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RADIOLOGICAL RISK ASSESSMENT IN DRINKING WATER: EVALUATION OF RADON CONCENTRATIONS IN ONDO TOWN, SOUTHWESTERN NIGERIA

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ABSTRACT

Radon exposure is a significant public health risk, accounting for 3-14% of all lung cancer cases. Radon exposure is the second biggest cause of lung cancer in smokers and the first among nonsmokers. This study evaluates radon concentrations and assesses the annual effective doses of radon via ingestion and inhalation in drinking water sources in Ondo town. For this purpose, forty samples of groundwater used for drinking were analyzed for radon concentration using RAD7 alpha spectrometry. Activity concentrations of radon in Ondo town ranges from 0.41 to 5.57 Bql^{-1} with an average value of 1.94 Bql^{-1}. The mean concentration of radon is substantially lower than the United State Environmental Protection Agency suggested limit of 11.1 Bql^{-1}. The annually effective dosage for ingestion for infants (10.28 μSvy^{-1}), children (3.78 μSvy^{-1}) and adults (4.96 μSvy^{-1}) and inhalation (0.005 μSvy^{-1}) were below the action level value of 0.1 $mSvy^{-1}$ suggested by World Health Organization and 3-10 $mSvy^{-1}$ proposed by the International Commission on Radiological Protection (ICRP). The data and results from this study could serve as a guide for future policies guiding the development, operation, and preservation of groundwater resources in the investigated region.

Keywords: Groundwater, Radon, Ingestion, Inhalation, Radiological risk.

INTRODUCTION

Water is essential for all human activities and crucial importance for society. Water may be described as economic, social, and physical lifeblood, providing the foundation for agriculture, industry, transportation, energy generation, and life itself. Good water quality keeps up biodiversity of terrestrial and aquatic species and ensures wellbeing of individuals. Despite its importance, warning indications point to imminent dangers to this essential resource. Water pollution is caused by the complex interplay of natural hydrological cycle dynamics, physical changes to the earth's surface, water resource utilization, and waste emissions from anthropogenic activity.

Impurities such as radium can enter the water as it flows due to variations in underlying morphology. Water contamination represents serious health risks to living organisms, and is a major environmental problem in many nations around the world. There are significant health concerns associated with radon in groundwater. Radon is prevalent in the majority of groundwater sources worldwide. Groundwater has higher radon concentration than surface water. Radon has twenty recognized isotopes. ^{222}Rn, the daughter product of ^{226}Ra, is the most stable isotope. It emits radioactive alpha particles and has a half-life of 3.823 days (Hunse *et al.*, 2010).

Radon may be used economically for a variety of purposes, including mining and spa therapy. Thousands of individuals seek out radon therapy in spas defying regulatory bodies' cautions about the possibility of radon exposure being a carcinogen (Erickson, 2007). Quantification of groundwater-freshwater mixing, earthquake precursor, and geological fault prediction are more areas in which it is applied. Radon concentrations in a geological setting typically vary between various rock types and can even vary significantly within the same geological group. Through voids and fissures in rocks and soil, radon travels from its source and can dissolve in groundwater. Radon concentration in groundwater has been shown to be influenced by a number of other parameters, including soil porosity, uranium mineralization, degree of metamorphism, joining intensity, and the existence of shear zones.

Radon accounted for more than 40% of the radiation to which people are exposed. (Miró *et al.*, 2014). It is typically derived from soil, construction materials, water, and natural gas (Kumar *et al.*, 2014; UNSCEAR, 2000). Breathing in radon-containing air that has been discharged from groundwater and ingestion through drinking water has been documented as the major pathways of exposure for individuals. The UNSCEAR 2000 assessment found that inhalation accounts for 90% of radon dosage in drinking water. The US EPA reports that ^{222}Rn, a chemical found in drinking water, is linked to 89% of lung cancer deaths and 11% stomach cancer. The stomach lining can be exposed to radiation from radon consumed in drinking water (Blomberg *et al.*, 2019). Leukemia and other malignancies are associated with indoor radon exposures (Gray *et al.*, 2009; Organization, 2009). To reduce the general public's exposure to radon, International and national agencies set standards for radon exposure in drinking water to prevent health risks. The World Health Organization recommends groundwater should not exceed 100 Bql^{-1} for human consumption. The US EPA suggests activity concentration of 11 Bql^{-1} for states without improved indoor policies.

