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Radon Emanation and Physicochemical Parameters Assessment of Well Water in Selected Area in Ondo State, Nigeria

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Abstract

In this study, water samples collected from hand-dug wells in Akoko area, Ondo State, Southwestern Nigeria, were analyzed for radon concentration using scintillation counter and physicochemical parameters such as turbidity, conductivity, PH, total dissolved solid, and temperature by chemical analysis. The concentration of radon was in the range 13.42 to 22.47 Bql^{-1} with a mean value of 17.25±2.03 Bql^{-1}. The radon concentration in all the water samples was more than 11.1 Bql^{-1} which is the maximum contamination limit proposed by the United State Environmental Protection Agency. Likewise, all the samples had radon activity concentration less than 100 Bql^{-1} WHO recommendation for protecting the public from radon exposure due to drinking water supplies. The estimated dose to the stomach varied from 4.10 to 6.87 (μSvy^{-1}) while the dose to the lung varied from 4.05 to 6.79 ($nSvy^{-1}$) with an average dose of 5.27±0.62 (μSvy^{-1}) and 5.21±0.61 ($nSvy^{-1}$) respectively. The total effective doses attributable to inhalation and ingestion of radon in the dug well water ranged from 37.88 to 63.43 ($nSvy^{-1}$) with an average value of 48.69± 5.72 ($nSvy^{-1}$). None of the water samples exceeded the individual dose criterion of 0.1 mSy^{-1}, this showed that the water from the wells are safe for drinking purposes. The physicochemical parameters results showed various physical and chemical parameters ranged, temperature (28.7-29.7)^{o}C, PH (6.13-7.11), TDS (31.1-1210) mgl^{-1}, electrical conductivity (46-1421) μscm^{-1}, turbidity (1.33-5.01) NTU. Most of the physicochemical parameters are within the WHO safe limits.

1. Introduction

Radon, a natural radioactive gas, is a chemically and biologically inert gas without odour, colour and taste. It is water soluble, imperceptible to the sense and has a half-life of 3.8 days [1]. Radon is found naturally in groundwater as a direct decay product of ^{226}Ra in the ^{238}U decay series of element. From the point of production in the rocks, radon being a noble gas, is capable of diffusing through pore spaces nearest to a geological fault. Radon can also travel by convection when there is presence of cracks and faults in rock [2]. The short half-life of radon and its solubility property have enabled radon gas to be used as a natural groundwater tracer to recognize and measure groundwater emission to surface water. In addition, radon easily dissolve in groundwater during its movements towards the land surface. Radon in well water can get into the body of human being through two ways; firstly, when the water is being used as a source of drinking water, it enter through the gastro-intestinal tract by ingestion, secondly, when it is being used for household activities, it escapes into indoor air and is inhaled. [3,4]

It has been noted that groundwater can be rich in radon, especially in places rich in granitic rock [5]. In surface water like a lake or river, radon is promptly made available into outer air when it moves over rocks and soils. Higher radon concentration is usually found in groundwater from wells and boreholes than in surface water [6]. Elevated amount of radon may be found in drinking water that derived its source from groundwater. The lining of the stomach may receive a radiation dose from radon ingested in drinking water [6]. Besides, certain amounts of doses may be received by other organs of the body such as the kidney and the bone marrow by somebody who take in radon dissolved water. Radon concentration in groundwater is affected by many factors such as concentration of uranium in the surrounding rock, distribution of the aquifer with respect to the surrounding rock [2]. Several radioactive compounds that are being liberated into the surroundings find their way into drinking water supply through the activities of human and man-made sources [6].

