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ORIGINAL RESEARCH ARTICLE

Measurement of Radon Gas Concentration in Sources of Drinking Water in Makurdi, Benue State, Nigeria Using Radon Detector (RAD-7)

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ABSTRACT

Concern over radon gas's potential health risks when used or ingested in homes is growing, as is the issue with its presence in sources of drinking water. In this study, water samples were collected from various locations in Makurdi, Benue State, Nigeria, and the amount of radon gas present was measured using the Radon Detector (RAD-7). The study used a methodical sampling strategy to gather water samples from wells, boreholes, and surface water bodies throughout various Makurdi locations. The gathered water samples were examined using the RAD-7 detector, a trustworthy and sensitive device for measuring radon gas. The radon levels ranged from trace levels (20.0 ± 1.0) to higher quantities (122.0 ± 16.0), raising worries about potential health implications for nearby people reliant on these water sources. Thirty (30) samples of water were gathered for this investigation. The samples' radon content ranged from 10.3 to 122.0 Bq L^{-1}, which is within the World Health Organization's (WHO) allowable limit and other regulatory bodies (100 Bq L^{-1}) except in the sample collected from Court 5 and Logo1, which was higher than the set limit. The results of the analysis demonstrated that there were large variations within the range of 0.61 ± 0.39-11.80 ± 1.85 and a mean of 57.36 ± 5.8 in the amounts of radon gas in the water samples obtained from the different sources. More research and monitoring are advised to gain a complete understanding of radon distribution and to develop workable radon risk reduction plans for water sources.

ARTICLE HISTORY

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Concentration, Drinking water, Radon, Makurdi, Permissible Limit, RAD-7

INTRODUCTION

The majority of living things on Earth, including streams, lakes, and seas, are made mostly of water. On average, water covers 71% of the surface of the planet. All known kinds of life, particularly humans, depend on it. Humans use water for many different things, including agriculture, transportation, energy production, and other household tasks. So, it's important and delicate to consider its accessibility and prominence with regard to pollution from radioactivity, microbes, biochemistry, and other sources (Jibril *et al., 2021;* Garba *et al*., 2008). Unfortunately, it is problematic for most developing nations, including Nigeria, to provide their citizens with access to hygienic and fit-to-drink water; therefore, the mainstream people rely mostly on untreated superficial and groundwater sources (Garba *et al*., 2008). There are three primary natural isotopes of Radon: radon-222 (^{222}Rn), radon-220 (also known as Thoron), and radon-219 (^{219}Rn) (US, National Academic Press, USNAP, 1988). Around the ecosphere, phosphate-rich soil counties, watercourses, and rocky and hilly locations typically have varied levels of Rn-222 (Fleisher *et al., 1980*). When humans gulp or consume radon progeny, which is not stable and releases highly ionising alpha radiation, they are exposed to a very hazardous radiation source (Alter and Oswald, 1988). Nearly 85% of the population's radiation exposure comes from naturally occurring radioactive sources, with radon exposure accounting for nearly half of that exposure (Singh *et al., 2008).*

One common naturally occurring radionuclide is radon. It can only be found via a detector and is invisible to human senses. Radon has historically been the main radioisotope

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that poses a risk to human health when it comes to natural background radiation. It is associated with approximately 55% of the annual radiation exposure that the general population encounters (George, 2009). Furthermore, El-Gamal *et al.* (2008) established that ^{222}Ra is a known health hazard in both mining and non-mining environments. Radionuclides naturally exist in surface and subterranean waters at varying levels, depending on their source. Radon is released into bodies of water by natural processes such as the decay of its parent nuclide, ^{226}Ra (radium), and primary fragmentation from the surrounding geological environment (rocks, soils), according to Moreno *et al.* (2014), Fonollosa *et al.* (2016), and Viktor *et al.* (2017).

Increased inflows of radon-containing water into the catchment area and radon that seeps into the water from the atmosphere are two additional sources of radon in the water. Radon, a noble gas with a half-life of 5,500.8 minutes, is produced by the radioactive conversion of the element ^{226}Ra, which is found in the decay chain of the element ^{238}U (uranium). Radon gas, which has a short half-life in the troposphere and is colourless, odourless, and tasteless, accounts for nearly half of the radiation that humans are exposed to from natural sources. (UNSCEAR, 2000). There is no such thing as pure water in nature. Radiation is harmful to humans and contaminates water. Radiation poisoning of water is caused by a variety of factors, including reactor accidents, nuclear weapon tests, naturally occurring radioisotopes in the soil and environment, and radioactive medical waste (Halime and Mahmut, 2021).

In addition to being soluble in water, radon gas also tends to seep into the surrounding area. Therefore, both people who drink the water and those who breathe it are seriously at risk from excessive radon concentrations found in thermal waters and groundwater (UNSCEAR, 2008). Given how easily radon gas can permeate soil, rocks, and water, the amount of radon in drinking water from groundwater sources is greater than that in surface water sources (Jibril *et al.,* 2021; Mostafa *et al.,* 2022). Water can absorb radon that has diffused from rocks from subterranean sources. The use of radon-contaminated water for domestic purposes causes radon gas to seep into the atmosphere (Kawthar and Osamah, 2022). If drinking water is obtained from wells in areas where radon may be found in the groundwater, it may contribute to another source of indoor radon that is airborne because it can then be inhaled. However, it is generally known that when this water is consumed, radon does not instantly enter the bloodstream and then leave the body. Because of the radon that remains in the stomach as a result of this polluted water, gastric tissues are vulnerable to radon, which may raise the risk of gastric cancer (Binesh *et al., 2010*). Ingestion of radon can have effects that are still not completely understood. However, household chores that cause the discharge of radon from water, such as showering, account for only 1% of radon exposure (Inácio *et al.,* 2017).

The results of this ground-breaking study on the radon concentration in water samples taken in Makurdi, Benue State, Nigeria, are significant in terms of public health issues. The majority of Makurdi homes where water samples were taken are supplied by rivers, water boards, boreholes, and subterranean pumping wells. This makes it important to assess the concentration of radon, even though most of it is released into the atmosphere.

MATERIALS AND METHOD

Study Area

This research was executed in Makurdi, Benue State-Nigeria, located on longitude $8^0 30'$E and latitude $7^0 44'$N (Figure 1). Based on the census conducted in 2006, Makurdi has a population of about 356,000 and a land area of about 804 square kilometer in a 16km radius circle. Makurdi, being the state capital of Benue State, has a nucleated settlement pattern and is averagely industrialized. The sampling site was selected based on the number of people living in the area and the importance of this research to the health of the entire inhabitants of Makurdi metropolis. The study area has an annual average temperature of 29.32^0C (84.78^0F), which is -0.14% lower than Nigeria's averages, and receives approximately 134.92 millimetres (5.31 inches) of precipitation and 159.68 rainy days (43.75% of the time) annually. The research area is located in the Guinea Savannah region, characterized by two major seasons: raining season (spring), which lasts for 6 to 7 months (i.e., April to October), and the dry season (summer), which lasts for 4 to 5 months (i.e. November to March). This research was done during the dry season (summer) due to peak usage and accessibility.

The Global Positioning System (GPS) coordinates were registered and displayed on the map (Figure 2) to assist in more precisely locating and mapping the area where sources of drinking water were collected for radon analysis.

