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INVESTIGATING THE INFLUENCE OF GEOLOGICAL PARAMETERS ON RADON CONCENTRATION OF GROUNDWATER IN SOME SELECTED LOCATION IN OSUN STATE, NIGERIA.

[1]Amodu, F. R, [2]Olawale, O. K, [3]Edaogbogun, G.O, [4]Agbono A. A. [5]Ogunwusi, B. A
[1,2,5]Department of Physics, Federal Polytechnic, Ede, Osun State, Nigeria
[3]Center for Advancement Material Research and Development, Federal Polytechnic Ede, Osun State, Nigeria.
[4]Department of Statistics, Federal Polytechnic, Ede, Osun State, Nigeria.

Corresponding Author: roselineamodu5@gmail.com.

Abstract: Water forms appreciable portion in living thing including man of which 80% of animal cells and 70% human body rely on water for several functions. Over the past three decades, groundwater precisely well and borehole water have been predominantly use as an alternative sources of drinking water in Nigeria as a result of insufficient supply of municipal water enough for the populace. Radon that emanate from rocks under the earth subsurface could be introduced into underground water. Hence, there exists the possibility of high radon concentration in groundwater. Ingestion and inhalation during domestic use of radon in this water could pose a health risk. However, radon concentration in groundwater in Southwestern Nigeria has been carried out without considering factors leading to high concentration of radon in these water types, therefore, this work developed a model through a statistical analysis that could predict groundwater radon concentration from the influence of geological parameters on radon concentration in groundwater of selected states in Southwestern Nigeria particularly Osun state with different bedrocks. Radon concentrations were measured using Rad7, a radon electronic detector manufactured by Durridge Inc. U.S.A. The measured parameters and radon concentration were subjected to descriptive statistics using Statistical Package for the Social Science (SPSS) package of 5% significance level. The measured radon concentration in Osun fell in the range 0.12 to 35.8 Bq/L with mean value of 10.37 Bq/L and standard deviation of 9.564Bq/L. From the Anova tools used in the statistical analysis to determine the variance of radon concentration based on the bedrock types, the highest and lowest mean radon concentration values of 16.03 Bq/L and 1.05 Bq/L in Osun State Southwestern Nigeria with granite bedrock (Migmatite) and feldspathic sandstone respectively. The Anova also showed a post hoc test on geological structure of bedrock in the study locations as similar. Furthermore. the lithology of the study areas contributed significantly (p>0.00) to radon concentration in ground water. The estimated radiological indices with mean total annual effective dose due to inhalation and ingestion of Osun State is $\mathbf{4.789}$ μ$\boldsymbol{Svy^{-1}}$*. The values observed lower than the world average permissible limit of* $\mathbf{100}$ μ$\boldsymbol{Svy^{-1}}$*. Thirty seven (37%) of the measured groundwater radon concentrations were higher than* $\mathbf{11.1}\ \boldsymbol{Bq/L}$ *recommended by World Health Organization (W.H.O)*

KEYWORDS: Geological Parameters, Radon, Statistic bedrocks, RAD-7 Detector.

1.0 Introduction

On global scale, groundwater had been gaining increasing attention as essential and vital water source. Its demand had been rising speedily in the last several decades with the overpopulation and enhance standard of living. It is one of the sources of water (freshwater) for many communities owing to its relatively low susceptibility to population in the comparison to surface water, and its relatively large storage capacity. Radon is produced in rocks and soil by an alpha decay of Radium- 226 (^{226}Ra) in uranium-238 (^{238}U) decay series. Radon can easily escape from mineral or soil grains, after its origin and dissolves in water by the process of percolation and pass through central crystalline rocks from elevated concentration of uranium or fractures with coatings of minerals containing enhanced concentration of radium-226 (Akerblom and Lindgren, 2018).

Radon is the second leading cause of lung cancer among smokers (Zayn Al -Bakhat, 2008). A report by World Health Organization (WHO) shows that radon is responsible for about 21,000 lung cancer death per year in United State of America and deaths due to cancers caused by radon in drinking water are estimated about 180 people per year (WHO, 2009). Over three decades, there has been increase in cancer incidence in Nigeria (Oni et al; 2014) and radon concenyration in drinking water and household uses have been reported above maximum contaminant limit (Oni et al; 2016).

Literatures have revealed global researches on various works carried on the effect of lithology in soil gas radon and geogenic radon potential (GRP) of different bedrocks using different predictive model for soil gas radon concentration and GRP the different bedrocks. A research by Farai et al; (2022) used Rad-7 and Artificial neuron network model. The study measured and developed a generalized predictive model for soil gas radon concentration and the geogenic radon potential of different bedrocks of the study area using Artificial neural network (ANN). Consequently, soil in granitic bedrocks had the highest mean soil gas radon concentration. Oladapo et al; (2022) worked on the variation of soil gas radon concentration from different bedrocks formation with respect to depth in Ogbomoso, Southwestern, Nigeria using electronic detector (RAD-7, DURRIDGE Company 2013). The result showed the maximum and minimum radon concentration were in granite and banded gneiss (80cm above the earth surface) and migmatite (0cm on the earth surface) respectively. Byong et al; (2020) in South Korea showed a maximum radon concentration in Jurassic granite aquifers in ground water and minimum in volcanic rock aquifer in treated water which could be due mainly to storage and purification of the water with granular acrivated carbon (GAD) filter. Szabo et al; (2014) in Central Hungary revealed a higher soil radon concentration in mountains and hills than plain in which the highest value was found in prohivial and deluvial sediment, rock debris on the downhill slopes eroded from hills. It was also highest in fluvial sediments located in the hilly areas and lowest values in plain areas covered by sand, fluvial sand and loess. Choubey et al; (2010) in Galvaley of Himlaya of India observed a high radon concentration in ground with Uranim mineralization.