The amount of radon in groundwater and its possible radioactive effects on the populace have been the subject of several investigations carried out throughout Nigeria (Ajiboye *et al.*, 2022; Isinkaye, 2017; Isinkaye *et al.*, 2021; Khandaker *et al.*, 2021; Oni and Adagunodo, 2019). However, information on the radon concentration of groundwater sources in Ondo City is quite limited. Demand for potable water in Ondo town has increased due to population expansion and the presence of three tertiary institutions. Most residents have resorted to groundwater as a readily available supply of drinkable water, with municipalities and individuals sinking shallow and deep wells to suit their daily domestic water needs. This study evaluates radon concentrations and assesses the annual effective doses of radon via ingestion and inhalation in drinking water sources in Ondo town. The findings of this study can serve as a guide for future policies governing the development, operation, and maintenance of groundwater resources in the studied region.

MATERIALS AND METHODS

Study Area

Ondo town is located within the Basement Complex area of Ondo State, Southwestern Nigeria (Figure 1). Precambrian crystalline rocks are made up of metamorphic and igneous rocks having isotopic ages greater than 300-450 Ma. The weathered and fractured basement aquifers are the two main aquifer units that distinguish the basement complex area of southwest Nigeria (Ako and Olufemi, 1989; Afolayan *et al.*, 2004). The fractured basement aquifer is the product of tectonic action, while the weathered aquifer unit is generated by chemical modification processes. The weathered layer aquifer may coexist in the same place as the fractured aquifer or it may exist apart. The wet and dry seasons are two of the region's distinctive climatic features. The wet season spans from May/June to September/October with an average annual rainfall of 1560 mm. The dry season, which runs from November to March, is often identified by cold, dry harmattan winds.