Experimental Determination of Radon in Water:

Samples of water were taken straight from the source and placed in a hygienic 250-mL container that had been rinsed with distilled water beforehand. Careful attention was paid to keeping the water from aerating during the collection process in order to stop any dissolved radon from escaping. Thirty water samples in total were taken from the study area and analysed with a RAD-H_2O fitment coupled to a standardised dynamic digital detector (RAD7) (Durridge, 2014, Oni *et al.,* 2016). By connecting the RAD7 detector to an aerated kit (Figure 3), which allows it to release radon into the air in a recursive loop from a water excerpt, radon in the water could be measured. Desiccant is used inside the recursive loop to desiccate the air before it enters the detector to measure the radon concentration. The detector makes use of the alpha-spectrometry method. In less than 20 minutes, RAD7 can precisely determine the amount of radon in a water sample. Since the duration is so short in comparison to radon's 5,500.8 minutes half-life, RAD7 is better than other detectors for measuring radon in water [Oni *et al.,* 2014, 2016).

Annual Effective Dose

The relationship given below is used to evaluate the effective dose of radon that a particular consumer would receive from drinking the water (Somashekar and Ravikumar, 2010; Inaam, 2015).

$$AED = C_R \times RAI \times IDC$$

Where,

AED = annual effective dose ($SV.\ y^{-1}$)

C_R = concentration of ^{222}R in the ingested drinking water ($Bq.\ L^{-1}$)

RAI = annual intake of drinking water (1095 $L.y^{-1}$). (Somashekar & Ravikumar, 2010; Inaam, 2015)

IDC = ingested dose conversion factor for ^{222}R ($5 \times 10^{-9} Sv.Bq^{-1}$). Recommended by the United Nations Scientific Committee on the Effects of Atomic Radiation has been used (UNSCEAR, 1993).

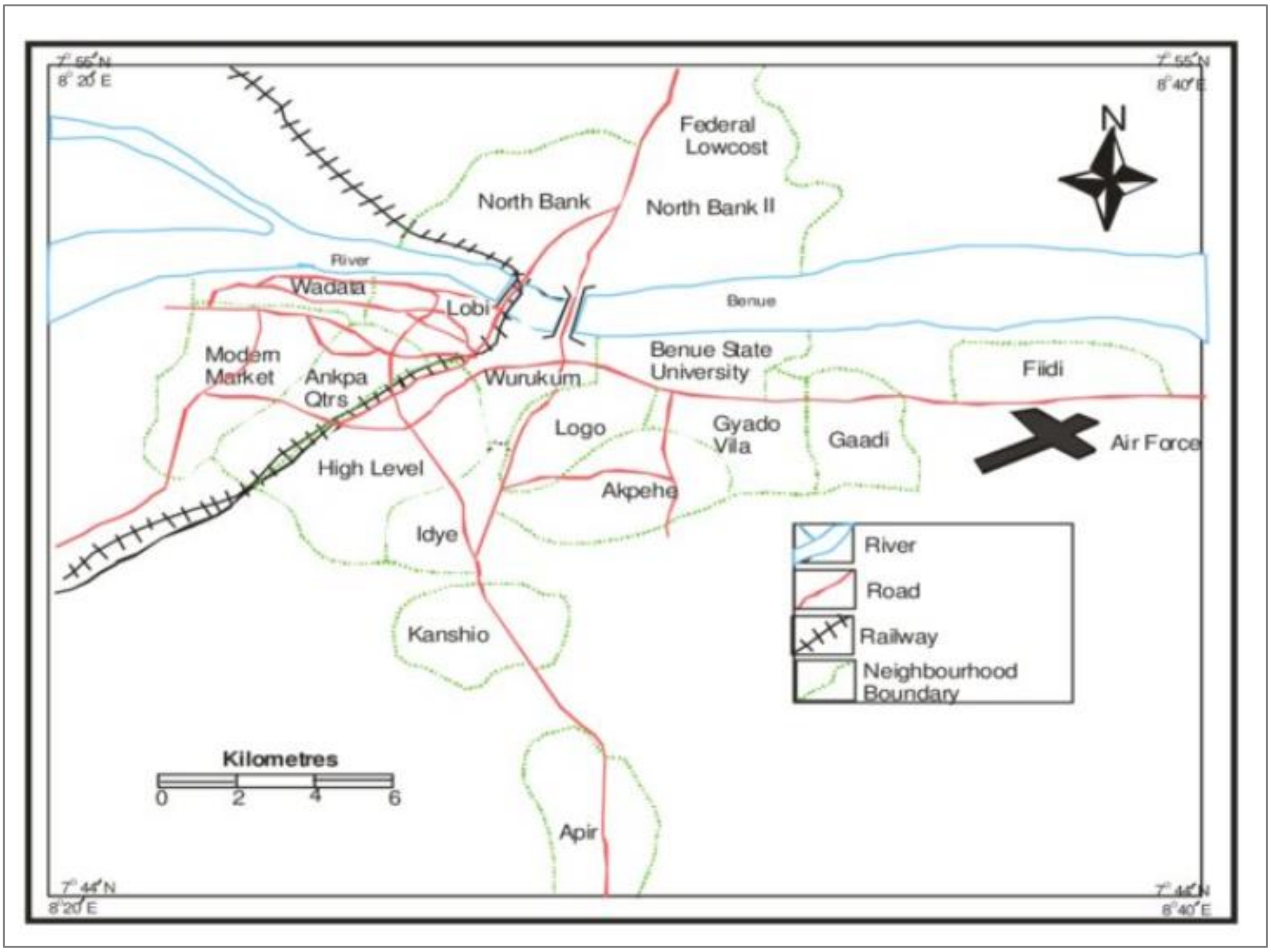

Figure. 1: An aerial map of Makurdi City illustrating the research areas.

Source: 2015, Lands and Survey, Ministry of Lands and Survey, Makurdi.