For over three decades, water in Southwestern Nigeria is predominantly underground with deep wells and boreholes as source of drinking water in homes, hospitals, schools and other public places. Due to radon migration from underground rock of different concentration of ^{226}Ra there exist the possibilities of a high concentration level of radon (^{222}Ra) in drinking water in Southwestern Nigeria. Thus, the ingestion or inhalation of radon contaminated water may lead to different health risk, primarily development of stomach and lung cancer.

Unfortunately, there is little or low level of awareness in Nigeria most especially inof the health implication of groundwater radon concentration in Osun State Southwestern Nigeria. Lately, attempts have been made to determine the concentration of radon in groundwater, specifically in borehole, well and hand-pumped water in southwestern Nigeria (Oni et al., 2019). However, there have been no considerations of the effect of geological parameters on the groundwater radon concentration in Nigeria, particularly in the southwestern region of the country. This work therefore investigates the influence geological parameters on the groundwater radon concentration in selected location of Osun State and come up with a model for future prediction of the radon concentration in geological conditions. The result of the study can be used as an alternative way of measuring groundwater radon concentration.

2.0 The Study Area

\The study areas location is in the Osun State Southwestern Nigeria is shown in Figure 2, GPS map of Osun State. The geological map of Nigeria showing the lithology of the selected locations is shown in figure 3. The water type taken from well and borehole have depths ranging from 17 to 30m and 50 to 78m respectively in the selected locations of Osun State Southwestern Nigeria

2.1 Geology of Osun State

Osun State southwestern Nigeria lies within the humid semi-hot equatorial zone. Osun state has metamorphic rocks of the basement complex as the underlain; cover many parts such as undifferentiated schist, metadiorite, banded gneiss, Phorphyritic, clay and shale, migmatite, amphibolites and feldspathic sandstone.

Figure 2: A map showing the GPS of Osun State (yourjigsawouzzles.com)

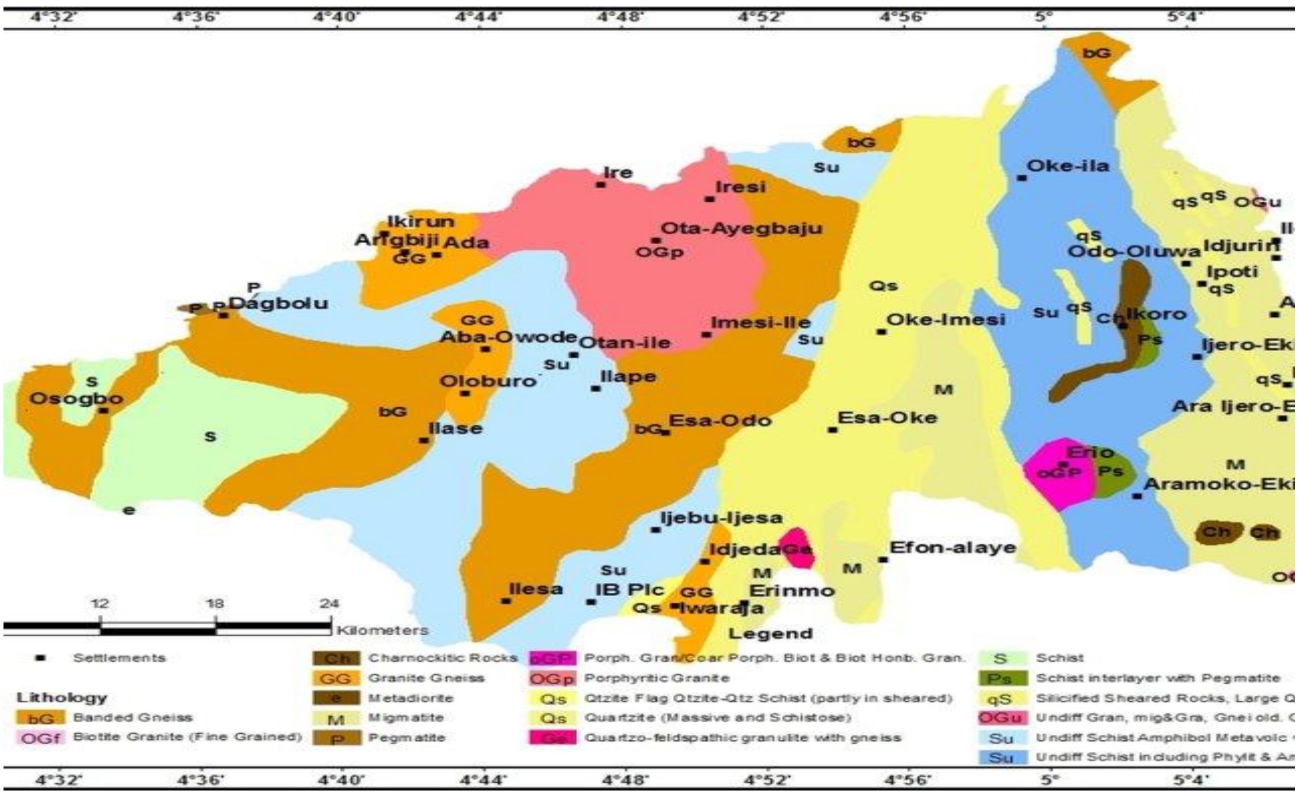

Figure 3: Geological Map of Osun State Southwestern Nigeria (Extracted from NGSA, 2006)

3.0 Methodology

3.1 Sample Collection and Sample Preparation

3.1.1 Sample Collection.

A total number of one hundred (100) groundwater samples were obtained from the highlighted locations; this is shown in Table 3 out of which twenty (20) water samples was from each location. Ten (10) samples from each were from well water and borehole water respectively. The depth of the collected well and boreholes were of varied depths. The well and borehole water in Osun State ranges from 17m to 30m and 50m to 78m respectively in Osun State.

