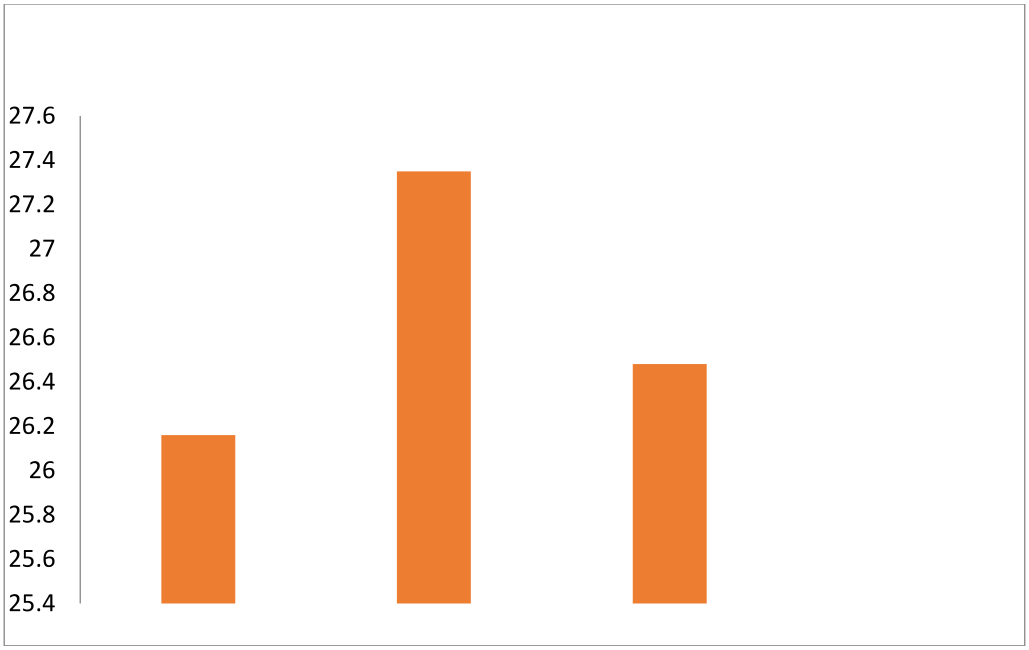

Figure 4: Radon Concentration in Borehole Water

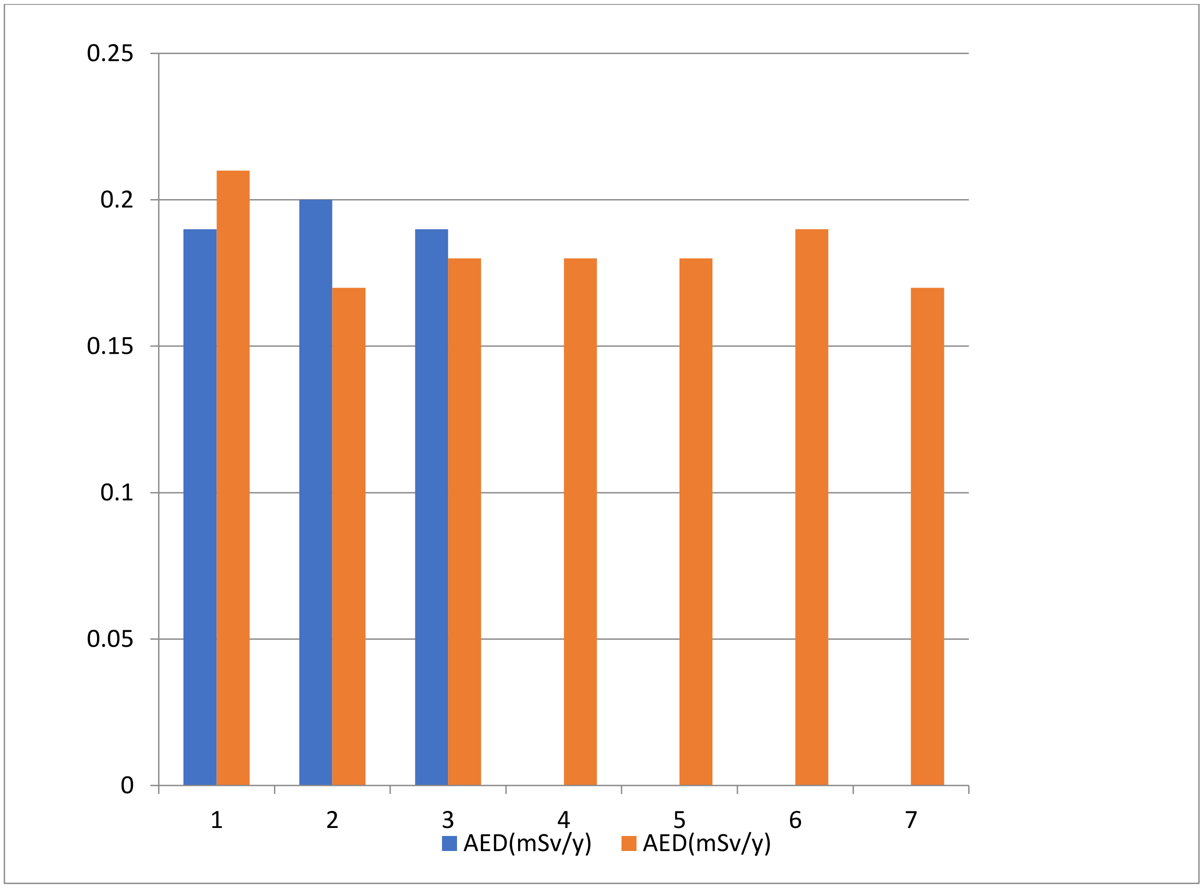

Figure 5: Comparison of the Annual Effective Dose of Borehole and well water in msv/y.

Discussion

From Table 2 above, the concentration of ^{222}Rn varies from a minimum value of 23.60 BqL^{-1} obtained from sample G to 25.30 BqL^{-1} evaluated at sample F. The mean value of 24.89 BqL^{-1} was calculated for the entire study area. Our findings indicate that the activity concentration of radon measured in all the water samples obtained from hand-dug wells within the study area were above the maximum contaminant level of 11.1 BqL^{-1} which was set by USEPA (USEPA, 1991). This is implies that residents who make use of this water source are vulnerable to severe health hazards. However, the mean concentration of ^{222}Rn was found to be lower than the recommended guideline level of 100 BqL^{-1}set by WHO (2004).

Table 3 and Figure 4 show the result of the analysis of ^{222}Rn concentration in borehole water samples collected from three locations. The activity concentration of ^{222}Rn ranged from 26.16 $BqL^{-1}$to 27.35 $BqL^{-1}$with a mean value of 26.66 BqL^{-1}. Although the values evaluated for groundwater from boreholes did not exceed the recommended guideline level of 100 BqL^{-1}set by (WHO, 2004), they exceeded the maximum contaminant level (MCL) of 11.1 BqL^{-1}proposed by United States Environment Protection Agency ((UNSCEAR, 2000; USEPA, 1991) and world average value of 10 BqL^{-1}set by WHO (1993). This has health hazard implications for residents who make use of this water source and care must be taken to ensure proper treatment before the water is fit for consumption.

