Preliminary probe of radon content in drinking water in Ibadan, south-western Nigeria

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ABSTRACT

***Background*:** It is generally accepted that smokers are more prone to lung cancers, however non-smokers also are at high risk if they are exposed to higher concentration of radon. Radon has been the major source of this alpha particle. ***Materials and Methods*:** The use of water in day to day activities has immensely increase the rate of exposure to radon in indoor. Therefore, 42 water samples (30 well and 12 borehole water) use for such domestics activities were systemically collected from different places for radon probing with the aid of an electronic active detector RAD7 produced by Durridge USA. The annual inhalation and ingestion were also estimated from the water samples. ***Result*:** After probing the radon in the water samples, the obtained results ranged for well and borehole water samples were 0.08 to 14.8 Bq/l and 0.004 to 5.41 Bq/l respectively. Statistical analysis results confirmed that there is a significant difference between the mean value of radon concentration in different sources of water from both well and borehole, (p=0.000). The estimated inhalation and ingestion doses were lower than the world average reference level. ***Conclusion*:** The areas with higher radon concentration in their water samples should take necessary actions to avoid consequences from exposure to higher radon. The total annual effective dose due to inhalation and ingestion were estimated to be 10.0 µSv/y for well water and 8.579 µSv/y for bore hole water which were lower than the recommended action level of 0.1 mSvy^{-1} set by WHO.

INTRODUCTION

Radon is a member of Uranium 238 decay series with short live daughter and contributes about 50% of natural radiation to human exposure, it is also associated with health risk when found in higher concentration in indoor or in water [1, 2]. The presence of radon in water has been attributed to these factors; nature of bedrock, soil type, presence of faults, cracks or fractures in the basement rock, permeability, physical, chemical or nature of geological aquifers [3, 4]. Water is vital for life's survival, its availability and quality is important to humans day to day activities [5, 6].Therefore, Preserving the quality of water cannot but be given an adequate attention because of potential hazards attached to water that is contaminated with pollutants such as infectious agents, toxic chemicals and radiological hazards and one of the major radionuclides that possess such threat is radon. The long-term health effect of exposure to radon and its daughter from different sources over the past few decades cannot be over-emphasized [7]. It is reported from WHO, UNSCEAR and other agencies saddled with the responsibility of action plans on radon that radon is the leading major cause of lung cancer among passive or non-smokers. Radon is associated with lung and stomach cancer [2, 4, 8]. It is important to examine the level of internal exposure of radiation as a result of radon in drinking water to the populace of this region. Oni and other colleagues in 2014 carried out research on radon concentration in ground water of high background radiation in south-western Nigeria on 112 samples [9]. The results revealed steady trend of variation in the concentration of radon. However, all water samples assayed were greater than standard organization of Nigeria (SON), reference level for all radionuclides Ademola and Oyeleke in a study conducted in Ibadan, reported that about 58% of the total water samples examined had a higher concentration of radon than the 11.1 Bq l^{-1} recommended by United States Environmental Protection Agency (USEPA); the AMs of six LGAs and GMs of three LGAs were higher than the recommended value [10]. In a similar research conducted in the region by Fatoki and Adomla 2020, it was reported that annual effective dose due to ingestion ranged from 0.020 ± 0.004 to 0.254 ± 0.353 mSv.y^{-1} (adults), that of inhalation varied from 0.303 ± 0.053 to 3.108 ± 4.440 µSv.y^{-1} with some results greater than value recommended by International Commission for Radiological Commission [11].

