Measurement of Radon Concentration in Borehole and Well Water, and Estimation of Indoor Radon Levels in Jos, Plateau State, Nigeria

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Abstract
The effect of radon in drinking water and its contribution to indoor air, when combined with other sources of radon exposure portend a significant hazard to human health. In this study, measurements of radon concentration in drinking water comprising of boreholes and wells in Jos and environs, using the radon detector RAD7 were taken and analysed. The contributions of the radon in the water to indoor air (concentrations) were then computed. The results obtained from this study were compared with the maximum contaminant level (MCL) set by some International regulatory bodies, and it was noted that a significant number of the values exceeded the MCL. Even though the effective dose seemed lower than the world average, prolonged exposure to the radiation may increase the likelihood of severe health hazard.

Key words: Radon, Jos and environs, drinking water, lung cancer, maximum contaminant level.

Introduction
Access to potable water and the required quality remains a challenge to most developing countries particularly in Nigeria. Therefore, Jos metropolis and its environs is no exception, and a significant population of its citizens still depend on untreated groundwater (shallow wells and boreholes) for drinking and other household needs.

Since the formation of the earth, water and other segments of the environment (soil and air) have been associated with radiations. The most important of these being (^{222}Rn), and its progeny which constitute more than half of the dose to which the general public is exposed (ICRP, 1994, UNSCEAR, 2000).

Consequently, an individual's life-time risk of developing cancer is increased when exposed to radon in water and air over a long period of time (Nomura, 1996; Lubin et, al., 2004). It has been proven (for mine workers) that at high levels, radon is a known human carcinogen. Although radon in drinking water does not pose a direct health risk (Cross and Hofmann, 1985), the contribution of radon concentration in water to indoor air partially enhances the levels in indoor dwellings. This implies that long-term exposure to high concentration of radon in indoor air increases the risk of lung cancer (EC, 2001).

The Jos Plateau is known to be one of the coldest locations in Nigeria, with temperature ranging between 7℃ to 29℃. During cold seasons, most windows and doors are kept closed or sealed for long periods, which lowers ventilation to the barest minimum, and can cause radon to be concentrated to dangerous levels indoors. In addition, high radon concentration of up to 161.6Bq/L has been reported in the Jos-Plateau (Farai and Sanni, 1992).

Due to the importance attached to good drinking water quality, the developed countries have adopted regulations that make it mandatory to analyse for its radon content among other parameters. One of such regulations is the new EURATOM Drinking Water Directive (EURATOM, 2013).

The purpose of this study therefore is to measure and analyse the radon concentration in boreholes and well water which serve as drinking water, and to estimate the contribution of the radon in the water samples to the indoor radon levels in Jos and environs. The values obtained from the analysis shall then be compared with the MCL of international regulatory bodies viz: WHO, USEPA, UNSCEAR. This study will also provide data that will assist in formulating regulations on radon in drinking water in Nigeria.

Materials and Method

The Study Area

The study area lies between latitudes 9°55'42.56''N and longitudes 8°53'31.63''E. It is located within Jos, the Plateau state capital, Nigeria, covering an area of approximately 60km. Jos is a cosmopolitan city in the middle belt of Nigeria.

Two out of the six major mining fields in the state are within the study area. These are the Jos-Bukuru field and the Rayfield areas. Plateau state is bordered by Bauchi state to the North East, Kaduna state to the South West and Taraba state to the South East, and its boundaries totally surround the Jos Plateau. Bare rocks are scattered across the grasslands, which cover the plateau. The altitude ranges from around 1,200m to a peak of 1,829m above sea level. The state is known with intense mining of tin and columbite in the past which resulted into the formation of deep gorges and lakes. The Jos Plateau makes it the source of many rivers in northern Nigeria including the Kaduna, Gongola, Hadejia and Yobe rivers (https://www.plateaustate.gove.ng).

