Correlation Between Soil-gas Radon and Soil-surface Radon Concentration and Estimation of Annual Effective Dose From Outdoor Concentration in Abeokuta, Southwestern Nigeria

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Abstract

In the U series, Rn − 222 ($T_{1/2}$ = 3.82 days) builds up more quickly in homes. Although it originates from rocks and dirt, it dissolves in water. A RAD7 solid state detector was used to test the outdoor and soil gas in-situ radon-222 activity at 26 locations in Abeokuta, Nigeria. The six geological formations that were picked for a cell and spaced at least 3 km apart served as the basis for choosing the measuring site. The Global Positioning System compass was used to determine the locations of the measurement sites. Outdoor radon levels ranged from (0.001 to 4530) Bqm^{-3} while soil gas levels ranged from (52.5 to 19250) Bqm^{-3}. In comparison to the reference level for outdoor radon recommended by the International Commission on Radiological Protection (ICRP), which ranges from (100 to 300) Bqm^{-3}, the average outdoor radon concentration value measured was 463.52 Bqm^{-3}. The exhalation rate ranged from (0.000108 to 0.0395) $Bqm^{-2}s$, and the rate of production of soil gas activity ranged from (0.00011 to 0.0404) $Bqm^{-3}s$. The mean annual effective dose from outdoor radon activity was determined to be 4.242 mSv/year, which is greater than the ICRP-recommended limit of 1 mSv/year for dosage from public exposure. The annual effective doses ranged from 0 to 16.57 mSv/year. The measured values did not correlate, which may be partially explained by the characteristics of the soil and by meteorological conditions.

Introduction

Cosmic rays and gamma ray emitters found in soil, construction materials, water, food, and the air are the principal sources of radiation that humans are exposed to. The primary external source of exposure to gamma radiation for humans comes from naturally occurring radionuclides, particularly when these processes are aided by other natural phenomena such aging deposition and wind erosion (Alaamer, 2008; Elles et. al., 1997). With or without his consent, man is exposed to ionizing radiation, which can result in damage and clinical symptoms such chromosomal changes, cancer induction, free radical generation, bone necrosis, and radiation carcinogenesis (Norman, 2008). Both high dosage and extended low dose exposure may result in damage and clinical signs. Ionizing radiation has a deadly effect, so it has been common practice to monitor and evaluate one's exposure levels and keep it as low as is practically possible (ALARA principle). The radioactivity in his environment, both natural and man-made, is referred to as the ambient radiation (Farai and Vincet, 2006). The bulk of lung cancer-related deaths are brought on by radon, one of the radionuclides present in the environment surrounding humans that delivers a substantial quantity of potentially deadly dosage (UNSCEAR 2000).

Radon, which makes up more than half of all natural source radiation, is the primary source of this radiation. In comparison to its other isotope, Rn − 220 ($T_{1/2}$ = 50s), in the Th series, Rn − 222 ($T_{1/2}$ = 3.82 days) in the U series builds up more readily in residences, making it relevant in terms of radiological health hazard. Ra − 226 ($T_{1/2}$ = 1602 years), a radioactive noble gas that is a part of the U-238 series, undergoes alpha decay to produce radon. It comes from dirt and rocks, but it dissolves in water. The two primary ways that radon travels through soil are diffusion and advection, and its half-life of 3.82 days is long enough for it to diffuse into and accumulate in soil interstices. Radon is transported through soil interstices mostly by diffusion, and its half-life of 3.82 days is long enough for it to diffuse into and accumulate in dwellings. Radon is carried through soil by both diffusion and advection (Samuel et. al., 2022)

Release of radon from residue repository to the environment happen by the accompanying arrangement of procedures: (Moed, et. al., 1988, Yousif, et. al., 2017).

a. Production rate - This is said to be the soil gas radon concentration produced within the soil per unit time

$$a\left(Bqm^{-3}\right) = C_{Rn} \times \lambda$$

1

Where; C_{Rn} is the radon concentration in the soil air in Bq/m^3, λ is the radon decay rate of emanation ($2.1E\text{-}6s^{-1}$).