In a study conducted in 2020 at Perek State Malaysia by Habila Wuhu et al on Radon activity concentration measurement in water sources. The result shows that the radon in water is lower than EPA values action values of 11.1Bq/L [1].In a similar study conducted in 2012 at Mashhad Iran by Binesh, on the drinking water sources [12]. The results revealed that about 70% of water samples had radon concentration above 11.1Bq/L level recommended by USEPA. In addition to this, annual effective dose in stomach and lung per person were estimated with mean value of 0.040mSV and 0.043 mSV per year respectively. In a similar research investigated in 2017 by Malakootian and sultan in Ban villages on determination of radon concentration in drinking water, the results obtained show that the minimum radon was 1.2Bq/L which was water tank in Baravat [2]; with a mean value of 9.88Bq/L. The radon content in the drinking water were lower than WHO guidelines and EPA. In the study carried out 2019 in Ghana on an assessment of radon in same bottle water in market by Irene Upoku-Ntim, Owiredu Gyampo and Aba Bentol Anelam, the output of the research revealed that the range of radon gas in the bottle is 0.03 – 0.09Bq/L and 0.06 ± 0.01 Bq/L respectively. The range were found in the range of reference level sets by WHO [13]. Therefore, the present study was carried out to assess the level of radon-222 concentration in ground water in the selected areas and also estimate the annual effective dose of radon in the district of Ibadan.

Study area

This research was carried out in Ibadan metropolis, capital city of Oyo state South-western Nigeria. Ibadan was an administrative coordinating centre of the region during colonial period. Ibadan is the largest city in Nigeria with area of 3080 km^2 with estimated metro population of about 6,000,000. It is on Longitude 3^0 32' East of Greenwich Meridian and 7^0 32' North of the equator. Base on geological formation, the basement rock in Ibadan are classified as major and minor rock types. Quartize of the meta-sedimentary series, augen gneiss and magnetite were dominant, while pegmatite, quartz, aplite and amphibolites were found to be minor according to Akintola 1994 [14]. The area was carefully selected as shown in figure 1, because the inhabitants cannot access public water, therefore they were totally dependent on ground water for domestic activities coupled to the fact the area is densely populated and major houses for commercial activities in the centre.

MATERIALS AND METHODS

Sampling

A total of 42 ground water samples were collected in selected Local Government in Ibadan. The well water samples were systematically selected with the permission from the owners; however, access to borehole water was limited due to security challenges in the zone amidst tight security ten boreholes could be assayed in this work to have a representation of the area. In determining the radon contents, an error in the technique was avoided, sampling of water was done with minimum or no contact with air. Sample were collected with plastic bottles, which were filled and immediately screwed to avoid degassing [16, 17]. After the collection of the water samples from different location by using the standard procedure, the samples were then moved to Department of Physics, Radiation laboratory Ladoke Akintola University of Technology where the radon concentration in the samples were measured.

Measurement procedure

A well calibrated active electronic detector (RAD7) connected to a RAD accessory produced by Durridge Company, Incorporated, United State America (Durridge, 2013) was used for measuring radon in water by connecting it with a bubbling kit which enables it to degas radon from a water sample into the air in a closed loop. Within the closed loop is desiccant to dry the air before entering the detector for radon concentration measurement. The detector uses alpha spectrometry technique. The device is capable of obtaining radon between an hours of taking the samples [18]. The technique adopted by RAD H_20 was a closed loop aeration system that removed radon from water continuously till equilibrium position is attained as shown in figure 1. It is important to note that this state of equilibrium is attained within 5minutes, after the 5 minutes operation, the pump stops automatically and the process is repeated for 6 times, in which it takes 30 minutes to complete a measurement reading. In this work, a watt 250 protocol was adopted according to Malakootian *el al.* (2017) [2]. Before each measurement the RAD 7 device was purged for certain period of time to avoid accumulation of radon in the chamber [18]. In addition, Radon measurement from water samples were performed before the half-life of radon, therefore makes the use of decay correction not essential [1]. The figure 1 represents the diagram of RAD7 device operation.