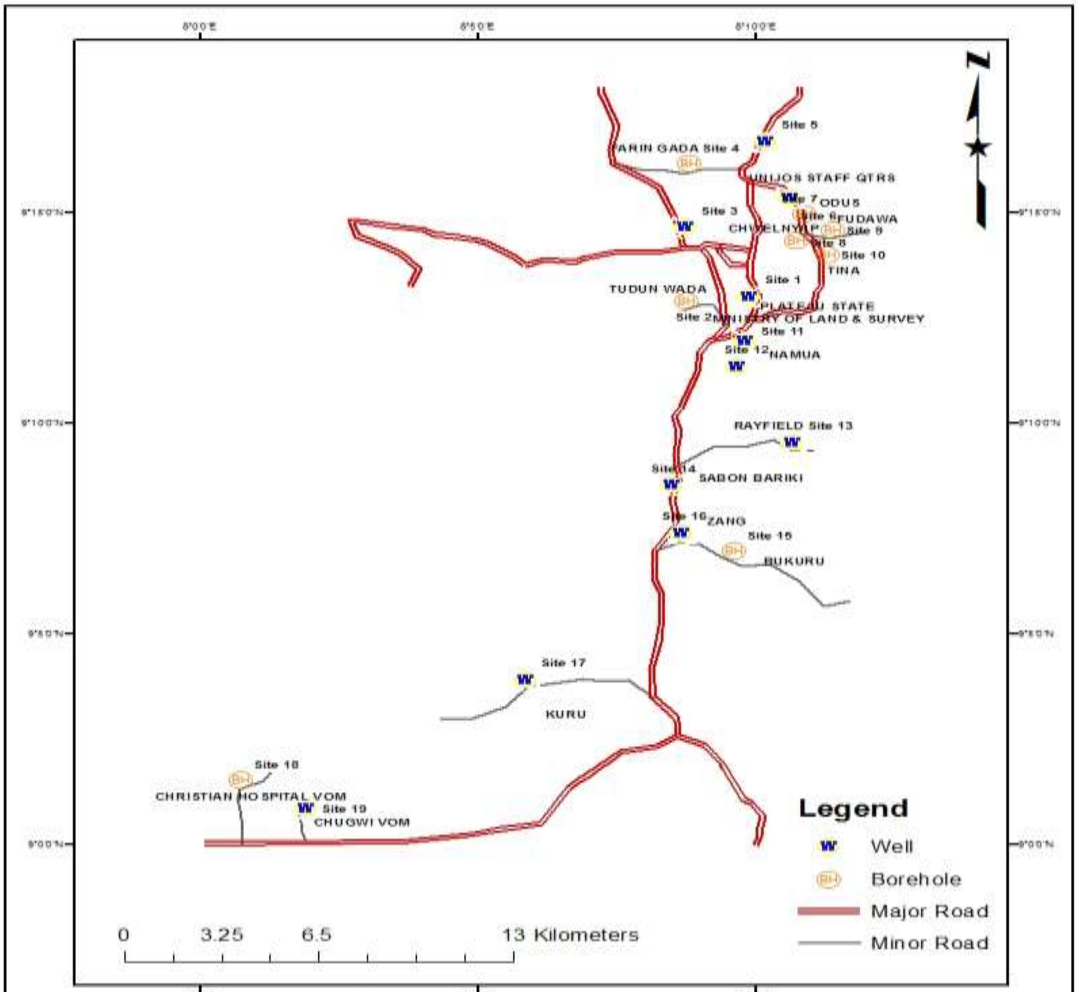

Figure 1: Map of Jos and Environs Identifying Sampling Locations
Source: (KADGIS, 2020)

Jos metropolis comprises of Jos North, Jos South and Jos East local government areas (LGAS). The city has formed an agglomeration with the town of Bukuru to form Jos-Bukuru metropolis (https://en.wikipedia.org/wiki/Jos).

Table 1: Locations of Sampling Sites

S/n	Site name	Site code	Source of water	Coordinates
1	Land & Survey Head Qtr	Site 1 (Jos North)	Well	09°54'21.6"N 08°53'21.4"E
2	Tudun Wada Park	Site 2 (Jos North)	Borehole	09°54'13.6"N 08°52'10.0"E
3	Alheri Area	Site 3 (Jos North)	Well	09°56'06.6"N 08°52'10.5"E
4	Faringada	Site 4 (Jos North)	Borehole	09°57'44.9"N 08°52'17.4"E
5	Bauchi Road	Site 5 (Jos North)	Well	09°58'19.3"N 08°53'40.6"E
6	Uni. Jos Staff Qtrs	Site 6 (Jos North)	Well	09°56'52.6"N 08°54'12.7"E
7	Odus, Bauchi by Pass	Site 7 (Jos North)	Borehole	09°56'28.0"N 08°54'26.1"E
8	Chwdnyap, by Pass	Site 8 (Jos North)	Borehole	09°55'47.3"N 08°54'17.5"E
9	Fudawa, Opp. Nasarawa area	Site 9 (Jos North)	Borehole	09°56'03.3"N 08°54'59.6"E
10	Tina Junction	Site 10 (Jos North)	Borehole	09°55'25.6"N 08°54'49.2"E
11	Abbatoir Jos South	Site 11 (Jos South)	Well	09°53'15.0"N 08°53'15.1"E
12	Namua, Bukuru Road	Site 12 (Jos South)	Well	09°52'39.5"N 08°53'08.6"E
13	Rayfield	Site 13 (Jos South)	Well	09°50'36.8"N 08°54'06.8"E
14	Sabon Barki, Bukuru Road	Site 14 (Jos South)	Well	09°49'31.7"N 08°51'51.3"E
15	TCNN, Bukuru	Site 15 (Jos South)	Borehole	09°47'52.2"N 08°52'58.8"E