b. Exhalation rate - which is the number of radon atoms that have been transported from the soil per unit surface area per unit time and then exhaled to the atmosphere. Radium concentrations in the soil, soil permeability and wetness, the condition of the vegetation cover, and weather conditions all affect how much radon is exhaled from the soil. The changes in radon activity in indoor spaces may be partially attributed to meteorological factors, way of life, and tenant habits (Gulan, 2017).

$$E\left(Bqm^{-2}s^{-1}\right) = a\sqrt{\frac{d}{\lambda}}$$

2

Where; d is the diffusion constant/coefficient (2.5E-6m^2s^{-1}), and a is the rate of production within the soil.

c. Emanation and transportation - Diffusion and adventive flow cause the movement of radon atoms formed from the decay of radium escape through the residue or soil profile to the ground surface.

Because of the potential health implications, radon levels in the environment are well known and regularly monitored in most regions of the world (Abumurad et al., 1997). On this element of our environmental health challenges, there are not that many data available in Nigeria. Therefore, research on radon concentration indoors and outdoors are required in places highlighted by a geological layer with a high potential for uranium 238. Additionally, the effective dose it contributes to society each year. The aim of this research is to measure outdoor and soil-gas radon concentration in estimating the annual effective dose, production and exhalation rate as well as well as establish a possible connection between them.

The established value of 9 nSv per ($Bqhm^{-3}$), used in previous UNSCEAR calculations, is still regarded as adequate for average effective dose estimates given the current range of values for the dose conversion factor. The following annual effective doses are calculated using the representative radon concentrations (C_{Rn}), equilibrium factors (F) of 0.6 outdoors, occupancy factors (O) of 1760 outdoor hours, and the dose coefficient previously mentioned (UNSCEAR, 1988; UNSCEAR, 2000)

Outdoor: AED(mSv/y) = $C_{Rn} \times F_{out} \times O_{out} \times DCF$ (3)

The reference level for outdoor radon recommended by International commission on Radiological Protection (ICRP) ranges from (100 to 300) Bqm^{-3}.

Study Area

The Basement Complex rocks surround the city of Abeokuta. These rocks, which date from the north-eastern region of Ogun state and range in age from Precambrian to early Palaeozoic, run southwestward and drop towards the coast (Akinse and Gbadebo, 2016). Between latitudes 7° 10 and 7° 15 N and longitudes 3° 17 and 3° 26 E, Abeokuta occupies a region of approximately 40.63 km^2. The metamorphic rocks of the basement complex, which include granite, granitic gneiss, and pegmatite, are characterized by a variety of folds, structures with varying degrees of complexity, faults, and foliation. High background radiation levels and crystalline rock formations dominate the studied locations (Jibiri and Famodimu, 2013; Oni et al., 2014, Samuel et al., 2022).

Materials And Methods

The Durridge RAD7 uses a Solid State alpha detector. A Solid state detector is a semi-conductor material usually silicon that converts alpha radiation directly to an electric signal. Advantage of Solid State devices are; (a) Ruggedness (b) ability to electronically determine the energy of each alpha particle which makes it possible to tell exactly which isotope (polonium-218, polonium-214 etc.) produced the radiation so as to distinguish radon from thoron and signal from noise. The RAD7 is a highly versatile instrument that can form the basis of a comprehensive radon measurement system. It may be used in many different modes for different purposes; it is a rugged and long-lasting piece of equipment.

Soil surface radon concentration measurement.

The outdoor radon activity (at ground surface) was measured in-situ at each location, by connecting a tube to the desiccant (drying tube) which in turn was connected to the inlet of the Rad7 detector set to undergo two 5 minute recycle and sniffing air from the surrounding, after which the detector was purged to attain a humidity. This measurement was carried out with the use of a polythene can attached to the tube and the ground surface to prevent surrounding air from distorting the measurement.

In-situ Soil gas radon concentration measurement

At the same location where the outdoor activity was measured, the soil gas radon activity concentration was measured with a Rad 7 detector coupled with a soil probe connected to a desiccant. The inner diameter of the soil probe is ¼ inches. The soil gas was pumped out from 80-100cm depth of the soil as shown in Fig. 1.