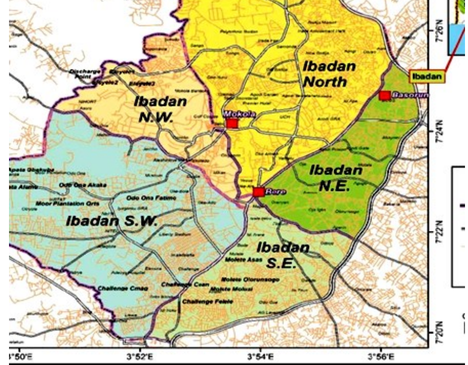

Figure 1. Map showing the study area [15].

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Since water contributes significantly to indoor radon, when the water it is being used for bathing and domestics' purposes in the study area, therefore, it is utmost essential to evaluate the amount of radon releases from ground water into radon air. This contribution of radon was determined according to equation 1 [19].

$$C_{aRn222} = C_{wRn222} \times w \times \frac{e}{V \times \lambda_c} \quad (1)$$

C_{aRn} 222: radon from water to indoor air radon contribution,
C_{wRn} 222: radon in water concentration,
w: water consumption per hour per person (0.01 m^3 h^{-1}),
e: the coefficient to indoor air (0.5)
V: bulk volume of indoor air per person (20 m^3)
λ_c: is the air exchange rate (0.7 h^{-1}) [20, 21].

Determination of annual effective doses of radon

When radon is dissolved in groundwater, it can cause radiation exposure by consumption of drinking water and inhalation of radon emitted into the atmosphere when water is utilised [22]. Humans' radiological threats from consuming and inhaling dissolved radon in utility water were calculated in terms of the effective radiation dose received by the general public as a result of frequent groundwater use. The annual effective dose for inhalation and ingestion were determined using the formulars in equations (2 and 3) below respectively

$$AED_{Winh} = C_{Rnw} \times R_{aW} \times F \times O \times DCF \quad (2)$$

AED_{Winh} : inhalation effective dose,
C_{Rnw} : radon concentration in water,
R_{aW} : ratio of radon in air to radon in water (10^{-4}),
F: the equillibrum factor between radon and its progenies (0,4),
O: average indoor occupancy time per individual (7000 h y^{-1}), and
DCF : dose conversation factor fpr radon exposure (9 $\times 10^{-6}$ mSv $Bq^{-1} h^{-1} m^{3}$) [19].

$$AED_{Wing} = C_{Rnw} \times C_w \times EDC \quad (3)$$

AED_{Wing} : the effective dose for ingestion,
C_{Rnw} : the radon concentration in water,
C_w : the weighted estimation for water consumption (730 L y^{-1}), and
EDC : the effective dose coefficient for ingestion (3.5 $\times 10^{-6}$ mSv $Bq^{-1} h^{-1} m^{3}$) [20, 21].

The dose contribution from inhalation and ingestion to the lung and stomach is estimated by multiplying the value of annual effective dose for ingestion and inhalation by the standard value of 0.12 for lung and stomach [23].

An Analysis of Variance (ANOVA) between the two sources of water were analysed by the use of BMI SPSS version 20. A p – value of less than 0.05 was considered as statistically significant.

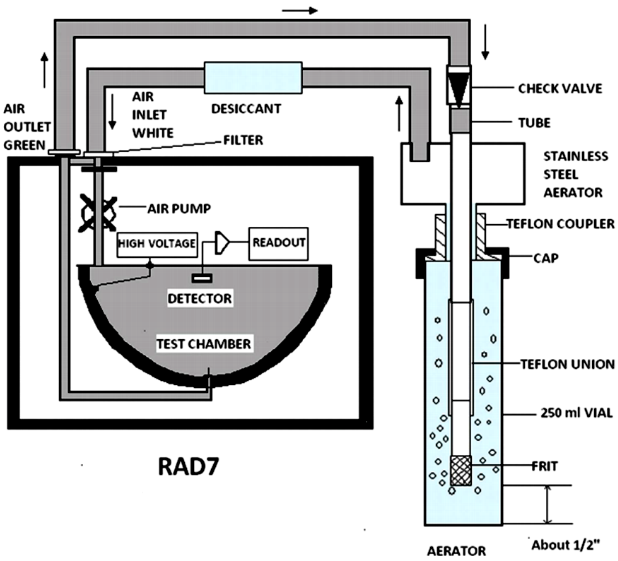

Figure 2. Schematic diagram of Rad 7.