A comparison of the mean activity concentrations for groundwater obtained from both hand-dug wells and drilled boreholes shows that the activity concentration of radon in the shallow hand-dug wells was slightly lower than that obtainable in borehole water. This may be due to the relative ease with which radon may evaporate at the surface compared to depths at which groundwater in boreholes are found. Furthermore, the fractional increase in groundwater radon concentrations could indicate reduced radon concentrations with reducing depth due to high surficial temperatures or lowering oxygen levels at depth (Ajibola et al., 2021).

The results of our study are compared with that obtained from other researchers within the catchment of the study environment and elsewhere as presented on Table 4. The results of radon concentration obtained for Idah Kogi state shows a Rn concentration ranging from 10.16±1.00 to 21.21±1.10 with average value for the study of 13.77±1.05. The effective dose range was found to be between 0.029 mSv/y to 0.077 mSv/y with average value of 0.055 mSv/y. These average values are somewhat lower than those obtained for the present study. This may be because part of Idah falls within a sedimentary environment. The results obtained for Ijero and Edu are comparable to that obtained within the study area. This is expected due to the similar geological terrain of these environments. The remarkable similarity in results obtained between Edu, Kwara state and our present study lends support to the association between increased radioactive concentration due to anthropogenic sources such as mining as has been established by prevailing studies (Ademola et al., 2014; Aliyu et al., 2015; Adagunodo et al., 2018; Usikalu et al., 2017). Generally, our results are comparable with those obtained by other researchers.