The RAD-7 pumps the air for 5 minutes into the cell of the detector, and then waits for 5 minutes and count only for 5 minutes. ^{218}Po has a half-life of 3.05 min and it takes about 3–5 half-lives for the ^{218}Po activity to reach secular equilibrium, hence, in about 9–15 minutes. The decays of the ^{218}Po would then be counted after 10 minutes (5 min of pumping plus 5 min of waiting), in which time 95% of equilibrium would have been reached. Finally, each set of readings includes four 5- min cycles that at last takes 30 min (Durridge, 2010)

The production rate, exhalation rate, and annual effective dose were estimated using equations 1, 2 and 3 respectively.

Results And Discussion

Table 1
Result for Soil gas and Outdoor radon concentration of the locations and their GPS coordinates and their geological layers

S/no	Locations	Co-ordinates	Soil surface Radon Conc. (Bqm^{-3})			Soil-gas Radon Conc. (Bqm^{-3})			Geological Layer
			Minimum	Maximum	Mean	Minimum	Maximum	Mean	
1	Osiele	N7^0 11.12’ E3^0 27.23’	0.001 ± 765	0.001 ± 987	0.001	11700 ± 1390	12400 ± 1440	12050	Migmatite
2	Camp	N7^0 11.01’ E3^0 26.50’	35.6 ± 367	35.8 ± 176	35.7	2710 ± 707	3440 ± 781	3075	Migmatite
3	Eleweran	N7^0 10.99’ E3^0 25.93’	828 ± 452	251 ± 274	542.5	10700 ± 1340	12600 ± 1460	11650	Migmatite
4	Somorin	N7^0 10.54’ E3^0 25.07’	35.2 ± 170	35.2 ± 181	35.2	2080 ± 630	2550 ± 680	2315	Migmatite
5	Abiola Way	N7^0 09.99’ E3^0 23.95’	280 ± 280	770 ± 406	525	35.0 ± 191	70.0 ± 191	52.5	Porphyroblastic Gneiss
6	Itoko	N7^0 08.02’ E3^0 21.94’	35.0 ± 169	35.2 ± 211	35.1	69.7 ± 190	70.0 ± 191	69.85	Porphyroblastic Gneiss
7	Oke Bode	N7^0 10.56’ E3^0 21.65’	70.4 ± 192	176 ± 243	123.2	420 ± 350	634 ± 393	527	Porphyritic Biotite
8	Ilu Gun	N7^0 10.88’ E3^0 21.50’	141 ± 257	282 ± 293	211.5	8460 ± 1180	8570 ± 1180	8515	Biotite-garnet-gneiss
9	Mokola	N7^0 11.08’ E3^0 21.32’	2510 ± 696	6550 ± 1040	4530	528 ± 369	634 ± 377	581	Porphyritic Biotite

S/no	Locations	Co-ordinates	Soil surface Radon Conc. (Bqm^{-3})			Soil-gas Radon Conc. (Bqm^{-3})			Geological Layer
			Minimum	Maximum	Mean	Minimum	Maximum	Mean	
10	Iberekodo	N7^0 11.03’ E3^0 21.02’	177 ± 271	248 ± 295	212.5	739 ± 430	743 ± 432	741	Biotite-garnet-gneiss
11	Ago-Odo	N7^0 10.76’ E3^0 20.36’	248 ± 295	493 ± 361	370.5	1830 ± 597	2180 ± 634	2005	Biotite-garnet-gneiss
12	Enu-Gada	N7^0 09.42’ E3^0 19.49’	282 ± 304	743 ± 432	512.5	2570 ± 684	3630 ± 799	3100	Biotite-garnet-gneiss
13	Brewery	N7^0 09.97’ E3^0 19.98’	951 ± 463	2040 ± 638	1495.5	0.00 ± 191	247 ± 293	123.5	Biotite granite gneiss
14	Olomore	N7^0 08.99’ E3^0 19.08’	35.2 ± 211	35.2 ± 228	35.2	493 ± 369	560 ± 367	526.5	Biotite granite gneiss
15	Aro	N7^0 09.52’ E3^0 18.48’	175 ± 280	317 ± 293	246	630 ± 406	634 ± 385	632	Biotite granite gneiss
16	Kere	N7^0 08.09’ E3^0 18.35'	0.001 ± 248	0.001 ± 255	0.001	6440 ± 1030	7080 ± 1080	6760	Pegmatite
17	Ewekoro	N7^0 06.52’ E3^0 18.37’	38.7 ± 352	70.4 ± 304	54.55	19100 ± 1740	19400 ± 1022	19250	Pegmatite
18	Wasimi	N7^0 08.67’ E3^0 18.72’	68.2 ± 300	380 ± 322	224.1	1800 ± 602	2250 ± 655	2025	Pegmatite
19	Maku	N7^0 09.03’ E3^0 18.66’	54.2 ± 765	70.8 ± 677	62.5	743 ± 410	810 ± 456	776.5	Biotite granite gneiss