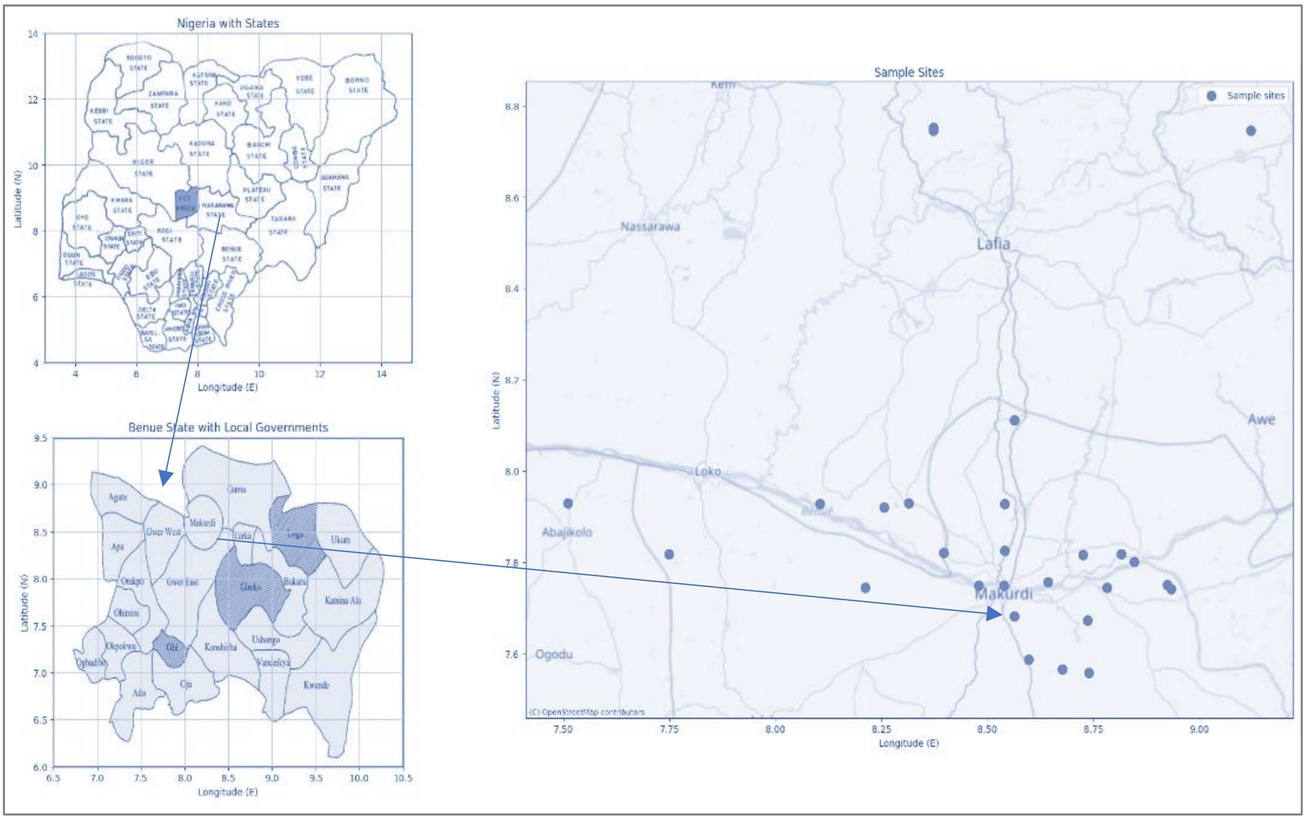

Figure 2: Map of the Study Area Showing Sampling Points

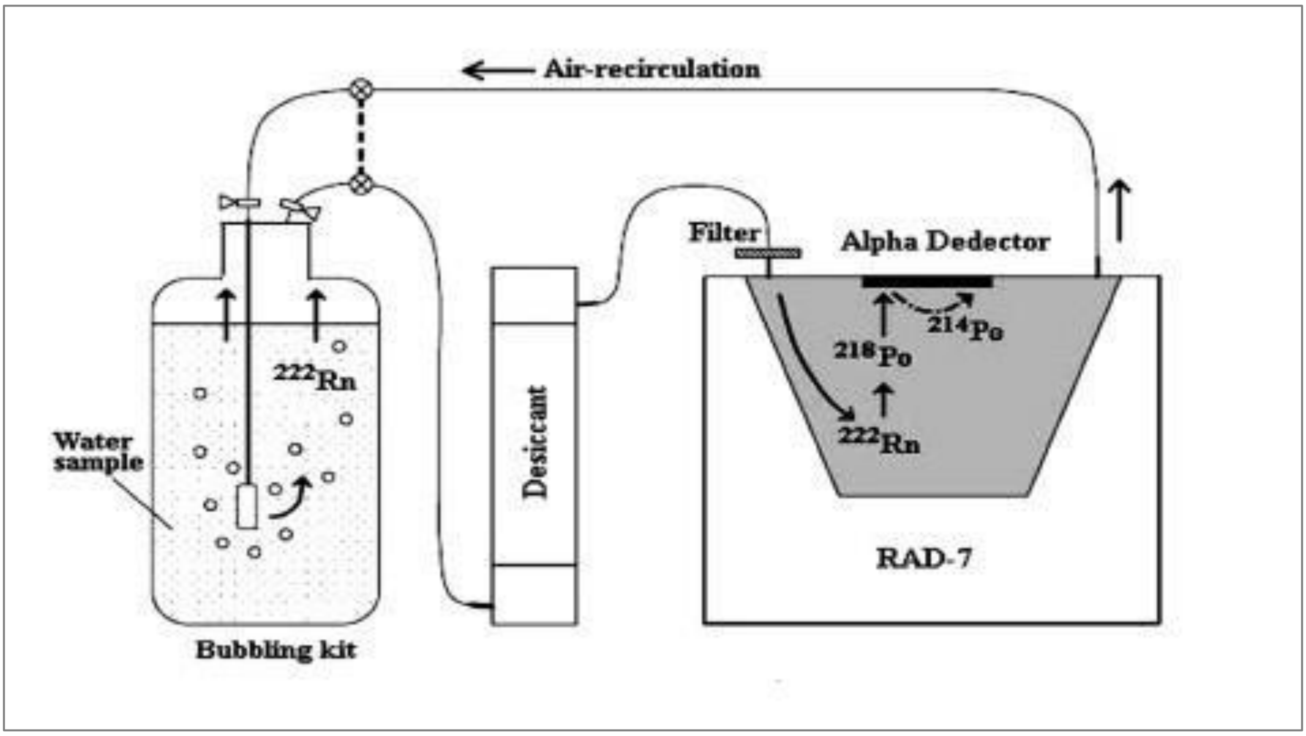

Figure 3: Radon in a water concentration setup schematically represented (Malakootian and Nejhad, 2017)

RESULTS AND DISCUSSION

The analysis of drinking water samples from Makurdi, Benue State, Nigeria, provided concentrations of Radon-222 in Becquerel per litre (BqL^{-1}) and the annual effective dose rates in millisieverts per year (mSv/y). The study found radon concentrations ranging from 20.0 ± 1.0 to 122.0 ± 16.0 BqL^{-1}), with corresponding effective doses from 0.10950 to 0.66135 mSv. y^{-1}. Table 1, Figure.4 and 5 shows the concentration in Becquerel per liter (Bq. L^{-1}) and the yearly effective dose rate in milli sievert per year (mSv.y^{-1}) of Radon-222 obtained from the analysis of drinking water sample collected across Makurdi, Benue State, Nigeria respectively.

Table 1: Radon concentration in drinking water samples obtained from Makurdi, Benue State, Nigeria.

SAMPLE ID	CONCENTRATION (BqL^{-1})	S. D	EFFECTIVE DOSE (mSv.y^{-1})
S1	54.0 ± 8.0	0.61 ± 0.39	0.29565
S2	120.5 ±14.2	11.53 ± 1.52	0.65974
S3	84.0 ± 9.0	4.86 ± 0.57	0.45990
S4	20.0 ± 1.0	6.82 ± 0.89	0.10950
S5	22.0 ± 3.0	6.46 ± 0.52	0.12045
S6	83.0 ± 9.0	4.68 ± 0.57	0.45443
S7	66 .0 ± 5.0	1.58 ± 0.07	0.36135
S8	122.0 ± 16.0	11.80 ± 1.85	0.66135
S9	75.0 ± 6.0	3.23 ± 0.03	0.41063
S10	39.0 ± 3.0	3.35 ± 0.52	0. 21353
S11	66.0 ± 8.0	1.58 ± 0.39	0. 36135
S12	50.0 ± 3.0	1.34 ± 0.52	0.27375
S13	45.0 ± 4.0	2.26 ± 0.34	0. 24638
S14	42.0 ± 4.50	2.80 ± 0.25	0. 22995
S15	32.0 ± 5.0	4.63 ± 0.07	0.17520
S16	53.0 ± 6.0	0.80 ± 0.03	0.29018
S17	40.0 ± 4.0	3.17 ± 0.34	0.21900
S18	30.0 ± 2.0	4.10 ± 0.70	0. 16425
S19	28.0 ± 3.0	5.36 ± 0.52	0.15330
S20	88.0 ± 12.0	5.59 ± 0.45	0.48180
S21	90. 0 ± 9.0	5.96 ± 0.57	0. 49275
S22	65.0 ± 6.0	1.39 ± 0.03	0.35588
S23	72.0 ± 8.0	2.67 ± 0.39	0.39420
S24	62.0 ± 5.0	0.85 ± 0.16	0.33945
S25	64.0 ± 4.0	1.21 ± 0.34	0.35040
S26	39.0 ± 3.0	3.35 ± 0.52	0.21353
S27	52.0 ± 4.0	0.98 ± 0.34	0.28470
S28	34.0 ± 2.0	4.26 ± 0.70	0.23543
S29	49.0 ± 6.0	1.53 ± 0.03	0.26828
S30	50.0 ± 3.0	1.34 ± 0.52	0.27375
Average	**57.36± 5.86**	**4.74 ± 0.64**	**0.31834**
Maximum	**122.0 ± 16.00**	**0.61 ± 0.39**	**0.66135**
Minimum	**20.0 ± 1.00**	**11.80 ± 1.85**	**0.10950**