16	Zang Sec. Sch. Bukuru	Site 16 (Jos South)	Well	09°48'20.1"N 08°52'00.1"E
17	Kuru, near NIPSS	Site 17 (Jos South)	Well	09°44'43.59"N 08°49'05.59"E
18	Vom, Christian Hospital	Site 18 (Jos South)	Borehole	09°42'10.00"N 08°43'42.34"E
19	Vom, Chugwi	Site 19 (Jos South)	Well	09°41'24.12"N 08°44'57.91"E

Sample Preparation and Analysis for Radon

Sample Preparation and Analysis

A total number of 19 water samples from boreholes and wells were collected and analysed for radon concentration. Samples of 1L were collected in pre-cleaned plastic empty Coke bottles. The containers were cleaned with detergent solutions in water and rinsed with distilled water to avoid contamination. For boreholes sources, the samples were collected after turning on and allowing free flow of water for over five minutes. This was to enable the water temperature to stabilize and also to purge any air that might have been trapped within the pressure line. More than 95% of the borehole sources were of the hand-pump type. The well samples were collected with the aid of bailers. The bottles were filled to the brim to prevent the occurrence of air bubbles in them. The samples were then carefully labeled indicating the date, time of collection and location. The samples were taken to the laboratory within the shortest possible time in order to reduce the decay coefficient. For all the samples, analysis was done before the elapse of the maximum holding time of 3days, thereby ruling out the need of any preservation. To avoid the samples giving up radon easily at higher temperatures, they were transported to the laboratory in a bag containing ice which provided low temperature condition of the samples. Although other methods of radon measurement in water such as Lucas Cell Scintillation, Liquid Scintillation Counting and Gamma Counting have shown their precision and quality, they are associated with some complexities which render them disadvantageous. However, an active approach using RAD 7 radon detector have proven to be very convenient and efficient for both in-situ and laboratory measurements of radon in water and soil (Saadi et al.,2018). The RAD 7 is a sophisticated measuring system widely used in laboratories, in the field and research work in several disciplines. This system enables ^{222}Rn to be released in continuously circulating air (in a closed air loop), which is in equilibrium with a constant stream of water passing through an air-water exchanger. The resulting alpha activity directly gives the radon concentration of the water.

Sample Analysis

The samples were analysed using the Durridge Inc. Rad 7 which is a sophisticated and active radon detector. This device uses a solid state detector (usually Silicon) that converts alpha radiation directly into an electrical signal. The system determines ^{222}Rn and ^{220}Rn (thoron) activity concentration released into continuously circulating air (in closed loop), which is in equilibrium with a constant stream of water passing through an air water exchanger. To analyse radon in water, an accessory RADH$_2$O is connected to the Rad 7, which uses a computer driven electronic detector with pre-programmed set ups that prints out a summary showing the average radon reading in 30 minutes. The RAD7/RADH$_2$O system is well documented (Durridge, 2013).