RESULTS

Table 1 depicts the mean results of radon contents in water samples and its contribution from water to indoor air. The radon concentration of the different sources of water and its contribution to indoor air are show in table 2 and 3. The annual effective doses due to inhalation and ingestion are depict in table 4 and 5 respectively. The radon activity concentration in well water samples are within the range of 0.08 Bq/l and 14.8 Bq/l with the mean radon value of 3.415 Bq/l. These values were linked to Omi-Adio III and Odo ona Elewe III respectively. In addition, obtained results for the borehole water range from 0.004 Bq/l to 5.410 Bq/l with the mean of radon value of 1.684 Bq/l. The lowest radon activity was found in Olowoyo area while the highest was recorded in Odo ona II. The mean of the radon contribution into air that was estimated varies from 2.480 to 5.292 mBq/l. The obtained results were compared with the standard value of 11.1 Bq/l sets by USEPA, 6.67% of the water samples are greater than the values while 93.3% were lesser than the recommended values of 11.1 Bq/l set by USEPA as shown in the table 2 and 3 respectively.

The calculated annual effective dose for well water samples due to inhalation and ingestion are ranging from 0.202 μSv/y to 0.934 μSv/y and 0.2044 μSv/y to 37.9 μSv/y with an average of 4.97 and 5.03 μSv/y respectively, In addition the estimated result for borehole water samples as a result of inhalation and ingestion ranged from 0.011 μSv/y to 13.633 μSv/y and 0.011 μSv/y to 13.82 μSv/y with average of 4.256 μSv/y and 4.323 μSv/y respectively. The specific doses to lung and stomach for well water samples ranged from 0.02 to 4.482 μSv/y, 0.02 to

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4.553 with an average of 0.60 µSv/y and 0.61 respectively, for borehole water samples for lung and stomach was ranging from 0.001 to 1.636 µSv/y, 0.001 to 1.662 µSv/y with an average of 0.511 and 0.519 respectively as shown in table 4 and 5 respectively. The estimated annual effective doses for ingestion are compared with the world average value for drinking water set by European Commission at 0.1 mSv/y [12], it was observed the results in this work were within the standard limit.

Table 1. Average radon concentrations, average contributions to indoor air and the number of samples for each location.

CITY	WATER SAMPLE	SAMPLE NO.	AVERAGE RADON CONCENTRATION BQL^{-1}	AVERAGE CONTRIBUTION TO INDOOR AIR
ABEBI	Well water	5	1.296±0.654	0.466±1.18
AJAWENLE	Well water	6	3.692±0.467	1.33±0.385
OMI ADIO	Well water	3	0.57±0.467	0.21±0.167
BEERE	Well water	5	1.45±0.67	0.522±2.07
ODO ONA	Well water	3	5.805±1.56	2.07±0.853
ODO ONA	Bore hole	5	5.805±1.132	0.848±0.45
OWODE	Well water	2	8.473±3.14	3.026±1.685
OWODE	Borehole	2	2.16±1.16	0.77±o.655
APATA	Well water	3	5.786±2.91	1.966±1.12
APATA	Bore Hole	3	1.092±0.81	0.39±0.29
ARUTU	Well water	2	4.182±2.26	1.494±0.86
OLUYOLE	Well water	1	4.80±2.34	1.716±0.79
OLOWOYO	Bore Hole	1	0.004±0.0009	0.002±0.001
AWE	Bore Hole	1	0.794±0.52	0.284±0.52