KEY: S.D (Standard Deviation)

The samples collected had radon concentration values ranging from 20.0 ± 1.0 to 122.0 ± 16.0, with effective doses of 0.66135 mSv.y^{-1} and 0.10950 mSv.y^{-1}, respectively. Tables 2 and 3 show the overall radon concentration measurement ranges per water type, as well as the overall effective dose range.

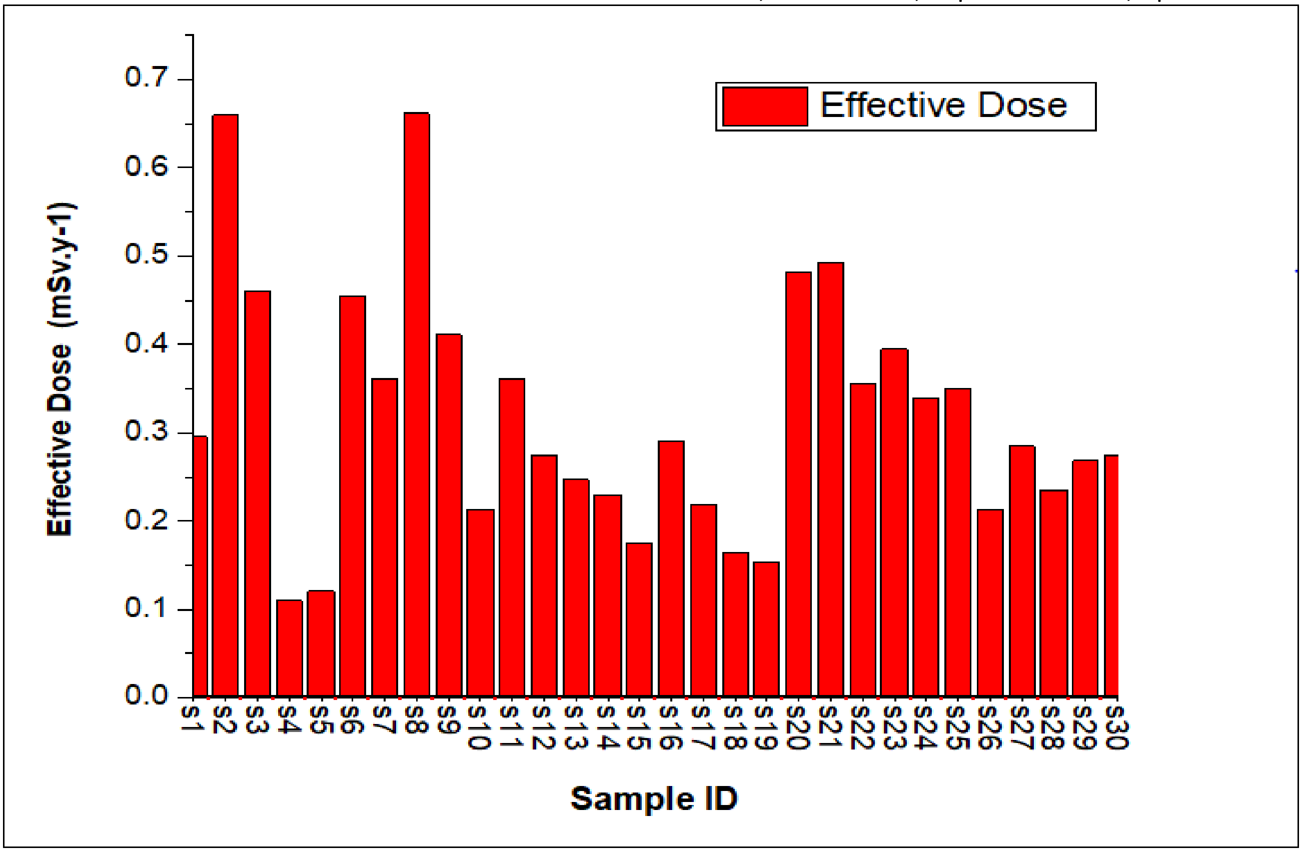

Figure 4: Bar Graph of Effective Dose against Sample ID

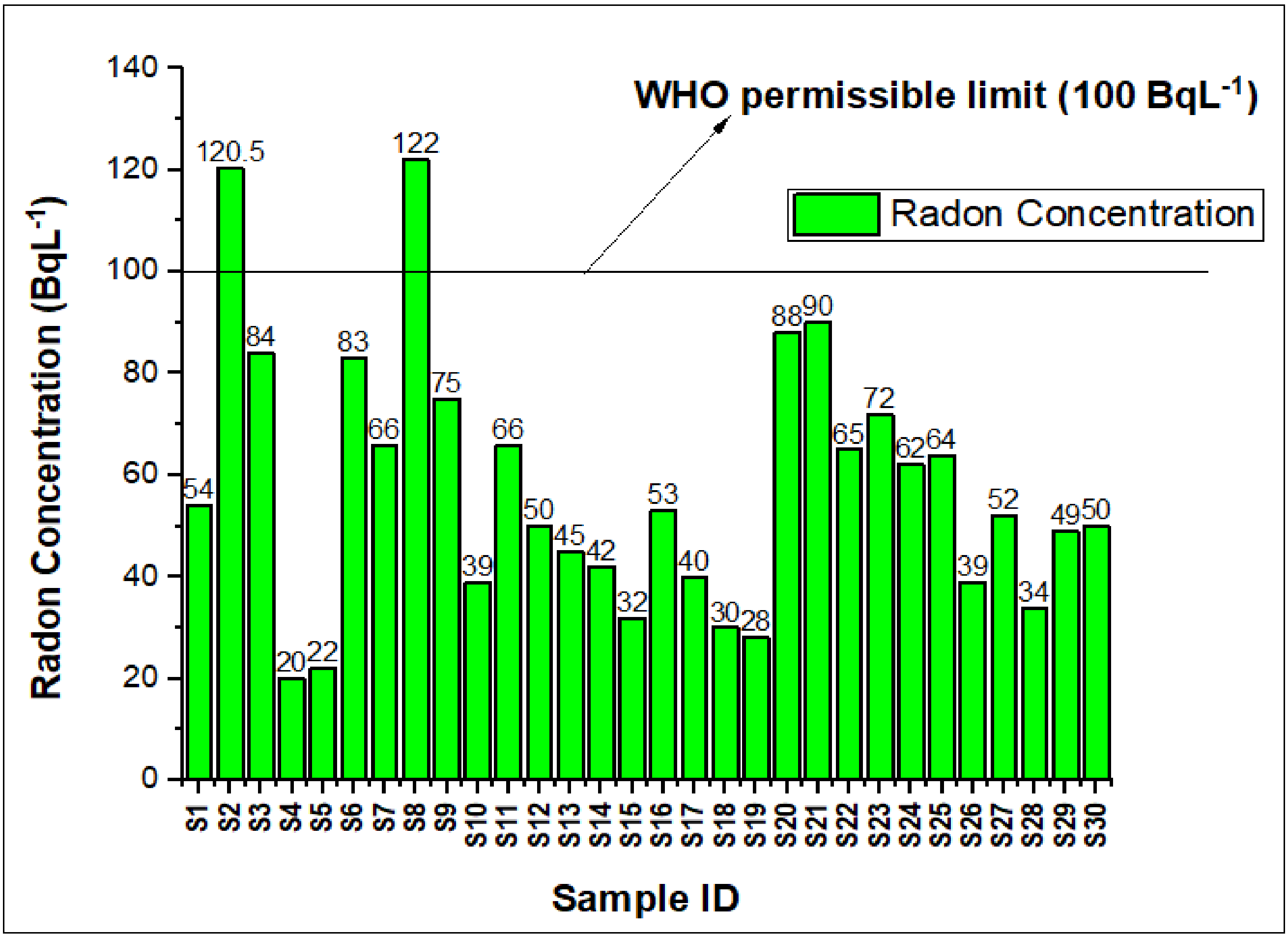

Figure 5: Bar Graph of Radon Concentration againts Sample ID

Figures 6, 7, 8, and 9 clearly show the radon concentration in the individual water samples collected from the study area. Meanwhile, the radon concentration in the well water samples has the highest value owing to the fact that the water samples were obtained from a depth, immobile and there was no release of any radon to air before it was obtained.

The water must have been contaminated by geological pollutants, which must have led to the increase in the radon concentration, unlike other sources of water. Though radon concentration level above 100 BqL^{-1} WHO is attributed to causes of lung cancer and Leukemia (ICRU, 2021), in the present work, only those users of water sources obtained from Logo 1 and Court 5 are very susceptible to lung cancer and Leukemia as depicted in Table 1 and Figure 4 and 5.