In addition, natural radionuclides ^{40}K, ^{226}Ra, ^{228}Ra, ^{234}U, ^{238}U and ^{210}Pb could be available in water due to natural process like mining, production of phosphate fertilizer or mineral sands processing. In the same vein, manufactured radionuclides may get into drinking water sources through usual industrial processes, inappropriate medical or industrial use and past release of radionuclides into water sources in the environment [6]. Furthermore, radon can enter indoor air when the groundwater is used in household activities like showering, washing, or when the tap is turned on [4]. The most important radon originator in indoor air is from natural pile up from the environment. Inhalation, rather than ingestion takes the largest dose ascribed to radon in drinking water [6]. The health effect due to radon is caused by either inhalation of radon or its progeny which could give rise to cancer of the lung or ingestion of radon in water which could make the risk in several internal organs becoming larger, especially the stomach. Researches testify from both human and animal studies that exposure to radon within any reasonable dose may increase the long time relative frequency of occurrence of cancer [6]. The classification of radon as a carcinogen has led to many researches in various part of the world [7–17]

The importance of water to life is unquantifiable. There is limited quantity of water on earth and the state of its quality demand attention. Maintaining the quantity of clean water for the purpose of drinking, production of food and recreation is imperative. The quality of clean water can be endangered by the presence of materials that are radioactive, infectious agents and toxic chemicals [18]. The quality of water is also distinguished by its biological, physical and chemical feature in relation to other hydrological properties [3,19]. Impure water could be attributed to be the cause of almost 80 % of the majority of the diseases in human [3]).

Apart from this, well water contains at least one trace element. Private Wells are not subject to regulations and could contain large amounts of unwanted chemicals. Contamination of private wells can be by natural occurrence and man-made sources. Basic parameters such as PH, conductivity, turbidity, colour and Escherichia coli have been recommended for regular monitoring (WHO, 2011). PH is the quantity of the hydrogen ion concentration in a solution. PH is a significant attribute of water, though it does not have any immediate consequences on consumer [6]. Total Dissolved Solid (TDS) in (mgl^{-1}) is the quantity of the mass of solid materials dissolved in a given volume of water. This comprises of whatsoever exist in the water beside the clean water molecules. Electrical Conductivity (EC) (μscm^{-1}) is the capacity of the water to conduct electricity. The solid materials that dissolve in water could split into positive and negative charged ions which conduct electricity. Turbidity in (Nephelometric Turbidity Unit, NTU) is an optical property of water that measures the relative clarity of the water. It measures the quantity of the scattered light by material in the water when light glowed via the water. The intensity of scattered light varies directly with the turbidity.

In Akoko area, the most accessible source of water that is available to each community without much difficulty is groundwater harnessed as dug well or drilled well popularly called bore hole by home owners for drinking and domestic purposes. In some homes, pumping machines are inserted inside the wells so that the wells remain closed throughout and the water pumped indoor for home use. Furthermore, the study area is characterized by granitic rock. Some parts of the area have shown higher indoor and outdoor radiation exposure dose in measurements across Ondo state [20,21]. This research was carried out to assess the concentration of radon in selected well water across Akoko area using Scintillation Counters. Physicochemical parameters such as PH, Turbidity, Total Dissolved Solid (TDS) and Electrical Conductivity [6] were also estimated in order to assess the quality of the well water. Previously, in Nigeria researchers have done various work on radon concentration. Some of which are [22–25].

2. Materials and Method

2.1 Study area

This research was carried out in Akoko area of Ondo State. The area lies between longitude 5^o30^1 and 6^o30^1 of Greenwich meridian and latitude 7^o20^1 and 7^o45^1 north of the equator. It occupies about 835,500 square kilometers of land. Akoko area is bounded by Ekiti States in the West, Edo State in the East, Ekiti and Kogi States in the North and by Owo and Ose Local Government Areas of Ondo State in the South. The area composes of undulating lowlands with disjointed hills. It is located within the transition zone of the tropical equatorial climate of Southern Nigeria and tropical continental climate of Northern Nigeria. The whole amount of rainfall in the area is around 1200 mm and the average temperature is roughly 21^oC. The range of the annual temperature is around 3^oC and the average relative humidity nearly 80 % [26]. Akoko area is located in the basement complex of Southwestern Nigeria, mostly called migmatite gneiss quartzite complex [21]. The rock types that could be found in the area includes, quartzite, grey gneiss, granite gneiss and other subordinates such as Charnokite [21].