Contribution of Radon Concentration in Water to Indoor Air

The concentration of radon in indoor that would accumulate owing to the contribution of radon concentration in the drinking water samples when used, were calculated using an expression originally proposed by Nazaroff et. al. (1987), and later modified as given below:-

$$C_a\,^{222}\text{Rn} = C_w\,^{222}\text{Rn} \times W \times \frac{e}{V \times \lambda c}$$

Where: $C_a\,^{222}$Rn, is the contribution of radon concentration in drinking water to indoor radon concentration (BqL^{-1})

$C_w\,^{222}$Rn, is the radon concentration of water (Bq/L)

W, is the water consumption (0.01m^3/h per person)

V, is the bulk of indoor room (20m^3 per person)

E, is the coefficient of radon transfer from domestic water to indoor air (0.5),

λc, is the air exchange rate (0.7h^{-1}) (UNSCEAR, 1993 and Xinwei, 2006)

The above equation can be re-written as

$$C_a\,^{222}\text{Rn} = C_w\,^{222}\text{Rn} \times f$$

Where: f is the conversion coefficient of radon in water or the contribution coefficient of water radon to indoor radon, whose value was obtained to be

3.57×10^{-4}, implying that 1Bq/L of ^{222}Rn in drinking water would produce an accessorial indoor concentration of 3.57×10^{-4} Bq/L.

The Annual Effective Dose (AED)

The AED (Sv) was calculated using:

AED (Sv) = K × G × C × t

Where: K is the ingesting dose conversion factor of ^{222}Rn (10^{-8}SvBq^{-1} and 2×10^{-8}SvBq^{-1} for adults and children respectively)

G, is the water consumption per day (2 liters/day and 1 liter/day for adults and children respectively)

C, is the concentration of ^{222}Rn (Bq/L)

t, the period of consumption, (365 days or 1 year) (Binesh et. al., 2010, UNSCEAR, 1993)

Table 2: Results

S/n	Source of water	Sample point	Mean ^{222}Rn concentration (BqL^{-1})	Annual effective dose (mSv/y) for adults	Contribution of ^{222}Rn concentration in water to indoor air $(BqL^{-1}) \times 10^{-4}$
1	Well	JN 1 (land & survey HQtr)	4.68	0.03	16.71
2	Borehole	JN 2 (Tudun Wada Park)	28.71	0.21	102.49
3	Well	JN 3 (Alheri Area)	21.67	0.16	77.36
4	Borehole	JN 4 (Faringada)	13.07	0.09	46.66
5	Well	JN 5 (Bauchi Road)	16.55	0.12	59.08
6	Well	JN 6 (Uni. Jos Staff Qtrs)	11.46	0.08	40.91

7	Borehole	JN 7 (Odus, Bauchi by Pass)	7.20	0.05	25.70
8	Borehole	JN 8 (Chwdnyap, by Pass)	59.41	0.43	212.09
9	Borehole	JN 9 (Fudawa, Opp. Nasarawa area)	43.11	0.31	153.90
10	Borehole	JN 10 (Tina Junction)	16.06	0.12	57.33
11	Well	JS 11 (Abbatoir Jos South)	22.37	0.16	79.86
12	Well	JS 12 (Namua, Bukuru Road)	16.65	0.12	59.44
13	Well	JS 13 (Rayfield)	10.06	0.07	35.91
14	Well	JS 14 (Sabon Barki, Bukuru Road)	6.22	0.04	22.21
15	Borehole	JS 15 (TCNN, Bukuru)	15.56	0.11	55.55
16	Well	JS 16 (Zang Sec. Sch. Bukuru)	17.26	0.13	61.62
17	Well	JS 17 (Kuru, near NIPSS)	4.14	0.03	14.78

18	Borehole	JS 18 (Vom, Christian Hospital)	5.99	0.04	21.38
19	Well	JS 19 (Vom, Chugwi)	2.77	0.02	9.89
	Total		322.94	3.324	1152.87
	Mean		17.00	0.12	61.00
	Std D		14.18	0.31	50.62

Results and Discussion

Radon Concentration

Radon concentrations in the water samples table 2 highlights the results of the ground water Rn^{-222} (radon) concentration, the annual effective dose and the estimated contribution of ^{222}Rn concentration in water to indoor air. The values of the radon concentration ranged between 2.77Bq/L to 59.41Bq/L. the mean value was 17.00Bq/L. Irrespective of the sources, 13 (68%) out of the 19 samples had radon concentrations higher than the MCL of 11.1Bq/L (USEPA, 2003) and the world average value of 10Bq/L (UNSCEAR, 1993); World Health Organization (WHO, 2004). For the 8 borehole samples, the concentration values ranged between 5.99Bq/L to 59.41Bq/L, while the mean value was 23.64Bq/L. These values are in agreement with previous work in the Jos Plateau (Farai and Sanni, 1999). The relatively high values may be attributed to the crystalline nature of the rocks of the Jos Plateau, whose aquifer is the fractured crystalline type which are easily tapped for borehole, hand dug wells and mining ponds (Ozoko, 2014).