Table 2. Radon concentration of well water and its contribution to indoor air

SAMPLE	LOCATION	SOURCE OF WATER	RADON CONC Bq/l	CONTRIBUTION OF RADON TO INDOOR
Well 1	ABEBI	WELL WATER	0.22±0.37	0.08±0.13
Well 2	ABEBI	WELL WATER	0.67±0.52	0.24±0.19
Well 3	ABEBI	WELL WATER	1.49±0.72	0.54±0.26
Well 4	ABEBI	WELL WATER	1.98±0.81	0.71±0.29
Well 5	ABEBI	WELL WATER	2.12±0.85	0.76±0.31
Well 6	AJAWENLE 1	WELL WATER	2.63±0.92	0.95±0.33
Well 7	AJAWENLE 1 MOSQUE	WELL WATER	2.77±0.95	1.00±0.34
Well 8	AJAWENLE 1	WELL WATER	3.40±1.03	1.22±0.37
Well 9	AJAWENLE 1	WELL WATER	3.61±1.06	1.30±0.38
Well 10	AJAWENLE 1	WELL WATER	3.80±1.09	1.37±0.39
Well 11	AJAWENLE 1	WELL WATER	5.94±1.33	2.14±0.48
Well 12	OMI-ADIO	WELL WATER	1.28±0.67	0.46±0.24
Well 13	OMI-ADIO	WELL WATER	0.35±0.43	0.13±0.15
Well 14	OMI-ADIO	WELL WATER	0.08±0.30	0.03±0.11
Well 15	BEERE	WELL WATER	0.18±0.34	0.06±0.12
Well 16	BEERE	WELL WATER	0.71±0.53	0.26±0.19
Well 17	BEERE	WELL WATER	1.51±0.73	0.54±0.26
Well 18	BEERE	WELL WATER	1.99±0.82	0.72±0.30
Well 19	BEERE	WELL WATER	2.86±0.95	1.03±0.34
Well 20	ODO-ONA ELEWE	WELL WATER	1.83±0.79	0.66±0.28
Well 21	ODO ONA	WELL WATER	0.766±0.34	0.274±0.12
Well 22	ODO ONA	WELL WATER	14.82±3.55	5.292±2.16
Well 23	OWODE	WELL WATER	5.652±2.58	2.018±1.28
Well 24	OWODE	WELL WATER	11.293±3.70	4.033±2.09
Well 25	APATA	WELL WATER	6.946±3.15	2.480±1.34
Well 26	APATA	WELL WATER	3.49±2.67	1.246±0.79
Well 27	ARUTU	WELL WATER	2.693±-1.96	0.962±0.52
Well 28	ARUTU	WELL WATER	5.67±2.56	2.025±1.19
Well 29	OLUYOLE	WELL WATER	4.806±2.34	1.716±0.79
Well 30	APATA	WELL WATER	6.923±2.90	2.472±1.24
Average radon			3.1415	1.223

Table 3. Radon concentration of bore hole and its contribution to indoor air.

SAMPLE	LOCATION	SOURCE OF WATER	RADON CONC	CONTRIBUTION OF RADON TO INDOOR
Borehole water 1	ODO ONA	BORE HOLE	1.346±0.98	0.481±0.02
Borehole water 2	ODO ONA	BORE HOLE	5.41±2.10	1.932±0.78
Borehole water 3	ODO ONA	BORE HOLE	0.763±0.52	0.272±0.52
Borehole water 4	ODO ONA	BORE HOLE	0.656±0.52	0.234±0.13
Borehole water 5	OLOWOYO	BORE HOLE	0.004±0.0009	0.002±0.001
Borehole water 6	APATA	BORE HOLE	0.767±0.52	0.274±0.25
Borehole water 7	APATA	BORE HOLE	1.263±0.98	0.451±0.31
Borehole water 8	APATA	BORE HOLE	1.247±0.93	0.445±0.31
Borehole water 9	OWODE	BORE HOLE	1.139±0.87	0.407±0.52
Borehole water 10	OWODE	BORE HOLE	3.18±1.45	1.136±0.79
Borehole water 11	AWE	BORE HOLE	0.794±0.52	0.284±0.52
Borehole water 12	ODO ONA	BORE HOLE	3.696±1.54	1.320±0.79
Average	-	-	1.684	0.603

DISCUSSION

In the present work, radon contents of different sources of water were assayed in selected place in Ibadan, and contribution of radon from water to indoor air, annual effective dose from inhalation and ingestion of water were measured.