The water sample were randomly collected from the source into 1.5 litres bottle, previously rinsed with distilled water, immediately closed and labeled. During water collection, conscious effort was taken to prevent bubbling of the water so as not to allow escape of radon in water. The labeled water samples were transferred to the laboratory of Physics Department in Ladoke Akintola University of Technology, Ogbomoso in Oyo State of Southwestern Nigeria before the radon in the sampled water exceed the decay time of 3.8 days. The radon in the sample water was measured using RAD7, an electronic radon detector manufactured by Durridge Inc. USA.

Table 3. The Locations and Number of Water Samples in Osun States

Locations	Sample number
Osogbo	20
Ede	20
Ilesha	20
Ile-Ife	20
Ejigbo	20

3.1.2 Sample Preparation

According to RAD7 manual, each sample was collected into 250ml vial and closed the vial immediately so that it has never been in contact with open air (Durridge RAD7 RADH$_2$O manual, 2012). Having been sealed tightly, the vial was shaken for more than two minutes to extract radon-222 in water phase into the organic scintillate and the samples were being counted for 30minutes in a liquid scintillation counter using energy discrimination for alpha particles.

3.2 Sample Measurement and Calibration of Detector

3.2.1 Samples Measurement

Measurement of radon from the water samples were carried out with Rad7 device and the values of radon detected were printed out from the device after the counts. These values of radon concentration of water samples were later subjected to statistical analysis and radiological indices based on the geological parameters.

3.2.2 Calibration of the RAD 7 Detector

The electronic radon detector RAD 7 used in this work was pre-calibrated by the manufacturer. The recalibration of the detector is recommended after 12 months of usage. The equipment was sent to the manufacturer for calibration after 12 months use of operation in accordance with manufacturer's recommendation.

3.3 Geological Data

A global positioning system (GPS) was used to obtain the geographical coordinates of every well and borehole water selected. The lithology of each study location as shown in figure 3.6 indicates the southwestern basement complex of Nigeria that lies within the rest of Precambrian rocks in Nigeria (Ademila *et al.,* 2018) and this leads to one hundred (100) selected groundwater with randomly selected equal sample number of well (50samples) and borehole water (50 samples) in each geographical location of Southwestern Nigeria. This makes a hundred (100) samples of groundwater for the geographical location.

3.4 Estimation of Radiological Indices of Radon Measurement

The radon measurement was translated to the annual effective dose due to inhalation and ingestion.

3.4.1 Estimation of Annual Committed Dose Due to Inhalation

The radon gas concentrations obtained was used to estimate the annual mean effective doses due to inhalation, since water for household activities is stored indoors and the same is used for other household activities i.e bathing, Washing, and cooking. The annual mean effective doses due to inhalation were calculated by using the parameters established in UNSCEAR report 2000, as:

$$E\ (m\ Svy^{-1}) = C_{Rnw} \times R_{aw} \times F \times T \times (DCF) \qquad 3.1$$

where;

$E\ (mSv\ y^{-1})$ = annual effective dose for inhalation

C_{Rnw} = Concentration of radon in water.

R_{aw} = Ratio of radon in air to water (10^{-4}),

F = the radon equilibrium factor between radon and its decay products (0.4)

(DCF) = Dose Conversion Factor for radon exposure (9.0×10^{-6} Sv h^{-1} per Bq m^{-3}).

(T) = An occupancy factor assumed based on the period inhabitants spend in indoor rooms out of 24 hours which is estimated by $\frac{9Hrs}{24Hrs} = 0.375 \approx 0.4$ = (0.4 x 24 hrs x 365 days = 3504 h y^{-1}). (Oni *et. al.,* 2014).

3.4.3 Estimation of Annual Committed Dose by Ingestion

The estimated annual effective dose by ingestion was assessed based on the usual intake of water by populace of the study area. The annual effective dose was calculated using the equation 3.2 as,

$$E = K \times C \times KM \times t \qquad (3.2)$$

where E = the committed effective dose from ingestion (mSv),

K = the ingesting dose conversion factor of ^{222}Rn (10^{-8} Sv Bq^{-1} for adult and 2×10^{-8} Sv Bq^{-1} for Children (UNSCEAR 2000),

C = the concentration of ^{222}Rn (Bq 1^{-1})

KM = the water consumption (2 litres day^{-1}),

t= the duration of consumption (365 days) (World Health Organization(WHO) 2004).For the dose calculation, a conservative consumption of 2 litres per day for standard adult drinking the same water and directly from the source point was assumed (UNSCEAR, 2008).