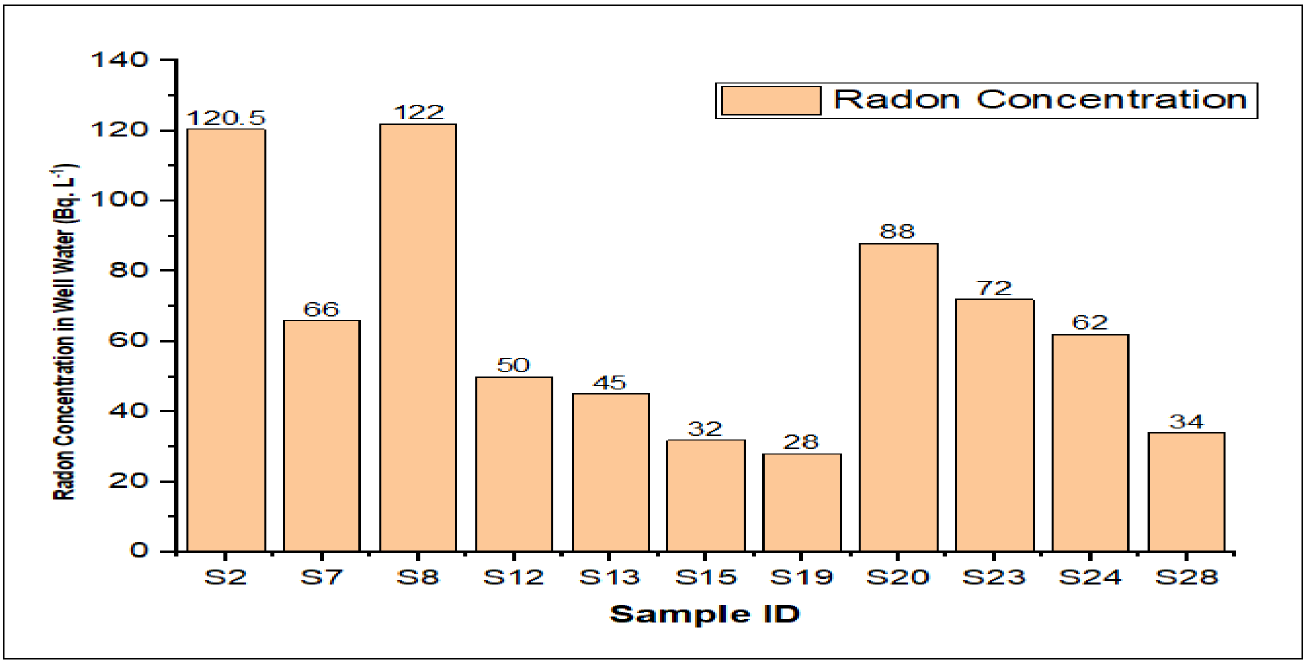

Figure 6 Bar graph of Radon Concentration in well water against sample ID

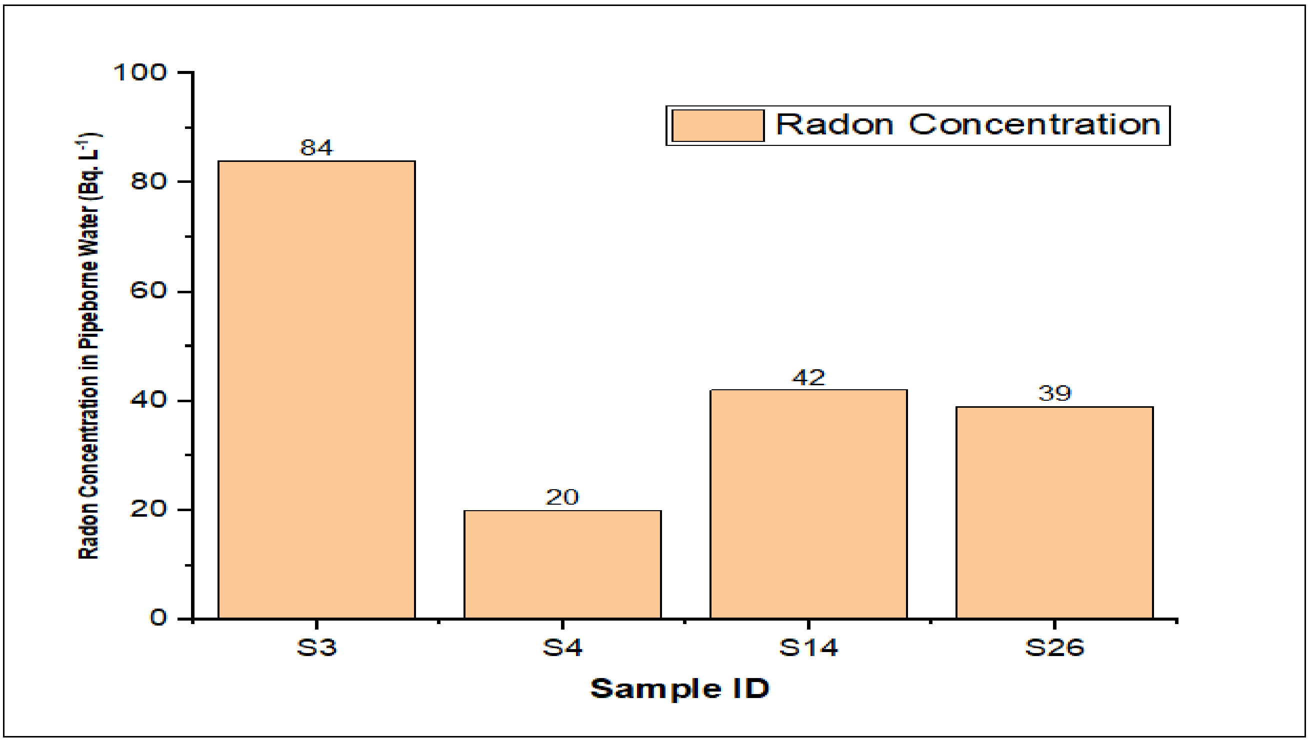

Figure7: Bar graph of Radon Concentration in pipe-borne water against Sample ID

Figure 4 is a bar graph that shows the effective dose in mSv.y^{-1} With respect to the samples collected from various locations in Makurdi. The bar graph depicted that the effective dose following descending order magnitude is given as S8>S2>S21>S20>S3>S6>S9>S23>S11, S7>S24>S22>S25>S1>S16>S27>S12, S30>S29>S13>S28>S20>S17>S10,26>S15>S18>S19>S5>S4. Hence, the