The statistical tool was engaged on the obtained results to examine the variation between the mean of the two sources of water considered in this present study. Analysis results confirmed that there is a significant difference between the radon concentration of the sources of water from both well and borehole, ($p = 0.000$).

Different works have been done on determination of radon in the different areas of Ibadan and in some zone in the region, for instance Ademola and Oyeleke, Oni and Adagunodo, Oni *et al.* Fatoki and Ademola [10, 24, 25, 26]. In the present study, the obtained results revealed that 6.67% of the water samples are greater 11.1 Bq/l sets by USEPA. Comparing the mean of radon in different sources of water in this work with other works carried out in different countries like Malaysia, China, South-Korea, the mean in this work was lower than radon measured in their works.

In a work done by Ahmad et al in 2015 on Tap and Well water samples, predicted the average radon for both Tap and well water to range from 5.37 to 14.7 Bq/l [27] and in another study by Hajo and fellow examined the content of radon and physiochemical parameters in ground water of Khartoum State and the results revealed that the results were far below the contaminant level set EPA of 11 Bq/l, except for

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five samples [28]. Byong and other scientists conducted a study on radon concentrations in both raw water and treated water used for bottled water in South Korea, this study pointed that the mean radon levels in raw water samples were high in Jurassic granite aquifers and low in volcanic rock aquifers [29]. However, the maximum radon levels were observed in metamorphic rock aquifers, with the radon ranging from 3.7 to 476.8 Bq/L, with a geometric mean of 49.0 Bq/L [29]. In a similar research performed by Ahmad *et al.* 2018 on determination of radon and heavy metals in drinking and irrigated water sampled from Kulim, Malaysia, the obtained results showed that the measured radon concentrations, age dependent associated annual effective doses and donation of radon in drinking water to indoor air was estimated and found below action level [27]. All the results were compared with the results of radon content in both sources of water in this work. In this work, it can be seen that obtained result are within the range of the results of the published works above. However the work done in

Table 4. Radon concentration of well water samples and annual effective dose for inhalation and ingestion and their total dose.