S/no	Locations	Co-ordinates	Soil surface Radon Conc. (Bqm^{-3})			Soil-gas Radon Conc. (Bqm^{-3})			Geological Layer
			Minimum	Maximum	Mean	Minimum	Maximum	Mean	
20	Onikolobo	$N7^0$ 07.44’ $E3^0$ 20.01’	222 ± 232	285 ± 208	253.5	9930 ± 1260	9930 ± 1260	9930	Biotite granite gneiss
21	Adatan	$N7^0$ 10.22’ $E3^0$ 21.98’	986 ± 456	2500 ± 280	1743	140 ± 268	176 ± 257	158	Porphyritic Biotite
22	Saje	$N7^0$ 10.78’ $E3^0$ 21.71’	106 ± 257	106 ± 775	106	3030 ± 738	3420 ± 770	3225	Porphyritic Biotite
23	Ikija	$N7^0$ 10.54’ $E3^0$ 20.46’	196 ± 270	211 ± 257	203.5	665 ± 391	845 ± 443	755	Porphyritic Biotite
24	Olumo	$N7^0$ 10.04’ $E3^0$ 21.85’	176 ± 270	560 ± 361	368	35.0 ± 255	70.0 ± 242	52.5	Porphyritic Biotite
25	Ibara	$N7^0$ 07.03’ $E3^0$ 19.05’	47.5 ± 211	70.0 ± 227	58.75	3680 ± 801	4080 ± 839	3880	Pegmatite
26	Ojere	$N7^0$ 06.87’ $E3^0$ 18.99’	65.7 ± 766	68.7 ± 909	67.2	6130 ± 1010	6800 ± 1070	6465	Pegmatite

The result from Table 1 shows that for soil gas radon concentrations, Ewekoro underlined by pegmatite layer, has the maximum concentration of 19250 Bq/m^3, with a difference of 7200 Bq/m^3 higher than Osiele underlined by migmatite having a concentration of 12050 Bq/m^3, and the minimum value is at Olumo and Abiola Way with a concentration of 52.5 Bq/m^3, underlined by porphyritic Biotite and Porphyroblastic gneiss respectively. The soil surface (outdoor) radon concentrations measured are also shown on Table 1 at same location as the soil gas, with a maximum value of 4530 Bq/m^3 at Mokola which is approximately 4.5 million times greater than the minimum value of 0.001 Bq/m^3 recorded at Osiele and kere. Comparing the soil gas radon concentration to the outdoor radon concentration as shown on Fig. 3, it is seen that there is a negative (inverse) correlation (-0.2347) between them.

Table 2
Result for Annual effective dose from the outdoor air radon concentration.

S/no	Locations	Surface Radon Conc. (Bqm^{-3})	AED(mSv/year)
1	Osiele	0.001	0.000009504
2	Camp	35.7	0.3392928
3	Eleweran	542.5	5.15592
4	Somorin	35.2	0.3345408
5	Abiola Way	525	4.9896
6	Itoko	35.1	0.3335904
7	Oke Bode	123.2	1.1708928
8	Ilu Gun	211.5	2.010096
9	Mokola	4530	43.05312
10	Iberekodo	212.5	2.0196
11	Ago-Odo	370.5	3.521232
12	Enu-Gada	512.5	4.8708
13	Brewery	1495.5	14.213232
14	Olomore	35.2	0.3345408
15	Aro	246	2.337984
16	Kere	0.001	0.000009504
17	Ewekoro	54.55	0.5184432
18	Wasimi	224.1	2.1298464
19	Maku	62.5	0.594
20	Onikolobo	253.5	2.409264
21	Adatan	1743	16.565472
22	Saje	106	1.007424
23	Ikija	203.5	1.934064
24	Olumo	368	3.497472
25	Ibara	58.75	0.55836
26	Ojere	67.2	0.6386688
		463.5193	4.4052875

Table 3
Result of rate of production and Exhalation rate of the soil gas radon concentration.