In the case of hand dug wells, numbering 11, the radon concentrations ranged from 2.77Bq/L to 22.37Bq/L, while the mean was 11.91Bq/L. Six out of these samples had radon concentration greater than the maximum permitted limit of 11.1Bq/L (USEPA, 2003). Some of the samples had unusually high values inspite of the shallow nature of the wells. This may be explained by the generally high background radiation in the Jos environment (Jwanbot et. al., 2013 and Farai and Sanni, 1999). However, some wells had higher radon concentrations than some boreholes. This could be attributed to the highly variable nature of groundwater radon concentrations. Hence, the concentrations of radon in groundwater at specific sites cannot be predicted (USGS, 2007).

More so, the variability in radon activity concentrations does not only exist among the different water types but also within the same type. This can however be explained by their origin, lithology of the acquifer host rock and the different processes through which the water reaches the consumer (Jobbagy et. al., 2017).

Assessment of the Annual Effective Dose

The annual possible effective dose to an individual consumer (adult) due to the intake of radionuclides (^{222}Rn, ^{3}H, ^{40}K, etc) from drinking water was evaluated. As depicted in table above, the minimum and maximum effective doses from the samples were 0.02mSv/y and 0.43msv/y respectively, whereas the overall mean was 0.12mSv/y, while that of wells was 0.09mSv/y. it was observed that, 62.5% of the borehole samples, and 45.5% of the well samples had AED greater than the 0.1mSv/y maximum permissible limit for adult consumers (WHO, 2004).

However, none of the samples had an AED of up to the 1mSv/y recommended dose limit for members of the public (UNSCEAR, 2000 and WHO, 1993).

The average radon concentration obtained in this study (17.00Bq/L) will therefore correspond to an AED, 0.12mSv/y, which is not up to the world average value (UNSCEAR, 1993). The comparison with the world average may not be justified since the world average is population weighted, whereas the value obtained in this study is not.

Contribution of Radon Concentration in Drinking Water to Indoor Air

The radon concentration in indoor environment that would result from the use of the drinking water samples ranged between 9.89×10^{-4}Bq/L to 212.09×10^{-4}Bq/L. the contribution of the indoor radon is significantly higher fort the water taken from the location with the maximum value (JN9), which is from a borehole. Generally, samples locations with high values of radon concentration will have corresponding high values of radon concentration indoor since the latter is directly proportional to the former.

Comparison of Radon Concentration in Drinking Water with Previous Work

Radon concentration (Bq/L)

S/n	Range	Source	Methodology	Country	References
1	1.7-161.6	Spring, Borehole	Gamma-ray Spectrometer	Nigeria, 1992	
2	2.2-410	Spring, Well	Liquid Scintillation Counter	Kenya, 2002	

3	11.1-11,100	Wells (Boreholes)	LSC	U.S.A, 2006	
4	0.91-49.6	Spring, Well	E-PERM	Lebanon, 2007	
5	5.40-46.74	Well (Boreholes)	Nuclear Track Detector	Ghana, 2012	
6	0.42-10.52	Wells (Boreholes)	Liquid Scintillation Counter	Poland, 2014	
7	0.76-9.15	Well (Boreholes)	RAD 7	Saudi Arabia, 2015	
8	0.5-22	Well (Boreholes)	RAD 7	India, 2016	
9	17.06-24.08	Boreholes/Open well	LSC	Nigeria, 2018	
10	2.77-59.41	Borehole/Open well	RAD 7	This work	

Conclusion

The RAD7 RADH$_2$O system has been used to measure the radon concentration of groundwater samples from the study area. Using the radon concentration values, the indoor radon concentration that would result from the use of the water indoors were calculated. It was observed that the geological structure and the high background radiation in the environment of the study are is a predominant factor for the high, and relatively high radon concentrations in the boreholes, and some wells respectively. Though the effective dose appears lower than the world average, the high radon levels compared to most of the data obtained from the northern and central states of Nigeria, and the effects of prolonged exposure to radiation may be hazardous to the health of the inhabitants of the study area. The public water system which utilizes local dams already being used in some parts of Jos metropolis should be improved upon, in order to reduce heavy reliance on the use of groundwater. There is also the need to enlighten the public on the effects of radon, and methods of mitigating it.

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