SAMPLE	RADON CONC.	INHALATION	LUNG l	INGESTION	STOMACH s	TOTAL DOSE t
	Bq/l	(µSv/y)	(µSv/y)	(µSv/y)	(µSv/y)	(µSv/y)
Well 1	0.22±0.37	0.55±0.93	0.07±0.11	0.56±0.95	0.07±0.11	1.11±1.88
Well 2	0.67±0.52	1.69±1.31	0.20±0.16	1.71±1.33	0.21±0.16	3.4±2.64
Well 3	1.49±0.72	3.75±1.81	0.45±0.22	3.81±1.84	0.46±0.22	7.56±3.65
Well 4	1.98±0.81	4.99±2.04	0.60±0.24	5.06±2.07	0.61±0.25	10.05±4.11
Well 5	2.12±0.85	5.34±2.14	0.64±0.26	5.42±2.17	0.65±0.26	10.76±4.31
Well 6	2.63±0.92	6.63±2.39	0.80±0.29	6.72±2.35	0.81±0.28	13.35±4.74
Well 7	2.77±0.95	6.98±2.39	0.84±0.29	7.07±2.43	0.85±0.29	14,05±4.82
Well 8	3.40±1.03	8.57±2.60	1.03±0.31	8.69±2.63	1.04±0.32	17.26±5.23
Well 9	3.61±1.06	9.10±2.67	1.10±0.32	9.22±2.71	1.11±0.33	18.32±5.38
Well 10	3.80±1.09	9.58±2.75	1.15±0.33	9.71±2.78	1.17±0.33	19.32±5.53
Well 11	5.94±1.33	14.97±3.35	1.80±0.40	15.18±3.40	1.82±0.41	30.15±6.75
Well 12	1.28±0.67	3.23±1.69	0.39±0.20	3.27±1.71	0.39±0.21	6.5±3.4
Well 13	0.35±0.43	0.88±1.08	0.11±0.13	0.89±1.10	0.11±0.13	1.77±2.18
Well 14	0.08±0.30	0.20±0.76	0.02±0.09	0.20±0.77	0.02±0.09	0.4±1.53
Well 15	0.18±0.34	0.45±0.86	0.05±0.10	0.46±0.87	0.06±0.10	0.91±1.73
Well 16	0.71±0.53	1.79±1.34	0.21±0.16	1.81±1.35	0.28±0.16	3.6±2.69
Well 17	1.51±0.73	3.81±1.84	0.46±0.22	3.86±1.87	0.46±0.22	7.67±3.71
Well 18	1.99±0.82	5.01±2.07	0.60±0.25	5.08±2.10	0.61±0.25	10.09±4.17
Well 19	2.86±0.95	7.21±2.39	0.87±0.29	7.31±2.43	0.88±0.29	14.52±4.82
Well 20	1.83±0.79	4.61±1.99	0.55±0.24	4.68±2.02	0.56±0.24	9.29±±4.01
Well 21	0.766±0.34	1.930±0.79	0.232±0.095	1.961±0.79	0.235±0.087	3.891±1.18
Well 22	14.82 ±3.95	37.346±9.67	4.482±2.19	37.939±9.87	4.553±2.17	75.285±15.26
Well 23	5.652 ±2.58	14.243±5.02	1.709±0.79	14.469±4.98	1.736±0.79	28.712±7.37
Well 24	11.293±3.70	28.458±7.56	3.415±1.72	28.910±7.67	3.469±1.76	57.368±13.19
Well 25	6.946±3.15	17.504±5.02	2.10±1.09	17.782±5.45	2.134±1.56	35.286±9.12
Well 26	3.49±2.67	8.795±3.09	1.055±0.89	8.934±3.89	1.072±0.67	17.729±5.19
Well 27	2.693±-1.96	6.786±2.90	0.814±0.52	6.894±3.02	0.827±0.52	13.680±4.04
Well 28	5.67±2.56	14.288±4.63	1.715±0.79	14.515±4.87	1.741±0.79	28.803±7.29
Well 29	4.806±2.34	12.111±4.28	1.453±0.96	12.303±4.27	1.476±0.82	24.414±6.78
Well 30	6.923±2.90	17.446±5.79	2.093±1.02	17.723±5.34	2.127±1.08	35.169±9.56
MIN	0.08±0.30	0.20±0.76	0.02±0.09	0.20±0.77	0.02±0.09	0.4±1.53
MAX	14.82 ±3.55	37.346±9.67	4.482±2.19	37.939±9.87	4.553±2.17	75.285±15.26
AVERAGE	3.299±1.38	8.544±2.905	1.036±0.48	8.734±2.965	1.052±0.495	17.345±5.206

Table 5. Radon concentration of borehole and annual effective dose for inhalation and ingestion and their total dose.