source of drinking water from logo 1 has the highest radon concentration level and hence has to be monitored from time to time, or the habitant of Makurdi that depends on the source of water from this source should find an alternative source to prevent the effect of radon concentration, especially risk of lung cancer. The result of the effective dose obtained shows that well water has the highest effective dose level.

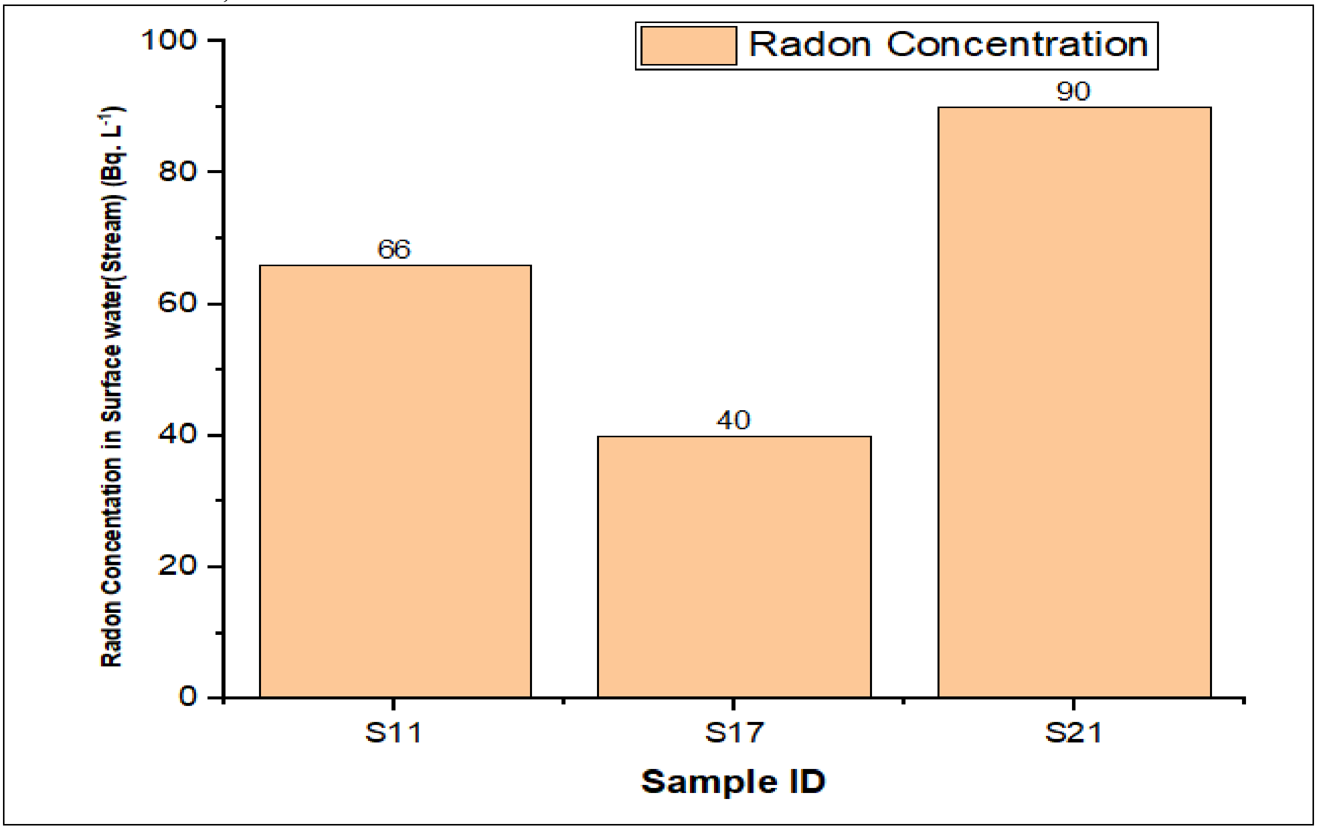

Figure 8: Bar graph of Radon Concentration in surface water (stream) against Sample ID