3.4.4 Data Analysis Technique

In this work descriptive statistical analysis of different rock with radon concentration of the study areas are used. Statistical analysis such as Analysis of Variance (ANOVA) of different bedrock with radon concentration was employed to show whether there is significant difference in the mean radon concentration with the different bedrock in the study areas. Correlation by bedrock to radon was employed for further investigation.

Measures of central tendency and variability used in this work include minimum, maximum, median, arithmetic mean, standard deviation and standard error. The data sets were found not to be normally distributed. ANOVA was used for the test of significance.

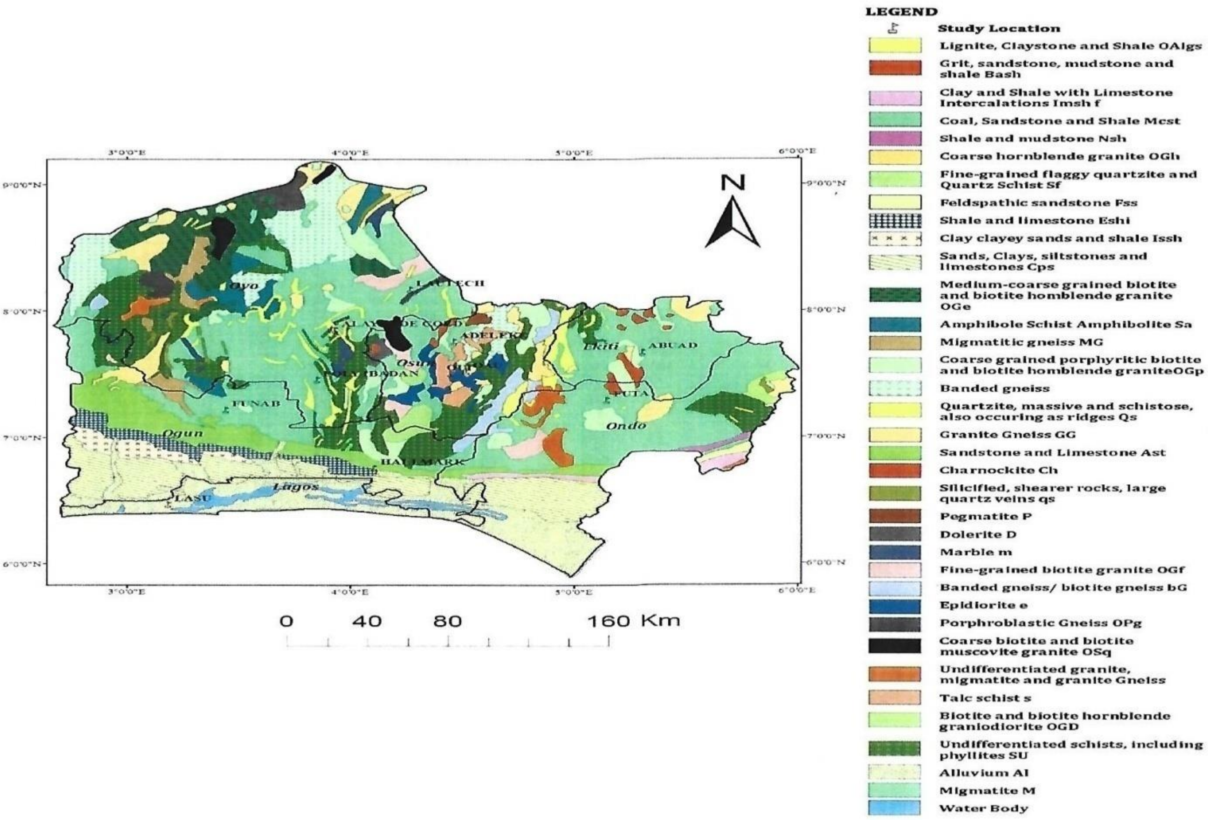

Figure 3.6: Map of the study area showing the lithology of Osun State Southwestern Nigeria (Ademila *et. al.*, 2018).

4.0 Results and Discussion

4.1 Radon Concentration in Groundwater

The measured value of radon concentration 100 ground water samples collected from Osun State in Southwestern Nigeria. From Table 4.1, it is clearly seen that the concentration of radon in groundwater varies from Osun State the variation is from 0.12 to 35.9 Bq/L with the mean value of 10.37 Bq/L. The lowest mean value of radon concentration was recorded in well water from Osun State while the highest mean value was recorded in borehole water from Osun State. However, the recorded highest mean value from all the locations was from borehole water. Most studies have concluded that there are strong correlations between the concentration of radon and depth of water (Mostafa and Olaoye 2022). The mean value results of radon concentration from study areas were lower than the mean value radon concentration reported by Oni *et. al.*, 2022.

Table 4.1 Radon Concentrations and Radiological Indices from Different Groundwater Samples in Osun State