SAMPLE	RADON CONC. Bq/l	INHALATION (µSv/y)	LUNG l (µSv/y)	INGESTION(µSv/y)	STOMACH s(µSv/y)	TOTAL DOSE t (µSv/y)
Borehole water 1	1.346±0.98	3.392±1.76	0.407±0.093	3.446±1.98	0.414±0.23	6.838±3.56
Borehole water 2	5.41±2.10	13.633±4.13	1.636±0.78	13.850±3.98	1.662±0.828	27.483±7.34
Borehole water 3	0.763±0.52	1.923±0.962	0.231±0.0076	1.953±0.79	0.234±0.109	3.876±1.87
Borehole water 4	0.656±0.54	1.652±0.97	0.198±0.097	1.678±0,86	0.201±0.13	3.33±1.85
Borehole water 5	0.004±0.0009	0.011±0.0087	0.001±0.0023	0.011±0.0095	0.001±0.0024	0.022±0.0098
Borehole water 6	0.767±0.52	1.932±0.79	0.232±0.12	1.963±0.79	0.236±0.12	3.895±1.907
Borehole water 7	1.263±0.98	3.184±2.0	0.382±0.23	3.234±1.98	0.388±0.19	6.418±2.90
Borehole water 8	1.247±0.93	3.142±1.98	0.377±0.21	3.192±1.97	0.383±0.18	6.334±2.87
Borehole water 9	1.139±0.87	2.870±1.18	0.344±0.14	2.916±1.38	0.350±0.17	5.786±2.76
Borehole water 10	3.18±1.45	8.014±3.16	0.962±0.62	8.141±3.01	0.977±0.57	16.155±5.63
Borehole water 11	0.794±0.52	2.00±0.99	0.24±0.22	2.033±1.13	0.244±0.012	4.033±2.28
Borehole water 12	3.696±1.54	9.314±3.17	1.118±0.89	9.462±3.18	1.135±0.78	18.776±5.45
MIN	0.004±0.0009	0.011±0.0087	0.001±0.0023	0.011±0.0095	0.001±0.0024	0.022±0.0098
MAX	5.41±2.10	13.633±4.13	1.636±0.78	13.850±3.98	1.662±0.828	27.483±7.34
AVERAGE	1.689±0.913	4.256±1.758	0.511±0.284	4.323±1.755	0.519±0.276	8.581±3.202

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South Korea is greater than the result obtained in this study. The dose calculated also reveals that the water in the zone are safe for drinking. The amount of radon inhaled and ingested is a function of the concentration of radon in the water sources, therefore the effective dose by ingestion and inhalation are ranging from 0.202 μSv/y to 0.934 μSv/y and 0.2044 μSv/y to 37.9 μSv/y with an average of 4.97 and 5.03 μSv/y respectively , in addition the estimated result for borehole water samples as a result of inhalation and ingestion ranged from 0.011 μSv/y to 13.633 μSv/y and 0.011 μSv/y to 13.82 μSv/y respectively. This result were compare with the work of Ademola and Oyegoke that estimated annual effective dose due to ingestion of radon in water ranged from 0.036 to 1.261 mSv y^{-1}, 0.071 to 2.521 mSv y^{-1} and 0.042 to 1.471 mSv y^{-1} for adult, child and infant, respectively and these amounts were greater than the results obtained in this present study [10].

The variation in the radon contents in different sources of water could be due to bedrock formation of the sampling site and it was noticed that what may contribute to high radon in sample Odo Ona II was that the well is always closed and sealed compare to other wells which does not allow the escaping of the radon gas and the depth could be significant factor. From the results obtained it is clear indication that people in the different locations are exposed to different content of radionuclides.

Correspondingly, areas with higher radon content should be guided on remediation level in such environment by creating an awareness on the danger pose on taking high radon into the body system. In addition, determination of radon content in water should be made mandatory by policy maker before water is allow to be consumed. The data could also be used as baseline data for radon in water in the areas considered in this works.

CONCLUSION

In the present study, radon activity concentration in well water and borehole water samples were measured and the annual effective dose as a result of inhalation and ingestion are also estimated. The results were within the range of maximum contaminant level of 11 Bq/l sets by USEPA. However, the location with samples with high radon content should be advised to take necessary actions to avoid consequences that may occur as result of long exposure.

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