2.2 Water Samples Collection

A total of 30 samples of well water were taken randomly at dissimilar locations and depth in prewashed one liter plastic bottles for radon concentration and physicochemical parameters measurement. The samples were taken during the dry season between January and February. The location of the wells were taken by the GPS and samples were taken in every community in the study region. The bailer was used to collect the water from the well. The plastic bottles were cautiously submersed into the bailer to be filled with water samples without any air bubbles. In an easy way and with no space on top, the plastic bottles were completely filled with the well water. After collection the bottles were immediately plastered with tape, labelled with date and time of collection. The temperature of the water samples were taken at every location using mercury thermometer during sampling. The water samples were transported to the laboratory in a container containing ice blocks in a short time.

2.3 Measurement of ^{222}Rn in water

The measurement of radon concentration was carried out in Ahmadu Bello University, Zaria, Nigeria, at The Centre for Energy Research and Training, using a well calibrated Liquid Scintillation Analyzer (Tri-carb-LSA 1000) (CERT). With the use of a hypodermic syringe, about 10 ml of each water sample was added into a scintillation ampule containing 10 ml of Insta-gel scintillation cocktail. In order to extract radon-222 in water stage into the organic scintillation, the ampules were capped firmly and in a vigorous manner shaken for 3 minutes. The samples were left for 3 hours after preparation so that radioactive equilibrium could be established between radon-222 and its progeny.

The radon-222 activity concentration from the samples was calculated using Equation (1) [22].

$$C_{Rn}(Bql^{-1}) = \frac{100\times(SC-BC)\exp(\lambda t)}{60\times CF\times D} \quad (1)$$

Where C_{Rn} is Concentration of Radon-222 in Becquerel per liter, SC is sample count (Count min^{-1}), BC is background count ($Count\ min^{-1}$), t is time elapsed between sampling to counting (minutes), $\boldsymbol{\lambda}$ is decay constant ($1.26\times10^{-4}\ min^{-1}$), 100 is conversion factor from per 10ml to per liter, CF is calibration factor, D is fraction of ^{222}Rn in the cocktail in a ampule of 22 ml total content for 10ml of sample, 10 ml of cocktail and 2 ml of air.

2.4 Estimation of Annual Effective Dose

Well water is used for drinking, bathing and all household chores in this area. The annual effective doses due to ingestion of radon in water through the process of drinking and due to inhalation of radon in water from other uses were determined. The ingestion dose was calculated using Equation (2) [4].

$$H_{Ing}(\mu Svy^{-1}) = C_{water} \times D_{ing} \times L \quad (2)$$

Where H_{ing} is the annual effective dose due to ingestion, C_{water} is the concentration of radon in water (Bql^{-1}), L is the annual ingested volume of drinking water, assumed to be 730 ly^{-1} [27], D_{ing} is the coefficient for annual effective dose due to ingestion (3.5 $nSvBq^{-1}$) [1,28].

The inhalation dose was calculated using Equation (3) [4,28].

$$H_{Inh}(\mu Svy^{-1}) = A_{RNW} \times C_{aw} \times F \times I \times DCF \quad (3)$$

Where H_{ing} is the annual effective dose due to inhalation, C_{aw} is the ratio of radon in air to radon in water (10^{-4}), A_{RNW} is the concentration of radon in water samples (Bql^{-1}), F is the equilibrium factor between radon and its progenies (0.4), I is the occupancy time for indoor (7000 hy^{-1}) and DCF is the radon exposure dose conversion factor {9 nSv $(Bqhm^{-1})^{-1}$}.