LOCATION	AREA	RADON (Bq/m3)	RADON (Bq/L)	Ingestion (μSvy-1)	Inhalation (μSvy-1)	Total Annual Effective dose (μSvy-1)
OSUN 1	Alekwode	825.5	0.8255	0.173355	0.208026	0.381381
OSUN 2	Olaiya	2075	2.075	0.43575	0.5229	0.95865
OSUN 3	Shiyabola 1	4515	4.515	0.94815	1.13778	2.08593
OSUN 4	Shiyabola 2	180.5	0.1805	0.037905	0.045486	0.083391
OSUN 5	Oba abidjan	118.05	0.11805	0.0247905	0.0297486	0.0545391
OSUN 6	Beulah strt	274.5	0.2745	0.057645	0.069174	0.126819
OSUN 7	Adebowole	1690	1.69	0.3549	0.42588	0.78078
OSUN 8	Ilesha grg 1	2310	2.31	0.4851	0.58212	1.06722
OSUN 9	Ilesha grg2	2580	2.58	0.5418	0.65016	1.19196
OSUN 10	Ilesha grg3	3350	3.35	0.7035	0.8442	1.5477
OSUN 11	Ilesha grg 4	724.5	0.7245	0.152145	0.182574	0.334719
OSUN 12	Sekona 1	2370	2.37	0.4977	0.59724	1.09494
OSUN 13	Sekona 2	4180	4.18	0.8778	1.05336	1.93116
OSUN 14	Poly road 1	5605	5.605	1.17705	1.41246	2.58951
OSUN 15	Poly road 2	2685	2.685	0.56385	0.67662	1.24047
OSUN 16	Ibode ede	496	0.496	0.10416	0.124992	0.229152
OSUN 17	Sab ede	2310	2.31	0.4851	0.58212	1.06722
OSUN 18	Odeomu 1	7260	7.26	1.5246	1.82952	3.35412
OSUN 19	Odeomu 2	3400	3.4	0.714	0.8568	1.5708
OSUN 20	Odeomu 3	4400	4.4	0.924	1.1088	2.0328
OSUN 21	Odeomu 4	5340	5.34	1.1214	1.34568	2.46708
OSUN 22	Moro 1	5320	5.32	1.1172	1.34064	2.45784
OSUN 23	Moro 2	4330	4.33	0.9093	1.09116	2.00046
OSUN 24	Moro 3	5510	5.51	1.1571	1.38852	2.54562
OSUN 25	Moro 4	9730	9.73	2.0433	2.45196	4.49526
OSUN 26	Moro 5	2540	2.54	0.5334	0.64008	1.17348
OSUN 27	Abere 1	4510	4.51	0.9471	1.13652	2.08362
OSUN 28	Abere 2	6870	6.87	1.4427	1.73124	3.17394
OSUN 29	Abere 3	9930	9.93	2.0853	2.50236	4.58766
OSUN 30	Ogooluwa1	10800	10.8	2.268	2.7216	4.9896
OSUN 31	Ogooluwa2	12700	12.7	2.667	3.2004	5.8674
OSUN 32	Alekwode	13200	13.2	2.772	3.3264	6.0984
OSUN 33	Olaoluwa	18700	18.7	3.927	4.7124	8.6394
OSUN 34	Ayegbigbo1	18600	18.6	3.906	4.6872	8.5932
OSUN 35	Ayegbigbo2	20000	20	4.2	5.04	9.24
OSUN 36	Oko road1	496	0.496	0.10416	0.124992	0.229152
OSUN 37	Oko road2	2310	2.31	0.4851	0.58212	1.06722
OSUN 38	Sekona 1	7260	7.26	1.5246	1.82952	3.35412
OSUN 39	Sekona 2	18900	18.9	3.969	4.7628	8.7318
OSUN 40	Sekona 3	3400	3.4	0.714	0.8568	1.5708
OSUN 41	Sekona 4	4400	4.4	0.924	1.1088	2.0328
OSUN 42	Ede 1	5340	5.34	1.1214	1.34568	2.46708
OSUN 43	Ede 2	5320	5.32	1.1172	1.34064	2.45784
OSUN 44	Ede 3	15900	15.9	3.339	4.0068	7.3458
OSUN 45	Ede 4	20800	20.8	4.368	5.2416	9.6096
OSUN 46	Ibodeede 5	20200	20.2	4.242	5.0904	9.3324
OSUN 47	Sabo ede 6	33600	33.6	7.056	8.4672	15.5232
OSUN 48	Odeomu	20800	20.8	4.368	5.2416	9.6096
OSUN 49	Idi-ape	6300	6.3	1.323	1.5876	2.9106
OSUN 50	Obaabidjan	23200	23.2	4.872	5.8464	10.7184

Radon Concentrations and Radiological Indices from Different Groundwater Samples in Osun State