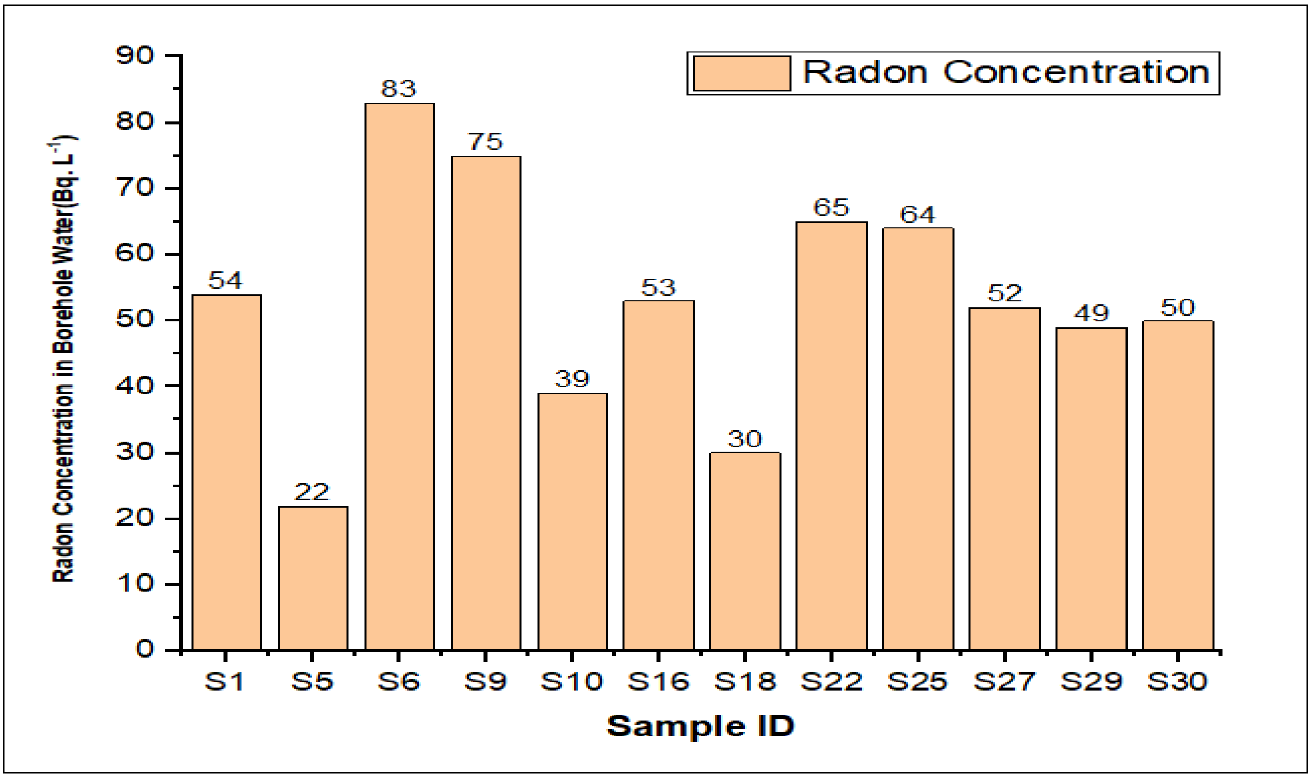

Figure 9. Bar graph of Radon Concentration in bore-hole water against Sample ID

Figure 5 depicts the relationship between radon concentrations and water samples collected from various locations. The bar graph showed that the concentration of all the water samples collected was at the WHO permissible limit (100 BqL^{-1}), with the exception of the samples collected from Logo 1 and Court 5, which were above the set limit. This is due to the depth of the well where the water is obtained, as well as the immobility nature of well water, as the concentration of radon is intact because the water is not flowing like other sources. As a result, there is a need to monitor the source of drinking water in that environment.

Figure 6 depicts a bar graph illustrating the relationship between radon concentrations in well water collected from various sample points throughout Makurdi. The bar graph shows that sample S8 has the highest concentration of radon, while S19 has the lowest, as shown in the ascending order of magnitude below:S19<S15<S28< S13<S12<S7<S24<S23<S20<S2<8.

Figure 7 depicts the concentration of radon in pipe-borne water collected throughout Makurdi, revealing that the concentration is highest in S3 and lowest in S4. However, the concentrations of all pipe-borne water samples collected were within the WHO permissible limit.

Figure 8 depicts the concentration of radon in surface water (stream) samples collected at various locations in Makurdi. It shows that S21 has the highest radon concentration while S17 has the lowest. However, the concentration level in all of the samples is within WHO's permissible limit.

Figure 9 depicts the concentration of radon in bore-hole water collected from various points throughout the sampled area. Sample S6 was shown to have the highest concentration, while sample S5 had the lowest. Meanwhile, the concentration in all samples is within WHO's permissible limit.

Table 2: Overall Radon Concentration measurement ranges per water type.

S/NO	Water type	Radon Concentration range (BqL^{-1})
1	Well	30.0 ± 2.0 to 122 ± 14.20
2	Pipe born	20.0 ± 1.0 to 42 ± 4.50
3	Surface Water (stream)	40.0 ± 4.0 to 90 ± 9.0
4	Borehole	22.0 ± 3.0 to 83 ± 9.0

Table 3: Overall Effective dose ranges per water type.

S/NO	Water type	Effective Dose ($mSv.y^{-1}$)
1	Well	0.16425 to 0.66135
2	Pipe born	0.10950 to 0.22995
3	Surface Water (stream)	0.21900 to 0.49275
4	Borehole	0.12045 to 0.45443

Table 4: Comparison between the radon concentrations in this study and those in other parts of the world.

Location	Range (Bq/L^{-1})	Reference
Saudi Arabia	0.76 to 9.15	Wedad *et al.,* 2015
Ado-Ekiti, Nigeria	13.57	Oni *et al.,* 2016
Finland	Average of 630	Asikainen and Kahlos, 1980
The US	Average of 5.2	Nazaroff *et al.,* 1984
Kaduna, Nigeria	12.7 to 14.90	Jibril *et al.,* 2021
Dhaka, Bangladish	0.07 to 4.780	Pervin *et al.,* 2018
Jos, Nigeria	2.77 to 59.41	Aminu, 2020
AL-Shomaly, Iraq	0.036 to 2.146	Mohammed, 2014
Bam, Iran	Average of 1.2	Somashekar and Ravikumar, 2010
Dadri	17 ± 1 *to* 68 ± 3	Mukesh *et al.,* 2022
Lebanon	1.08 to 9.32	Abdalsattar *et al.,* 2014
Sudan	14.24 ± 3.62	Abd-Elmoniem, 2014
Iraq-Baghdad, Babylon	Average of 0.3	Inaam, 2015
Makurdi, Nigeria	10.3 to 122.0	Present Study

CONCLUSION

The purpose of this study is to use a radon detector to determine the radon concentration in various drinking water sources in Makurdi, Benue State, Nigeria. For 30 samples, the radon concentrations of various drinking water sources were measured. The findings show that the majority of the water sources examined are safe to drink for people living in the sampled area and surrounding areas.

Nonetheless, some of the water sources evaluated for this study show signs of radon content, particularly samples collected from Logo 1 and Court 5, which have radon concentrations higher than the WHO permissible limit (100 BqL^{-1}). The public water distribution system in the study area should be considered, and efforts should be made to educate residents about the risks of radon and its daughter cells to human health. As a result, careful monitoring of drinking water quality and the critical role it plays in human life must become a top priority. Radon levels in water are elevated for a variety of reasons, both anthropogenic and natural.

Because this is the first study of its kind in this field, the findings may be applicable to the study area. Meanwhile, more research is needed to determine the link between radon and cancer, as well as the prevalence of radon in bio-indicators. There is also a need for epidemiological studies to investigate the incidence of lung and stomach cancer in the study area as well as other areas in Nigeria with high radon concentrations, as reported in the literature. Meanwhile, the major limitations that were discovered in the cause of the research have to do with seasonal fluctuation of the radon levels in water due to changes in season, weather conditions, and water usage patterns. Health and safety risk in handling water sources with potentially high radon concentrations is also a major limitation in carrying out this research.

CONFLICTS OF INTEREST

There was no conflict of interest prior to, during, or following the conclusion of the study.

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REFERENCES

Abdalsattar, K. H., Burhan, R. A and Fadhil K. F (2014). Study of Radon and Radium Concentration in Water Samples in Some Regions of Lebanon. *Journal of Kerbala University*. 12 (2): 209 – 215.

Abd-Elmoniem A. Elzain (2014). Measurement of Radon-222 concentration levels in water samples in Sudan. *Advances in Applied Science Research*. 5(2):229-234. www.pelagiaresearchlibrary.com

Alter H.W and Price P.B. (1972). Radon detection using track registration material. US Patent. 3:665-149. biomedcentral.com

Alter, H.W and Oswald, R.A. Nationwide distribution of indoor radon measurements. APCA J. (1988). 37:227. [Crossref]

Aminu Kalip (2020). Measurement of Radon Concentration in Borehole and Well Water, and Estimation of Indoor Radon Levels in Jos, Plateau State, Nigeria. *International Journal of Pure and Applied Science*. 9 (19): 213-225.