2.5 Dose Contribution to the Lung due to Inhalation

It is the product of the lung tissue weighted factor (0.1199) and corresponding inhalation dose using Equation (4)

$$Dose\ to\ the\ Lung\ (D_{lung}) = H_{inh} \times 0.1199 \quad [28] \quad (4)$$

2.6 Dose Contribution to the Stomach due to Ingestion

It is product of the stomach tissue weighted factor (0.1196) with corresponding ingestion dose using Equation (5) below

$$Dose\ to\ the\ Stomach\ (D_{stomach}) = H_{ing} \times 0.1196 \quad [28] \quad (5)$$

3. Results and Discussion

Table 1: The concentration of radon and annual effective dose to the stomach and lung in well water samples in Akoko area

Samples	Location	Radon Concentration (Bql^{-1})	H_{ing} (μSvy^{-1})	H_{inh} ($nSvy^{-1}$)	$D_{stomach}$ (μSv^{-1})	D_{lung} ($nSvy^{-1}$)	Total dose ($nSvy^{-1}$)
1	N 07º27'29.0" E 005º48'10.9"	17.19	43.93	43.31	5.25	5.20	48.53
2	N 07º27'48.1" E 005º48'21.1"	19.43	49.65	48.97	5.94	5.87	54.53
3	N 07º27'46.9"	20.75	53.01	52.29	6.34	6.27	58.56

	E 005°48’26.5”						
4	N 07°27’37.2”	15.73	40.19	39.65	4.81	4.75	44.40
	E 005°48’27.4”						
5	N 07°27’20.4”	22.47	57.42	56.63	6.87	6.79	63.43
	E 005°48’19.0”						
6	N 07°27’14.2”	18.03	46.08	45.45	5.51	5.45	50.89
	E 005°51’38.9”						
7	N 07°27’16.1”	17.86	45.64	45.02	5.46	5.40	50.41
	E 005°51’45.3”						
8	N 07°27’31.9”	18.81	48.07	47.41	5.75	5.68	53.09
	E 005°52’06.1”						
9	N 07°27’36.2”	19.08	48.74	48.07	5.83	5.77	53.83
	E 005°52’19.4”						
10	N 07°27’39.5”	16.94	43.29	42.70	5.18	5.12	47.82
	E 005°52’34.3”						
11	N 07°27’12.7”	16.01	40.92	40.34	4.89	4.84	45.19
	E 005°54’40.6”						
12	N 07°27’12.3”	13.42	34.29	33.82	4.10	4.06	37.88
	E 005°54’44.2”						
13	N 07°27’07.8”	17.81	45.51	44.88	5.44	5.38	50.27
	E 005°54’35.1”						
14	N 07°27’07.5”	18.84	48.15	47.49	5.76	5.70	53.18
	E 005°54’39.6”						
15	N 07°27’13.3”	21.02	53.69	52.96	6.42	6.35	59.31
	E 005°54’46.0”						
16	N 07°27’15.7”	18.11	46.26	45.63	5.53	5.47	51.09
	E 005°44’09.5”						

17	N 07º28̕11.2" E 005º44'19.5"	16.55	42.28	41.70	5.06	5.00	46.70
18	N 07º28̕08.3" E 005º44'07.7"	16.97	43.36	42.76	5.19	5.13	47.89
19	N 07º28̕06.3" E 005º44'13.1"	16.00	40.88	40.32	4.89	4.83	45.15
20	N 07º28̕11.5" E 005º44'16.7"	15.42	39.39	38.85	4.71	4.66	43.51
21	N 07º27̕12.4" E 005º41'33.9"	16.7	42.68	42.09	5.10	5.05	47.14
22	N 07º27̕09.5" E 005º41'33.1"	16.59	42.38	4.1.80	5.07	5.01	46.81
23	N 07º27̕12.7" E 005º41'29.1"	15.71	40.15	39.60	4.80	4.75	44.35
24	N 07º27̕15.6" E 005º41'20.7"	17.83	45.55	44.93	5.45	5.39	50.32
25	N 07º27̕23.9" E 005º41'35.6"	17.98	45.93	45.30	5.49	5.43	50.73
26	N 07º31̕32.0" E 005º45'03.8"	15.96	40.78	40.23	4.88	4.82	45.05
27	N 07º31̕30.1" E 005º45'01.3"	16.1	41.12	40.56	4.92	4.86	45.42
28	N 07º31̕35.3" E 005º45'02.4"	14.59	37.28	36.77	4.46	4.41	41.18
29	N 07º31̕37.6" E 005º45'06.0"	15.4	39.35	38.81	4.71	4.65	43.47
30	N 07º31̕37.4" E 005º45'14.8"	14.25	36.42	35.92	4.65	4.31	40.23