OSUN 51	Ejigbo	20700	20.7	4.347	5.2164	9.5634
OSUN 52	Ayegbogbo, ejigbo	22700	22.7	4.767	5.7204	10.4874
OSUN 53	Ife-Odan	25400	25.4	5.334	6.4008	11.7348
OSUN 54	Owu	32000	32	6.72	8.064	14.784
OSUN 55	Ilawo	31500	31.5	6.615	7.938	14.553
OSUN 56	Inisha	4330	4.33	0.9093	1.09116	2.00046
OSUN 57	Osuntedo	15510	15.51	3.2571	3.90852	7.16562
OSUN 58	Songbe	9730	9.73	2.0433	2.45196	4.49526
OSUN 59	Isoko	15200	15.2	3.192	3.8304	7.0224
OSUN 60	Masifa	16810	16.81	3.5301	4.23612	7.76622
OSUN 61	Oguro	9210	9.21	1.9341	2.32092	4.25502
OSUN 62	Aba Igbira	10600	10.6	2.226	2.6712	4.8972
OSUN 63	Alabameta, ife	13400	13.4	2.814	3.3768	6.1908
OSUN 64	Balogun Aderibigbe	19500	19.5	4.095	4.914	9.009
OSUN 65	Fagbore	24600	24.6	5.166	6.1992	11.3652
OSUN 66	Ogangan	5610	5.61	1.1781	1.41372	2.59182
OSUN 67	Olorombo	6730	6.73	1.4133	1.69596	3.10926
OSUN 68	Wasinmi	13400	13.4	2.814	3.3768	6.1908
OSUN 69	Elemu-Alagba	17100	17.1	3.591	4.3092	7.9002
OSUN 70	Loode Olokuta	22200	22.2	4.662	5.5944	10.2564
OSUN 71	Olorombo-Gboloku	27000	27	5.67	6.804	12.474
OSUN 72	Osifila	30200	30.2	6.342	7.6104	13.9524
OSUN 73	Ologede	30900	30.9	6.489	7.7868	14.2758
OSUN 74	Olookun	33100	33.1	6.951	8.3412	15.2922
OSUN 75	Amugba	35900	35.9	7.539	9.0468	16.5858
OSUN 76	Isaleye	1705	1.705	0.35805	0.42966	0.78771
OSUN 77	Obalejugbe	1946	1.946	0.40866	0.490392	0.899052
OSUN 78	Odogbon	1220	1.22	0.2562	0.30744	0.56364
OSUN 79	Onirugbon	2930	2.93	0.6153	0.73836	1.35366
OSUN 80	Aba Moro	4060	4.06	0.8526	1.02312	1.87572
OSUN 81	Aba Abe	4970	4.97	1.0437	1.25244	2.29614
OSUN 82	Osi Sooko	1256	1.256	0.26376	0.316512	0.580272
OSUN 83	Arugbosegbe	12105	12.105	2.54205	3.05046	5.59251
OSUN 84	Agbonkuta	1196.1	1.1961	0.251181	0.3014172	0.5525982
OSUN 85	Isoyo	11140	11.14	2.3394	2.80728	5.14668
OSUN 86	Ajegunle	1128	1.128	0.23688	0.284256	0.521136
OSUN 87	Osi Luobe	1421	1.421	0.29841	0.358092	0.656502
OSUN 88	Aworo Ayedaade	1260	1.26	0.2646	0.31752	0.58212
OSUN 89	Idi Awere	2120	2.12	0.4452	0.53424	0.97944
OSUN 90	Ilupeju	2190	2.19	0.4599	0.55188	1.01178
OSUN 91	Abanju Akesin	2430	2.43	0.5103	0.61236	1.12266
OSUN 92	Oyi Araromi	2130	2.13	0.4473	0.53676	0.98406
OSUN 93	Oyi Adumi	13030	13.03	2.7363	3.28356	6.01986
OSUN 94	Aganju Asaoni	13240	13.24	2.7804	3.33648	6.11688
OSUN 95	Aba Ododo	3460	3.46	0.7266	0.87192	1.59852
OSUN 96	Abalagemo	24180	24.18	5.0778	6.09336	11.17116
OSUN 97	Isinmi Olootu	4500	4.5	0.945	1.134	2.079
OSUN 98	Majeroku	26710	26.71	5.6091	6.73092	12.34002
OSUN 99	Bamgbola	2140	2.14	0.4494	0.53928	0.98868
OSUN 100	Odeyinka	13230	13.23	2.7783	3.33396	6.11226

Generally, in the study locations, thirty-seven (37) water samples had radon concentration above the safe of 11.1Bq/L limit recommended by USEPA (1999) and sixty-three (63) had lower radon concentration compare to the USEPA permissible limit.
Moreover, the range of radon concentration in water in the locations is within 0.12 - 33.6 Bq/L and 1.19–35.9 Bq/L for well and borehole water respectively. Twelve 24% of well water samples from these locations had radon concentration (12.7 - 23.2 Bq/L) higher than safe limit recommended by USEPA (2000) while twenty-six 52% borehole water samples had radon concentration (11.14–35.9 Bq/L) higher than the recommended limit by USEPA (1999). Thirty-eight 76% well water samples had radon concentration (0.11 - 10.8 Bq/L) lower than the permissible limit of USEPA (2000). However, the measured radon concentration in all the water samples of the locations in this states in Southwestern Nigeria is found to be within the safe limit approved by EU (2001) but higher than the Nigeria standard limit (0.10 Bq/L) for drinking water quality.
The comparison of radon concentration in studied water samples from different locations is presented from which can be seen that the radon concentration in water samples of Bakaner and Jhunjhunu district of Rajasthan, India, Pakistan, Ojo Local Government, Lagos Nigeria, Abeokuta Nigeria, Ibadan Nigeria and Ogbomoso Nigeria is in the close agreement with the present work in Osun State Southwestern Nigeria. However, Poland, India, Rajasthan (India), Ojoo (Nigeria), Abeokuta (Nigeria), Bauchi (Nigeria), Ijero Ekiti (Nigeria) and Ede (Nigeria), the radon concentration is higher than the reported value in the present state whereas Ganganaga of Northern Rajasthan (Indian), Pakistan and Ogbomoso, the concentration of radon is lower than the reported values in the present investigation. (Table 4.5 and 4.6).
Table 4.7 reveals that the mean radon concentration in water samples of Zarand Kermon province Iran, Cooperative (NTPC) Dadan Atomic Energy Centre, Dhaka Bangladesh is higher than the present study under investigation while Areekodel Kerala India, Yaoundé Cameroon and Quassian Saudi Arabia has mean radon concentration lower than the present works.
The variation of radon in the study areas could be attributed to diverse factors such as characteristics and composition of the aquifer, radionuclide content of the bedrock, water residence time within the aquifer. e.t.c. (Choubey and Ramola 1997).
The areas with potential problems with radon in ground water are areas that have high level of uranium in the underlying rocks. Metamorphic rocks, sedimentary rocks, gneiss and granite, pegmatite, monzonites, clay and shale contain high uranium. Granite and metamorphic rock contain more uranium. The high concentration of radon can be attributed to the nature of the area with abundance of these rock types in surface and sub-surface of the soil. The geology of the study areas is prevalent with migmatite, gneiss and granites. Wells and boreholes in areas with these rock types are known to contain in the intramontaneous ground water with higher radon concentration (Akerblom and Lindgrem, 2018).
In the study areas, the higher concentration in radon was revealed in borehole water. A high activity concentration was found in the study area. The high concentration of radon could be attributed to the lithology of the area such as gneiss, clay and shale, metadiorite, porphyritic, amphibolites, migmatite, feldspatic sandstone and schist. The elevation in radon concentration in the above borehole water could be due to geological structure of the area and the depth of the water source (El-Taher, 2012). As also observed in the study carried out by Oni *et. al.*, 2014, radon concentration in ground water of areas of high background radiation level in Abeokuta, Southwestern Nigeria.