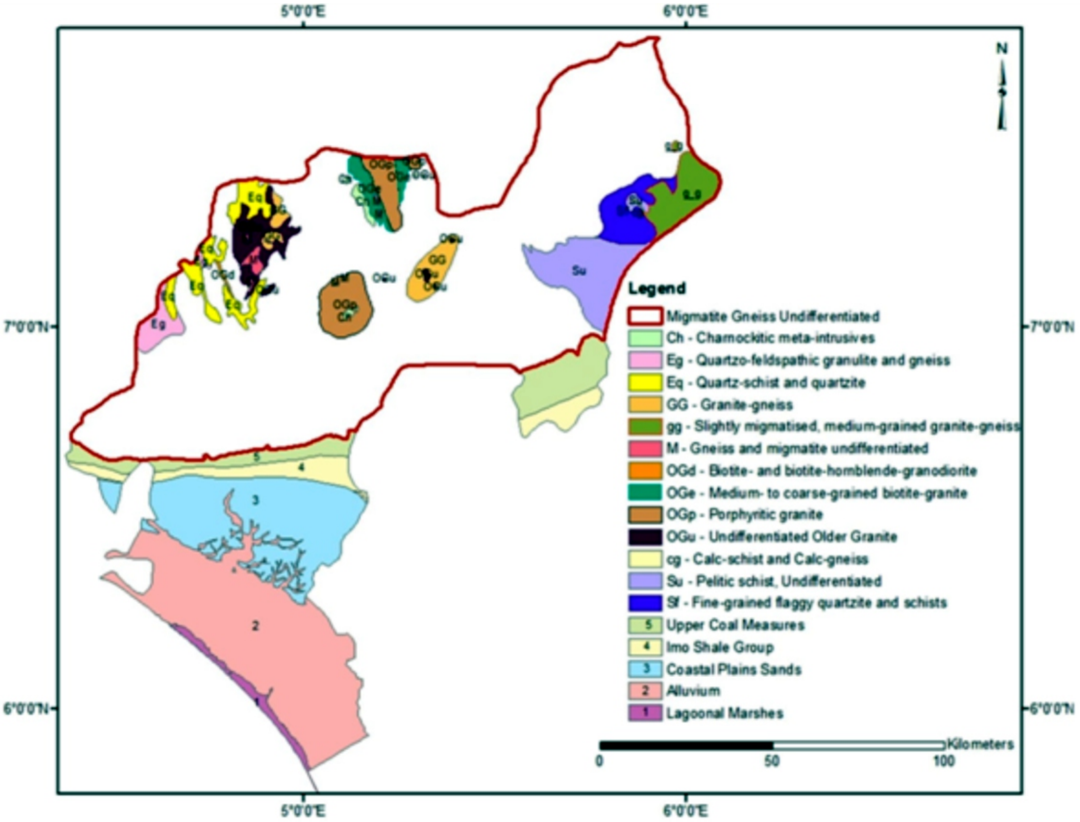

Figure 1: Geological Map of Ondo State

Sampling and Experimental Analysis

Forty (40) groundwater samples (Table 1) were taken from hand dug well use for domestic purposes in Ondo town, southwest, Nigeria. The depth to water table in Ondo town varies from 3-10.1 m. Prior to sampling, several volume purges were performed to permit the buildup of freshwater. The samples were taken in August 2023, in the midst of the rainy season; it is anticipated that at this time the groundwater's dissolved radon content reaches its maximum value. The RAD7 radon detector was used to measure radon in groundwater samples with 5 % accuracy. The equipment, which consists of a desiccant, aerator assembly, and RAD7 unit, enables radon monitoring in concentration ranges of 0.004 to 750 Bql^{-1} in less than two minutes. In order to avoid excessive humidity, the sample cell was dried out, and radon daughters and tiny dust particles were blocked using an intake filter. The measurement was conducted using the Wat-250 procedure, which removes dissolved radon until equilibrium is attained. The extracted radon is gathered and placed in a hemispheric sample cell that has been electrically conductor-coated. The positive ^{218}Po ion produced by the decay of the ^{222}Rn nucleus is propelled by a strong potential difference inside the detector. On the active surface of the detector, the radon ions decay and provide an electrical signal proportional to the energy of the alpha particle. The ^{218}Po signal is used by the RAD7 to calculate the radon concentration. Correcting the concentration at the time of sampling is essential since the concentration measured in the lab does not precisely reflect the original concentration. As a result, it's critical to adjust the observed concentration to the concentration during sampling. The decay correction factor (DCF) is used to adjust the observed concentration.

Table 1: Sample points coordinates.

SN	Sampling Code	Longitudes	Latitudes
1	ONT-1	4.83083	7.084
2	ONT-2	4.82894	7.08192
3	ONT-3	4.82872	7.0791
4	ONT-4	4.82889	7.07721
5	ONT-5	4.83201	7.08291
6	ONT-6	4.83375	7.08232
7	ONT-7	4.83748	7.08213
8	ONT-8	4.83806	7.08
9	ONT-9	4.83661	7.07918
10	ONT-10	4.83342	7.07987
11	ONT-11	4.831	7.08043
12	ONT-12	4.818	7.086
13	ONT-13	4.82314	7.09008
14	ONT-14	4.82644	7.08941
15	ONT-15	4.82782	7.08958
16	ONT-16	4.81037	7.08284
17	ONT-17	4.8109	7.08077
18	ONT-18	4.81015	7.07934
19	ONT-19	4.82848	7.08618
20	ONT-20	4.82456	7.08413
21	ONT-21	4.82202	7.07982
22	ONT-22	4.815	7.0776
23	ONT-23	4.83128	7.06962
24	ONT-24	4.82992	7.06921
25	ONT-25	4.824	7.071
26	ONT-26	4.816	7.072
27	ONT-27	4.82833	7.06729
28	ONT-28	4.82914	7.0679
29	ONT-29	4.82993	7.06773
30	ONT-30	4.83005	7.0668
31	ONT-31	4.823	7.076
32	ONT-32	4.83	7.073
33	ONT-33	4.80662	7.07917
34	ONT-34	4.80571	7.07967
35	ONT-35	4.80824	7.07488
36	ONT-36	4.832	7.075
37	ONT-37	4.80645	7.08145
38	ONT-38	4.83623	7.0821
39	ONT-39	4.832	7.06963
40	ONT-40	4.818	7.082

The relationship between original activity A^o and activity A of any radionuclide at time (t) is given as

$$A = A_o(e^{-\lambda t}) \tag{1}$$

$$\lambda = \frac{0.693}{t_{1/2}} \tag{2}$$

Where factor $e^{-\lambda t}$ is the decay correction factor, λ is the decay constant and $t_{1/2}$ is the half life of radon (3.82 d). The measured radon concentration is multiplied by the DCF to obtain the corrected radon concentration.