Asikainen, M. and H. Kahlos (1980). Natural Radioactivity of Drinking Water in Finland. *Health Phys*. 39:77. [Crossref]

Binesh, A., Mohammadi, S., Mowlavi, A., and Parvaresh, P (2010). Evaluation of the radiation dose from radon ingestion and inhalation in drinking water. *International Journal of Water Resources and Environmental Engineering*. 2 (7): 174–178.

Committee on Biological Effects of Ionizing Radiation, Board on Radiation Effects Research and Sciences. Health risk of radon and other internally deposited alpha emitters. US: National Acad Press; First; 1988:24:26.

Durridge (2013). Radon Instrumentation. Big Bottle RAD H_2O User Manual. DURRIDGE Company Inc. Billerica, USA. [Crossref]

El-Gamal, A. and Honsy, G. (2008). Assessment of lung cancer risk due to exposure to Radon from coaster sediment. *East. Med. Health J*. 14(6): 1257-1269.

Fleisher, R.L., Giard, W.R., Mogro-Campero, A., Turner, L.G., Alter, H.W., and Gingrich, J.E (1980). Dosimetry of environmental radon: methods and theory of low dose, integrated measurements. *Health Physics*. 9:957. [Crossref]

Fonollosa, E., Penalver, A., Borrull, F., Aguilar, C. (2014). Radon in spring waters in the south of Catalonia. *J. Environ. Radioact*. 151: 275-281. [Crossref]

Garba, N.N., Rabi'u, N., Yusuf, A.M. & Isma'ila, A. (2008). Radon: Its Consequences and Measurement in Our Living Environs. *Journal of Research in Physical Sciences*. 4(4), 23–25. [Crossref]

George, A.C. World history of radon research and measurement from the early 1900's to today; 2009. [Crossref]

Halime Kayakökü and Mahmut Doğru (2021). Radon concentration measurements in surface water samples from Van Lake, Turkey using CR-39 detectors. *Bitlis Eren University Journal of Science and Technology*. 10(1): 35-42. [Crossref]

Inaam H. K (2015). Analysis of Radon Concentration in Drinking Water in some Locations at Baghdad City/ Iraq. *Journal of Babylon University/Pure and Applied Sciences*. 4 (23):1686-1692.

Inácio, M., Soares, S., Almeida, P (2017). Radon concentration assessment in water sources of public drinking of covilhã's county, Portugal. *Journal of Radiation Research and Applied Sciences*. 10 (2): 135–139. [Crossref]

International Commission on Radiation Units and Measurements Measurement and Reporting of Radon Exposures (2021). *Journal of the ICRU*, 21:1-191.

Jibril, M. K., Garba, N. N., Nasiru, R. and Ibrahim, N. (2021). Assessment of Radon Concentrations in Water Sources from Sabon Gari Local Government Area, Kaduna State, Nigeria. *FUDMA Journal of Sciences (FJS). 5 (1), 254 – 260.* [Crossref]

Kawthar Hassan Obayes and Osamah Nawfal Oudah (2022). The Measurement of Radon Concentration in the Buildings of the College of Education, Al-Qadisiyah University, Iraq Using CR-39 Detector. *Nature Environment and Pollution Technology*. 21 (2): 669-674. [Crossref]

Malakootian, M. and Nejhad, Y. S (2017). Determination of radon concentration in drinking water of bam villages and evaluation of the annual effective dose. *International Journal of Radiation Research*. 15 (1): 81- 89. **[Crossref]**

Mohammed, W.M (2014). Measurement and study of radioactive radon gas concentrations in the selected samples of water for AL-Shomaly. Proc. book of ICETSR, Malaysia hand book on the emerging trends in scientific research.

Moreno, V., Bach, J., Baixeras, C., Font, L. (2014). Radon levels in ground waters and natural radioactivity in soils of the volcanic region of La Garrotxa. Spain. *J. Environ. Radioact.* 128: 1-8. **[Crossref]**

Mostafa, M., Olaoye, M. A., Ademola, A. K., Jegede, O. A A., Saka A. and Hyam K (2022). Measurement of Radon Concentration in Water within Ojo Axis of Lagos State, Nigeria. *Analytica.* 3: 325–334. **[Crossref]**

Mukesh, K., Pankaj, K., Anshu, A and Sahoo, B. K (2022). Radon concentration measurement and effective dose assessment in drinking groundwater for the adult population in the surrounding area of a thermal power plant. *Journal of Water and Health.* 20 (3): 551-558. **[Crossref]**

Nazaroff, W.W. Doyle, S.M. Nero, A.V. and Sextro R.G (1987). Potable Water as a Source of Airborne ^{222}Rn in US Dwellings: A Review and Assessment, *Health Phys.* 52: 281-295. **[Crossref]**

Oni E.A., Oni O.M., Oladapo O.O., Olatunde I.D. and Adediwura F.E (2016). Measurement of Radon Concentration in Drinking Water of Ado-Ekiti, Nigeria. *Journal of Academia and Industrial Research (JAIR).* 4 (8): 190-192. **[Crossref]**

Oni, M.O., Oladapo, O.O., Amuda, D.B., Oni, E.A., Adelodun, A.O., Adewale, Y.K. and Fasina, M.O (2014). Radon concentration in groundwater areas of high background radiation level in Southwestern Nigeria. *Journal of Academia and Industrial Research (JAIR).* 2(8): 110-118. www.nip.org

Pervin, S., Yeasmin, S., Ferdous, J and Begum, A. A (2018). Study of Radon Concentration in Tap Water of Dhaka City, Bangladesh. *J. Environ. Pollut. Manag.* 1 (2): 1-7. www.scholarena.com

Singh, J., Singh, H., Singh, S., Bajwa B. (2008). Estimation of uranium and radon concentration in some drinking water samples, Radiation Measurements. 43: 523–526. **[Crossref]**

Somashekar R. K., and Ravikumar P (2010). Radon concentration in groundwater of Varahi and Markandeya River basins, Karnataka State, India. *Journal of Radioanalytical and Nuclear Chemistry*. 285: 343-351. **[Crossref]**

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) (1993). Sources, Effect, and Risks of Ionizing Radiation, Report to the general Assembly with Scientific Annexes, United Nations.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiations) (2000). Sources and effects of ionizing radiation. Report to the General Assembly with scientific annexes (pp. 97-105). United Nations, New York, Annexure B.

UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiations) (2008). Report to General Assembly with Scientific annexes. United Nations Sales Publications. United Nations, New York.

Viktor Jobb_agy, Timotheos Altzitzoglou, Petya Malo, Vesa Tanner, Mikael Hult (2017). A brief overview on radon measurements in drinking water. Journal of Environmental Radioactivity 173 (2017): 18-24. **[Crossref]**

Wedad, R.A, Adel, G. E. A. and El-Taher, A (2015). Radon Concentrations Measurement for groundwater Using Active Detecting Method. *American Scientific Research Journal for Engineering, Technology, and Sciences (ASRJETS).* 14 (1): 1-11.

Wehr, R.M., Richards, J.A. and Adair, T.W. (1984). Physics of the Atom. Addison Wesley Pub. Co., Boston.