Table 4.3: Mean concentration of radon in ground water under investigation

Location	Mean Depth (m)	Mean Radon (Bq/L)	Mean Ingestion (μSvy^{-1})	Mean Inhalation (μSvy^{-1})	Mean total annual effective dose (μSvy^{-1})
Osun	49	10.37	2.178	2.612	4.789

Table 4.4 Range of radon concentration in groundwater under investigation

Location	Depth (m)	Radon (Bq/L)	Ingestion (μSvy^{-1})	Inhalation (μSvy^{-1})	Total annual effective dose (μSvy^{-1})
Osun	17 – 89	0.12 – 35.9	0.025 – 7.539	0.297 – 9.4047	0.055 – 16.586

Table 4.5: Comparison of Radon Concentration range in groundwater under investigation with those in other countries.

S/N	Region	Radon concentration in water(Bq/L)	Reference
1	India	12.5-86.2	Duggai *et. al.* 2020
2	Strzelin, Poland	0.5 – 119.4	Przylibski *et. al.* 2020
3	India	0.24 – 106.17	Shilpa *et. al.* 2017
4	Bikaner and Jhunjhunu district of Rajasthan, India	0.50 – 22	Sudhir *et. al.* 2016
5	Hanumangam and sri Ganganasa district of Northern Ragastha, India	1.8 – 8.2	Duggai *et. al.* 2012
6	Pakistan	2.0 - 7.9	Manzoor *et. al.* 2008
7	Osun, Nigeria	0.12 – 35.9	This work

Table 4.6 Comparison of radon concentration range in ground water under investigation with those in other States in Nigeria

S/N	Region	Radon concentration in water (Bq/L)	Reference
1	Ojo Local Government, Lagos, Nigeria	12.5 – 32.5	Mostafa and Olaoye 2023
2	Abeokuta, Nigeria	1.41 – 29.50	Idowu *et. al.* 2023
3	Ibadan, Nigeria	3.09 – 32.03	Oni *et. al.* 2022
4	Ekiti State university	0.6 – 41.50	Isinkaye *et. al.* 2021

5	Bauchi, Nigeria	4.92 – 82.89	Khandaker *et. al.* 2020
6	Ilori, Ede	2.15 - 40.00	Amodu *et. al.* 2020
7	Ogbomosho, Nigeria	0.21 - 1.86	Oni and Adagunodo 2019
8	Ijero, Ekiti, Nigeria	3.35 -78.51	Akinnagbe *et. al.* 2018
9	Osun, Nigeria	0.12 – 35.9	This work

Table 4.7 Comparison of the Mean Radon Concentration in groundwater under in investigation with those in other countries

S/N	**Region**	**Mean radon concentration in (Bq/L)**	**Reference**
1	Areekodel region, kerala, Indian	3.53	Ravi *et. al.* 2023
2	Zarand,kermon province, Iran	31.55	Mojtaba *et. al*. 2022
3	National capital power cooperation (NTPC) Dadri	33.00	Mukesh *et. al*. 2022
4	Yaoundé, Cameroon	0.48	Serge *et. al.* 2021
5	Coastal area of Bangladesh	2.33	Farah *et. al*. 2020
6	Atomic energy centre Dhaka city, Bangladesh	13.00	Shikha *et. al*. 2018
7	Quassian area, Saudi Arabia	3.56	Wedad *et. al*. 2015

Table 4.8 Comparison of the Mean Radon Concentration in groundwater under investtigation with other Southwestern State in Nigeria

S/N	**Region**	**Mean radon concentration in water (Bq/L)**	**Reference**
1	Oyo	125.9	Ajiboye *et. al.* 2022
2	Ondo	64.5	Ajiboye *et. al.* 2022
3	Ekiti	271.0	Ajiboye *et. al.* 2022
4	Osun	52.6	Ajiboye *et. al.* 2022
5	Lagos	271.2	Ajiboye *et. al.* 2022
6	Ogun	109.5	Ajiboye *et. al.* 2022

4.2 Estimated Annual Effective Dose

The ingestion dose obtained for wells in Osun state, ranged from 0.025 to 7.056 μSvy^{-1}with a mean value of 1.6282 μSvy^{-1}, for borehole, the value ranged from 0.237 to 7.539 μSvy^{-1}with a mean value of 2.7591 μSvy^{-1}. For the inhalation dose in Osun state, the value ranged from 0.030 to 8.467 μSvy^{-1} with a mean value of 1.9538 μSvy^{-1}in well water while for borehole water, the value ranged from 0.284 to 9.047 μSvy^{-1}with a mean value of 3.2711 μSvy^{-1}.