Annual Ingestion and Inhalation Effective Dose

The annual effective dosage from ingestion and inhalation of radon is calculated using equation 3 and 4 as specified by (UNSCEAR, 2000; UNSCotEoA and Annex, 2000)

$$ED_{ing}\ (\mu S_v y^{-1}) = AC_r \times A_w \times DCF \tag{3}$$

$$ED_{inh}(\mu S_v y^{-1}) = AC_r \times R_{a/w} \times F \times I \times DF \tag{4}$$

where ED_{ing} is ingestion dose due to radon, AC_r is activity concentration (Bql^{-1}) of radon in water, A_w is average consumption of water per year. Grandjean (2005) found that infants, children, and adults consume 230, 330, and 730 ly^{-1} of water per year, with radon ingestion dose (DCF) of 23, 5.9, and nS_vBq^{-1} 3.5 respectively (UNSCotEoA and Annex, 2000), $\frac{R_a}{w}$ is the ratio of radon in air to radon in water (= 10^4), F is equilibrium factor between radon and its progenies (= 0.4), I is the average indoor occupancy time per individual (= 7000 (hy^{-1}), and DF is dose conversion factor (= 9 $nS_v(Bqhm^{-1})^{-1}$

Statistical Analysis and Mapping

The descriptive statistics and radiological indices for all soil samples were calculated using SPSS and Excel. The non-parametric Spearman rank correlation method was employed to investigate the relationship between radioactive activity concentrations and radiological parameters. ArcGIS software was used to display the geographical distribution of soils and create a geological map of the research areas.

RESULTS AND DISCUSSION

Activity Concentration of Radon in Groundwater of the Study Area

The activity concentrations of radon in the forty groundwater samples collected in Ondo town are presented in Table 2. The activity levels of radon vary from a minimum activity of 0.41 Bql^{-1} (ONT 22) to a maximum activity of 5.57 Bql^{-1} (ONT 20), with a mean activity of 1.94 Bql^{-1}. The activity levels of radon in groundwater samples at all the sampled points were below the recommended value documented by regulatory bodies (USEPA, 1991; UNSCEAR, 2008; EU, 2001). However, all of the examined groundwater samples had radon concentrations beyond the recommended safe level (0.1 Bql^{-1}) set by the Nigerian Industrial Standard (NIS) in 2015. Figure 2 depicts a frequency distribution graph for radon concentration. Concentration was found to be between 0 and 2 Bql^{-1} in 60% of the samples, 2-4 Bql^{-1} in 35%, and 4-6 Bql^{-1} in 5% of the samples. The shallow depth of the well and the local geology of the area may have contributed to the relatively low concentration of radon observed in the groundwater. The sample locations (ONT 14, 16, 21, and 22) had the lowest radon levels when compared to other sampling sites. It should be noted that those locations are the most densely populated among the investigated sites, and that greater levels of human activity or disturbance in well water may greatly dilute the radon level, confirming the reported results. The forty groundwater samples examined in our investigation had a lower average radon (1.94 Bql^{-1}) content than the ten groundwater samples analyzed (38.32 Bql^{-1}) in Gadau, Bauchi State, Nigeria (Khandaker *et al.*, 2021).

Table 2: Radon concentration and annual effective dose in groundwater in Ondo town, Nigeria.