Table 1 present the results of the radon concentration in the collected 30 water samples from dug wells at different locations in Akoko area. The result showed that concentration of radon varied between 13.42 to 22.47 Bql^{-1} with a mean value of 17.25±2.03 Bql^{-1}. The concentration of radon was in the range 13.42 to 22.47 Bql^{-1} with a mean value of 17.25±2.03 Bql^{-1}. The radon concentration in all the water samples was more than 11.1 Bql^{-1} which is the maximum contamination limit. Likewise, all the samples have radon activity concentration less than 100 Bql^{-1} [6] recommendation for protecting the public from radon exposure due to ingested water.

Likewise, Table 1 present the results of the annual effective dose due to ingestion and inhalation, dose contribution to the lung due to inhalation, dose contribution to the stomach due to ingestion, per person for adults, and the effective total inhalation and ingestion dose contribution to the population due to the ^{222}Rn in water. The dose from ingestion varied from 34.29 to 57.42 (μSvy^{-1}) with an average dose of 44.08 ± 5.18(μSvy^{-1}). The doe from inhalation varied from 33.82 to 56.63 ($nSvy^{-1}$) with an average value of 43.48±5.11 ($nSvy^{-1}$). The estimated dose to the stomach varies from 4.10 to 6.87 (μSvy^{-1}) while the dose to the lung varies from 4.06 to 6.79 ($nSvy^{-1}$) with an average dose of 5.27±0.62 (μSvy^{-1}) and 5.21±0.61 ($nSvy^{-1}$). The effective total dose contribution in the dug well water varied from 37.88 to 63.43 ($nSvy^{-1}$) with an average value of 48.69± 5.72 ($nSvy^{-1}$).

Taking 2 liters of water in a day for 1 year by an individual would give in an effective dose of 0.1 $mSvy^{-1}$ [6]. The individual dose criterion (IDC) of 0.1 $mSvy^{-1}$ present a minimal risk that should not develop any noticeable unsuitable health issue in drinking water [6]. None of the water samples exceeded the dose criterion to an individual of 0.1 mSy^{-1}. This shows that using the water from the wells for drinking purpose is free of radiological risks. The average effective total dose value of 48.69 ($nSvy^{-1}$) is also less than the 1 $mSvy^{-1}$ accepted dose limit for the general public in exposure to radiation.

The results of the physicochemical parameters of the sampled well water is presented in Table 2. The PH value varies from 6.13 to 7.11 with an average value of 6.66. WHO (2011) advises PH range to be between 6.5 and 8.5. 20 % of the water samples were below the range 6.5 to 8.5 but none was above the limit. TDS varies between 31.1 mgl^{-1} to 1210 mgl^{-1} with a mean value of 347 mgl^{-1}. The palatability of drinking water with a TDS value below 600 mgl^{-1} is considered okay, for a TDS value above 1000 mgl^{-1}, the unacceptability increases and becomes substantial [6]. The TDS contents of the water from all the sampling points were below the WHO maximum contaminants level of 1000 mgl^{-1}. The electrical conductivity varies between 46 μscm^{-1} and 1421 μscm^{-1} with a mean value of 499.1 μscm^{-1}. 7 % of the sampled water had conductivity more than the WHO maximum contaminant level of 1200 μscm^{-1} [22]. The turbidity varies between 1.33 NTU and 56.01 NTU with an average value of 6.32 NTU. Turbidity is a vital sign of the probable existence of impurities that may cause health anxiety, specifically from inefficiently preserved or unclean surface water. The temperature ranges from 28.7 ^oC to 29.7 ^oC with a mean value of 29.14 ^oC. Cold water is largely more acceptable to taste than warm water. Increase in the temperature of water enriches the development of microbe and may enlarge problems related to palatability, smell and colour [6].