It is clearly shown that the annual effective dose due to ingestion and inhalation in location of Osun Southwestern Nigeria were 2.178 and 2.612 with a total annual effective dose of 4.789 μSvy^{-1}. The total annual effective dose due to ingestion and inhalation for all the ground water of the study area under investigation are lower than the $100\ \mu Svy^{-1}$recommended as the maximum permissible dose by W.H.O. (2007), European Council (E.U., 2001) and UNSCEAR (2000).

Table 4.10 Range and Mean Values of Annual Effective Dose of Ingestion and Inhalation of Radon in Well Water of the Study Area under Investigation

Location	Ingestion Range (μSvy^{-1})	Mean (μSvy^{-1})	Inhalation Range (μSvy^{-1})	Mean (μSvy^{-1})
Osun	0.025 – 7.056	1.62815121	0.030 – 8.467	1.953781452

Table 4.11: Range and Mean Values of Annual Effective Dose of Ingestion and Inhalation of Radon in Borehole Water of the Study Area under Investigation

Location	Ingestion Range (μSvy^{-1})	Mean (μSvy^{-1})	Inhalation Range (μSvy^{-1})	Mean (μSvy^{-1})
Osun	0.237 – 7.539	2.72591382	0.284 – 9.047	3.271096584

The total annual effective dose due to ingestion and inhalation for all the ground water of the study area under investigation are lower than the $100\ \mu Svy^{-1}$recommended as the maximum permissible dose by W.H.O. (2007), European Council (E.U., 2001) and UNSCEAR (2000)

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4.3 Lithology of the water sample locations of Osun states

4.4 Statistical Analysis

In Osun state, Undifferentiated Schist has mean radon concentration with standard error of 1937.9269 $\pm$ 411.04290, Metadiorite has 16005.6250 $\pm$ 229.93.49769, Banded Gneiss has 4532.7692 $\pm$ 659.19778, Porphyritic has 10737.8182 $\pm$2025.37512, Clay and Shale has 3385.4545 $\pm$ 410.90446, Megmatite has 16037.5625 $\pm$ 3253.010896, Amphibolites has 14174.5455 $\pm$ 2927.37933 and Felspahatic Sandstone has 1055.1222 $\pm$ 540.86319. This is shown in Table 4.15.

Anova of the different bedrocks with radon concentration has $p < 0.05$. This is shows that the bedrock in Osun state contributed to the radon concentration in the water collected. This is shown in table 4.16. From the post hoc test of bedrock to radon in the same state, felspahatic sandstone with the mean value of 1055.1222, undifferentiated schist with mean value of 1937.9269, Clay and Shale with mean value of 3385.4545, Banded Gneiss with the mean value of 4532.7692 and phorphyritic with mean value of 10737.8182 have similar geological features. In the second column of the table Clay and Shale with mean value of 3385.4545, Banded Gneiss with mean value 4532.7692, Phorphyritic with mean value of 10737.682 and Amphibolites with mean value of 14174.5455 have same geological structures. In the third column, banded gneiss with mean value of 453.7692, Phorphyritic mean value of 10737.8182, Amphibolites with mean value of 14174.5455, Metadiorite with the mean value of 18005.6250 and Migmatite with the mean value of 16037.5625 have the same geological characteristics. This is revealed in table 4.17. From the above table, there is a significant difference between Feldpathic sandstone bedrock radon concentration and the following bedrocks (Amphibolite, Metadiorite and Migmatite) also between Undifferentiated Schist radon concentration and the following bedrocks (Amphibolite, Metadiorite and Migmatite). In addition, Clay and Shale bedrock radon concentration is also different from Metadiorite and Migmitite.

5.0 Conclusion

The measured radon concentration in Osun State of the Southwestern Nigeria has been determined for 100 groundwater samples in the highlighted locations using active detector RAD 7 (DURRIDGE Company Inc., U.S.A.).

The mean radon concentration of Osun state were found to be and 10.37Bq/L. The radon concentration value in the ground water from Osun State fell in the range 0.12 to 35.9Bq/L with the mean value of 10.373Bq/L and standard deviation 9.564Bq/L.

The radon concentration in water samples was observed as generally low in well water. In the groundwater, value greater than 11.1 Bq/L recommended by W.H.O were observed in some locations in the study areas.

The mean total annual effective dose due to ingestion and inhalation in Osun 4.789µSvy^{-1}. These values were observed lower than the world average permissible limit of 100µSvy^{-1} as recommended by UNSCEAR (2000). The statistical analysis showed the highest mean radon concentration value of 16.038Bq/L found in Osun Southwestern of Nigeria with granite bedrock (migmatite). The highest radon concentration was observed from groundwater of granite bedrock.

The result of the measured radon concentration in the study areas as indicated by the ANOVA that the different bedrocks contributed to the radon concentration in water samples collected. The result also revealed the correlation of bedrock in the study area has similar geological features. Generally, there is a significant difference of ($P<0.05$) between bedrock and radon concentration in the water samples.

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Yourjigsawouzzles.com*: Map of Osun State showing the location of the study area*