Sampling Code	Radon Conc. (Bql^{-1})	Ingestion dose (μSvy^{-1})			Inhalation dose (μSvy^{-1})
		Infant	Children	Adult	
ONT-1	2.37	12.5373	4.6144	6.0554	0.0060
ONT-2	2.32	12.2728	4.5170	5.9276	0.0058
ONT-3	1.22	6.4538	2.3753	3.1171	0.0031
ONT-4	1.54	8.1466	2.9984	3.9347	0.0039
ONT-5	1.99	10.5271	3.8745	5.0845	0.0050
ONT-6	1.74	9.2046	3.3878	4.4457	0.0044
ONT-7	1.51	7.9879	2.9400	3.8581	0.0038
ONT-8	1.15	6.0835	2.2391	2.9383	0.0029
ONT-9	1.31	6.9299	2.5506	3.3471	0.0033
ONT-10	1.22	6.4538	2.3753	3.1171	0.0031
ONT-11	1.37	7.2473	2.6674	3.5004	0.0035
ONT-12	1.05	5.5545	2.0444	2.6828	0.0026
ONT-13	0.90	4.7451	1.7465	2.2918	0.0023
ONT-14	0.57	3.0365	1.1176	1.4666	0.0014
ONT-15	1.90	10.0351	3.6935	4.8468	0.0048
ONT-16	0.71	3.7295	1.3726	1.8013	0.0018
ONT-17	2.44	12.9076	4.7507	6.2342	0.0061
ONT-18	2.63	13.9127	5.1206	6.7197	0.0066
ONT-19	4.33	22.9057	8.4305	11.0632	0.0109
ONT-20	5.57	29.4653	10.8448	14.2314	0.0140
ONT-21	0.96	5.0810	1.8701	2.4541	0.0024
ONT-22	0.41	2.1948	0.8078	1.0601	0.0010
ONT-23	1.06	5.6074	2.0638	2.7083	0.0027
ONT-24	1.35	7.1415	2.6285	3.4493	0.0034
ONT-25	1.03	5.4487	2.0054	2.6317	0.0026
ONT-26	1.06	5.6074	2.0638	2.7083	0.0027
ONT-27	1.02	5.3958	1.9859	2.6061	0.0026
ONT-28	1.63	8.6227	3.1736	4.1647	0.0041
ONT-29	1.87	9.8923	3.6409	4.7779	0.0047
ONT-30	1.74	9.2046	3.3878	4.4457	0.0044
ONT-31	2.26	11.9554	4.4002	5.7743	0.0057
ONT-32	2.19	11.5851	4.2639	5.5955	0.0055
ONT-33	2.13	11.2677	4.1471	5.4422	0.0054
ONT-34	2.84	15.0236	5.5295	7.2562	0.0072
ONT-35	3.29	17.4041	6.4056	8.4060	0.0083
ONT-36	2.84	15.0236	5.5295	7.2562	0.0072
ONT-37	3.66	19.3614	7.1260	9.3513	0.0092
ONT-38	3.45	18.2505	6.7172	8.8148	0.0087
ONT-39	2.93	15.4997	5.7047	7.4862	0.0074
ONT-40	2.16	11.4264	4.2055	5.5188	0.0054
Min	0.41	2.1948	0.8078	1.0601	0.0010
Max	5.57	29.4653	10.8448	14.2314	0.0140
Mean	1.94	10.2783	3.7829	4.9643	0.0049
SD	1.07	5.6758	2.0890	2.7413	0.0027
Kurtosis	2.25	2.2479	2.2479	2.2479	2.2479
Skewness	1.30	1.2988	1.2988	1.2988	1.2988