Table 2: Physicochemical parameters of water samples from dug wells in Akoko area

Samples	**Location**	**Conductivity (μscm^{-1})**	**TDS (mgl^{-1})**	**PH**	**Turbidity (NTU)**	**Temp (ºC)**
1	N 07º27’29.0” E 005º48’10.9”	137	144	6.94	2.14	29.3
2	N 07º27’48.1” E 005º48’21.1”	591	463	6.93	2.16	29.6
3	N 07º27’46.9” E 005º48’26.5”	596	444	6.89	2.77	29.7
4	N 07º27’37.2” E 005º48’27.4”	887	590	6.85	9.17	29.7
5	N 07º27’20.4” E 005º48’19.0”	550	366	6.7	2.37	29.3
6	N 07º27’14.2” E 005º51’38.9”	438	298	6.69	2.34	29.3
7	N 07º27’16.1” E 005º51’45.3”	637	422	6.66	2.49	29.3
8	N 07º27’31.9” E 005º52’06.1”	906	604	6.66	13.24	29.1
9	N 07º27’36.2” E 005º52’19.4”	333	230	6.65	2.37	29.1
10	N 07º27’39.5” E 005º52’34.3”	440	284	6.93	2.46	29.0
11	N 07º27’12.7” E 005º54’40.6”	797	531	6.71	18.13	29.3
12	N 07º27’12.3” E 005º54’44.2”	481	332	6.95	2.61	29.1
13	N 07º27’07.8”	185	119	7.10	2.11	28.7

	E 005^{o}54’35.1”					
14	N 07^{o}27’07.5”	249	166	6.84	2.02	28.7
	E 005^{o}54’39.6”					
15	N 07^{o}27’13.3”	1399	936	6.55	23.02	29.0
	E 005^{o}54’46.0”					
16	N 07^{o}27’15.7”	535	363	6.47	2.04	28.9
	E 005^{o}44’09.5”					
17	N 07^{o}28’11.2”	385	254	6.69	2.13	29.2
	E 005^{o}44’19.5”					
18	N 07^{o}28’08.3”	785	524	6.48	8.56	29.0
	E 005^{o}44’07.7”					
19	N 07^{o}28’06.3”	333	211	6.28	1.46	28.7
	E 005^{o}44’13.1”					
20	N 07^{o}28’11.5”	762	510	6.49	8.11	28.9
	E 005^{o}44’16.7”					
21	N 07^{o}27’12.4”	395	273	6.13	2.26	28.9
	E 005^{o}41’33.9”					
22	N 07^{o}27’09.5”	250	166	6.43	1.89	29.2
	E 005^{o}41’33.1”					
23	N 07^{o}27’12.7”	171	114	6.66	2.31	29.1
	E 005^{o}41’29.1”					
24	N 07^{o}27’15.6”	220	143	6.50	3.24	29.2
	E 005^{o}41’20.7”					
25	N 07^{o}27’23.9”	46	31	6.79	1.33	29.5
	E 005^{o}41’35.6”					
26	N 07^{o}31’32.0”	199	129	6.46	2.36	29.2
	E 005^{o}45’03.8”					

27	N07º31̓30.1” E005º45’01.3”	375	243	6.39	2.24	29.3
28	N 07º31̓35.3” E 005º45’02.4”	215	140	6.55	3.11	29.2
29	N 07º31̓37.6” E 005º45’06.0”	1421	1210	7.11	56.01	28.8
30	N 07º31̓37.4” E 005º45’14.8”	255	170	6.45	3.24	29.0

4. Conclusion

This research work herein present the results of radon concentration and physicochemical parameters in hand-dug well water in Akoko area, Ondo State, Nigeria. The radon concentrations in all the water samples were greater than the 11.1 Bql^{-1} USEPA recommendation but lower than 100 Bql^{-1} WHO limit. The average annual effective dose values owing to inhalation and ingestion of radon were lesser than 0.1 $mSvy^{-1}$ WHO guidance level. The research further showed that the physicochemical parameters in most water samples studied lies in the range of the WHO safe limit. Therefore, the well water in the research neighbourhood is safe for consumption and household undertakings.

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