Table 4: Comparison of Radon activity concentration with literature values from Nigeria and other Parts of the World

S/N	Location	Water Source	Mean Radon Activity Concentration	Reference
1.	Idah, Kogi-Nigeria	BW	13.45±1.00	Aruwa et al., 2017
2.	Zaria, Kaduna- Nigeria	Groundwater	7.41 ± 2.04	Garba et al. 2012
3.	Ijero, Ekiti-Nigeria	Groundwater	0.168 – 78.509	Akinnagbe et al 2018
4.	Edu, Kwara-Nigeria	Groundwater	24.16±4.21	Ajibola et al., 2021
5.	Kerman, Iran	Well Water	15.62	Asadi et al., 2016
6.	Bahabad, Bab Tangal Taj abad, Motahar Abad, Iran	Well Water	13.8 ± 3.5	Darabi et al., 2020
7.	Shanono, Kano-Nigeria	Drinking Water	3.176-49.932	Bello et al., 2020

The annual effective dose due to intake of Radon from well water samples collected were estimated and found to range from 0.1723 mSv/y to 0.2078 mSv/y with mean values of 0.1817 mSv/y. The annual effective doses due to the intake of ^{222}Rn from the borehole water samples collected from the same area were found to range from 0.1910 to 0.1997 mSv/y with mean values of 0.1947 mSv/y. Our findings indicate that the results from both sources of groundwater are higher than WHO recommended reference level of 0.10 mSv/y for intake of radionuclide in water. As per WHO recommendation, water samples with AED rates less than 0.10 mSv/y could be taken without further treatment and would pose no threat to health of the people ingesting it. However, our findings show that water sample from the study area could pose threat to the health of the inhabitants of the study area, should the water be consumed directly without proper treatment.

Generally, results of this study has shown that both the mean values of ^{222}Rn concentration and the annual effective doses due to ingestion of borehole and well water from the samples exceeded the world average recommended values of 10 $BqL^{-1}$and 0.1 mSv/y set by the World Health Organization (WHO 1993) and (WHO, 2004) for radon concentration and annual effective dose due to intake of radionuclide in water respectively. The water source notwithstanding, values of the estimated radon concentration and effective doses were found to be higher than the relevant acceptable limits and therefore poses serious radiological hazard.

CONCLUSION

Ten (10) groundwater samples which consisted of seven (7) well water and three (3) borehole water samples analyzed using LSC at the Center of Energy Research and Training (CERT) Ahmadu Bello University Zaria, Nigeria for Radon concentration and mean Annual Effective Dose. The concentration of ^{222}Rn was found to vary from a minimum value of 23.60 BqL^{-1} in groundwater ffrom hand-dug wells to a maximum value of 25.30BqL^{-1} with the mean value of 24.89 BqL^{-1} calculated for the entire study area while the activity concentration of ^{222}Rn in groundwater obtained from borehole ranged from 26.16 $BqL^{-1}$to 27.35 $BqL^{-1}$with a mean value of 26.66 BqL^{-1}. The annual effective dose due to intake of Radon from well water samples ranged from 0.1723 mSv/y to 0.2078 mSv/y with mean values of 0.1817 mSv/y while the annual effective doses due to the intake of ^{222}Rn from the borehole water samples collected from the same area were found to range from 0.1910 to 0.1997 mSv/y with mean values of 0.1947 mSv/y. A comparison of the mean activity concentrations for groundwater obtained from both hand-dug wells and drilled boreholes shows that the activity concentration of radon in the shallow hand-dug wells was slightly lower than that obtainable in borehole water while the annual effective dose range showed no appreciable difference between groundwater from hand-dug wells and boreholes. The activity concentrations of ^{222}Rn in groundwater in Obajana were above the world average Minimum Contamination Level (MCL) of 10 BqL^{-1}set by WHO and MCL of 11.1 BqL^{-1}set by USEPA; however, the values did not exceed the recommended action level of 100 BqL^{-1}set by WHO. Similarly, the mean annual effective doses estimated for the two types of groundwater samples were found to be above WHO recommended reference level of 0.1 mSv/y for intake of radionuclide in water. The water source notwithstanding, values of the estimated radon concentration and effective doses were found to be higher than the relevant acceptable limits and therefore poses serious radiological hazard, therefore before consumption of water from these sources, proper treatment must be ensured to ameliorate threat to human health.

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