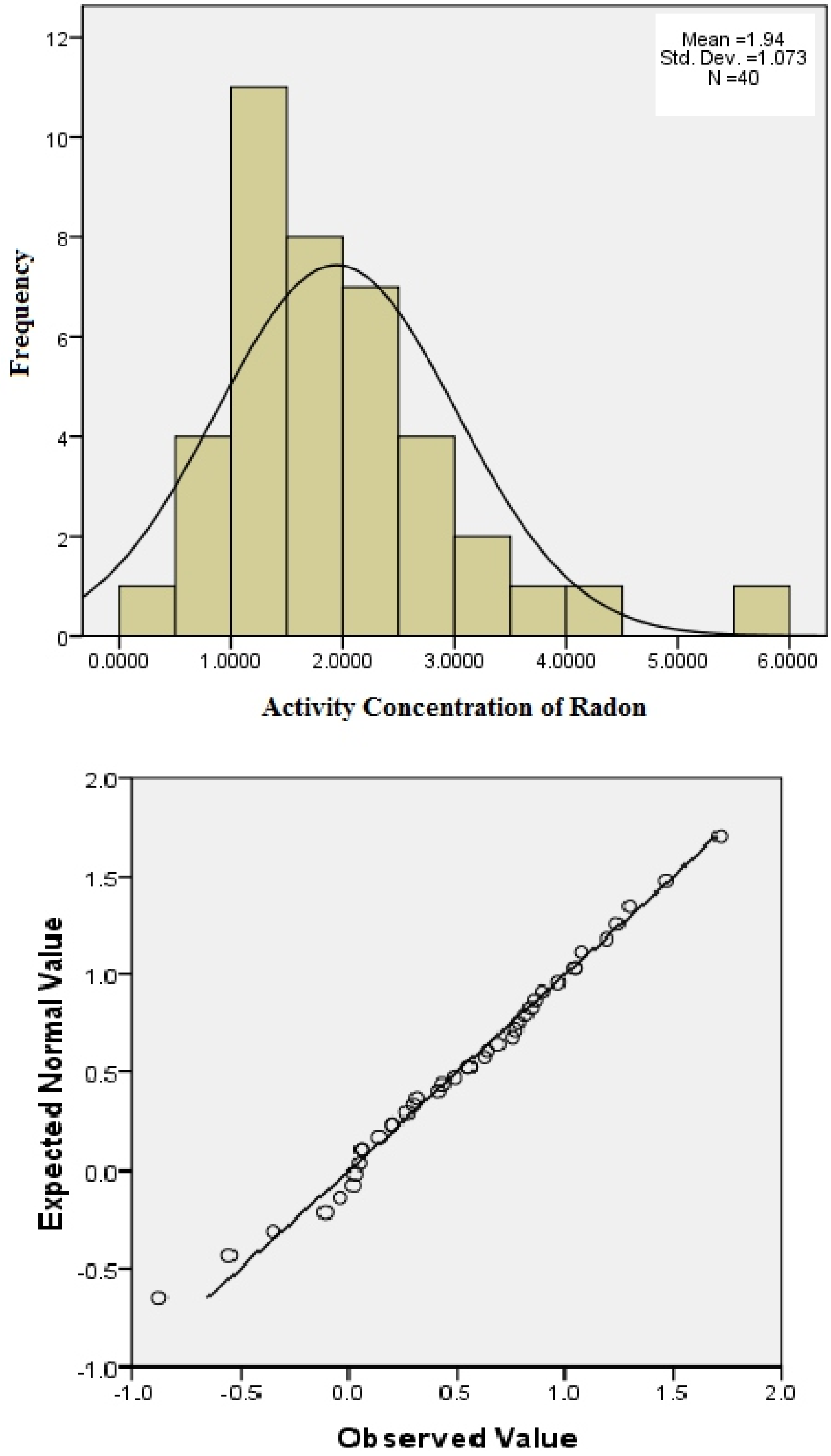

Figure 2: Frequency distribution graph for radon concentration.

The Gadau wells are deeper than those in the present study, which might explain the variation in measured radon concentrations. 50% of Gadau wells are deeper than 100 meters, although Khandaker) found that 40% of the wells were fewer than 10 meters deep. Thus, it appears that radon in shallower wells escapes more quickly than radon in deeper wells.

The univariate statistical properties of radon are also described in Table 2. The standard deviation measures the data's dispersion from the mean. A low standard deviation compared to the mean value indicates a high level of uniformity, and vice versa. The standard deviation of all examined radon is lower than the computed mean value, indicating a high degree of homogeneity in the distribution. The amount of asymmetry present in a probability distribution, known as skewness, is also shown in Table 2. Positive skewness in the radon activity concentrations suggests that their distributions are unequal. In contrast, the evaluation of peakness, known as kurtosis, indicated positive values for activity levels of radon in the current study, indicating leptokurtic behavior. Groundwater radon concentrations in Ondo town were compared to previous studies in various regions of the world (Table 3). The average radon concentration in Ondo town was less than the average concentration values reported for North-West region of Romania (Nita *et al.*, 2013), Saudi Arabia (Althoyaib and El-Taher, 2015), India (Rani *et al.*, 2021). However, the average radon concentration in the study area is greater in comparison to those reported in Vietnam (Le *et al.*, 2015), Sri Ganganagar, India (Singla et al., 2021). The radon concentration in this research is comparable to that of Ogbomoso, SW Nigeria (Oni and Adagunodo, 2019) with varying geology (mean 1.86*Bql*$^{-1}$). As a result, while it is not feasible to compare radon concentrations in Ondo town groundwater to those in other nations with distinct geological features, radon concentrations are definitely high in locations with significant granite and gneiss content.

Table 3: Comparison of groundwater radon activity concentrations with data from different sites.

Location	Radon Concentration (*Bql*$^{-1}$)	Mean Conc. (*Bql*$^{-1}$)	References
North-West region of Romania	0.9–68.9	11.4	Nita *et al.*, (2013)
Barnala district, Punjab, India	0.17 – 9.84	3.01	Rani *et al.*, (2021)
Sri Ganganagar, India	0.13–3.74	0.92	Singla *et al.*, (2021)
Southern Greater Poland	0.4 - 10.5	1.9	Bem *et al.*, (2014)
Canary Island, Spain	0.3-76.9	12.9	Alonso *et al.*, (2015)
Punjab, India	1.4-5.3	3.5	Jakhu *et al.*, (2020)
Saudi Arabia	0.01-67.4	4.62	Alabdula'aly, (2014)
Present Study	0.41 – 5.57	1.94	Present Study

Dosage Assessment

Table 2 also displays the annual effective dosage as a result of radon ingestion and inhalation in sampled groundwater for different age range. For infants between the age 0 to 2 year, the annual effective dose due to ingestion range from 2.2 – 29.5 μSvy^{-1} with a mean value of 10.3 μSvy^{-1}, for children between the age 8 to 12 years old, the range of the annual effective dose due to ingestion is 0.8 – 10.85 μSvy^{-1}, with a mean value of 3.78 μSvy^{-1}; the value range 1.1 – 14.23 μSvy^{-1}, with a mean value of 4.96 μSvy^{-1} for adults over 17 years old. The estimated inhaled radon generated from the groundwater ranging from 0.001 – 0.014 μSvy^{-1}, with an average of 0.005 μSvy^{-1}. These levels are lower than the 0.1 mSvy^{-1} suggested limit by the World Health Organization (WHO, 2008). It may be inferred that radon in water may not present a substantial radiological concern to the population because the observed values in the study location are below the advised permissive limits. Hence, it is possible to conclude that radon levels in Ondo town groundwater are low and unlikely to pose a radiological risk.

Limitations of the Study

In this study, radon content in Ondo town groundwater was determined and compared with permitted limit values, radiological index was assessed. One of the limitations of this study was that the calculated dose excludes the contribution from ^{40}K, meaning that the lower figure may not be adequately justified. Also, there are numerous additional potential radionuclide and their progenies that might have harmful health consequences that were not taken into consideration in this study, making radon not the sole category of radionuclide of concern.

CONCLUSION

Groundwater samples were obtained from forty hand-dug wells that provide drinking water to Ondo town and tested for radon. The results showed that the minimum, maximum, and average radon levels were 0.41, 5.57, and 1.94 Bql^{-1}, respectively. The study found that radon concentrations in groundwater samples from Ondo town were below the UNSCEAR (2008) reference level. The average annual effective exposure from groundwater intake was lower than the World Health Organization and European Commission's recommended safe threshold of 0.1 mSv per year. The study concludes that radon levels in Ondo town groundwater are low and unlikely to pose a health risk.

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DECLARATION OF INTEREST

No conflict of interest among the authors

AUTHOR CONTRIBUTION

Conceptualization of research idea: A.S.A., A.P.O and OAB.
Writing manuscript—original draft: A.S.A. APO, OAB and EOO.
Writing—manuscript review and editing: A.S.A, F.O.O, O.A.B and C.J.O.
Methodology and Formal Analysis: A.S.A, EOO, FOO, OAB and APO.
Investigation: APO, ASA, E.O.O, F.O.O, O.A.B, C.J.O.
Validation: A.S.A.

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