S/no	Locations	Soil-gas Radon Conc. ($kBqm^{-3}$)	Production rate (a($Bqm^{-3}s$))	Exhalation rate (E($Bqm^{-2}s^{-1}$))
1	Osiele	12.05	0.025305	0.027607755
2	Camp	3.08	0.006468	0.007056588
3	Eleweran	11.65	0.024465	0.026691315
4	Somorin	2.32	0.004872	0.005315352
5	Abiola Way	0.05	0.000105	0.000114555
6	Itoko	0.07	0.000147	0.000160377
7	Oke Bode	0.53	0.001113	0.001214283
8	Ilu Gun	8.52	0.017892	0.019520172
9	Mokola	0.58	0.001218	0.001328838
10	Iberekodo	0.74	0.001554	0.001695414
11	Ago-Odo	2.01	0.004221	0.004605111
12	Enu-Gada	3.1	0.00651	0.00710241
13	Brewery	0.12	0.000252	0.000274932
14	Olomore	0.53	0.001113	0.001214283
15	Aro	0.63	0.001323	0.001443393
16	Kere	6.76	0.014196	0.015487836
17	Ewekoro	19.25	0.040425	0.044103675
18	Wasimi	2.03	0.004263	0.004650933
19	Maku	0.78	0.001638	0.001787058
20	Onikolobo	9.93	0.020853	0.022750623
21	Adatan	0.16	0.000336	0.000366576
22	Saje	3.26	0.006846	0.007468986
23	Ikija	0.76	0.001596	0.001741236
24	Olumo	0.05	0.000105	0.000114555
25	Ibara	3.88	0.008148	0.008889468
26	Ojere	6.47	0.013587	0.014823417

From Table 2; the average outdoor radon concentration value measured was 463.52 Bqm^{-3}, which is higher than the reference level for outdoor radon recommended by International commission on Radiological Protection (ICRP) which ranges from (100 to 300) Bqm^{-3}. Also the annual effective dose of the study area ranges from 9×10^{-7} mSv/year to 16.57 mSv/year with a mean value of 4.242 mSv/year, this value is higher than the value for the limit on dose from public exposure which is 1mSv in a year as recommended by International commission on Radiological Protection (ICRP). rate of production of 1.1×10^{-4} Bq/m^3s – 4.04×10^{-2} Bq/m^3s and the exhalation rate of 1.08×10^{-4} Bq/m^2s to 3.95×10^{-2} Bq/m^2s as shown in Table 3.

Conclusion

The radon concentration for outdoor were found to be have an average value higher than the reference level recommended by the International Commission on Radiation Protection, The Annual effective doses have been calculated from the radon activity of emanation in outdoor air (at ground surface), the production rate and exhalation rate were also estimated from the soil-gas radon concentration. The correlation between the measured values was found to be negative which may be partially attributed to soil properties, as well as meteorological factors. For further studies, more research should be carried out to investigate other locations, as well as other radon sources so that guidelines for radon concentration could be established in Nigeria.

Declarations

Ethical Approval

Not Applicable

Consent of Participate

All authors give their consent of participating to this research.

Consent to Publish

All author gives the publisher the permission to publish the article

Authors Contributions

The study's inception and design involved input from all authors. T. D. Samuel, A. Aremu, O. M. Oni, and J. A. Fajemiroye prepared the materials, collected the data, and conducted the analysis. T. D. Samuel and I. P. Farai wrote the original draft of the manuscript, and all of the authors provided feedback on earlier drafts. The final manuscript was read and approved by all authors.

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Competing Interests

Not applicable

Availability of Data and Materials

Not applicable

Statement and Declaration

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The study's inception and design involved input from all authors. T. D. Samuel, A. Aremu, O. M. Oni, and J. A. Fajemiroye prepared the materials, collected the data, and conducted the analysis. T. D. Samuel and I. P. Farai wrote the original draft of the manuscript, and all of the authors provided feedback on earlier drafts. The final manuscript was read and approved by all authors.

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Figures

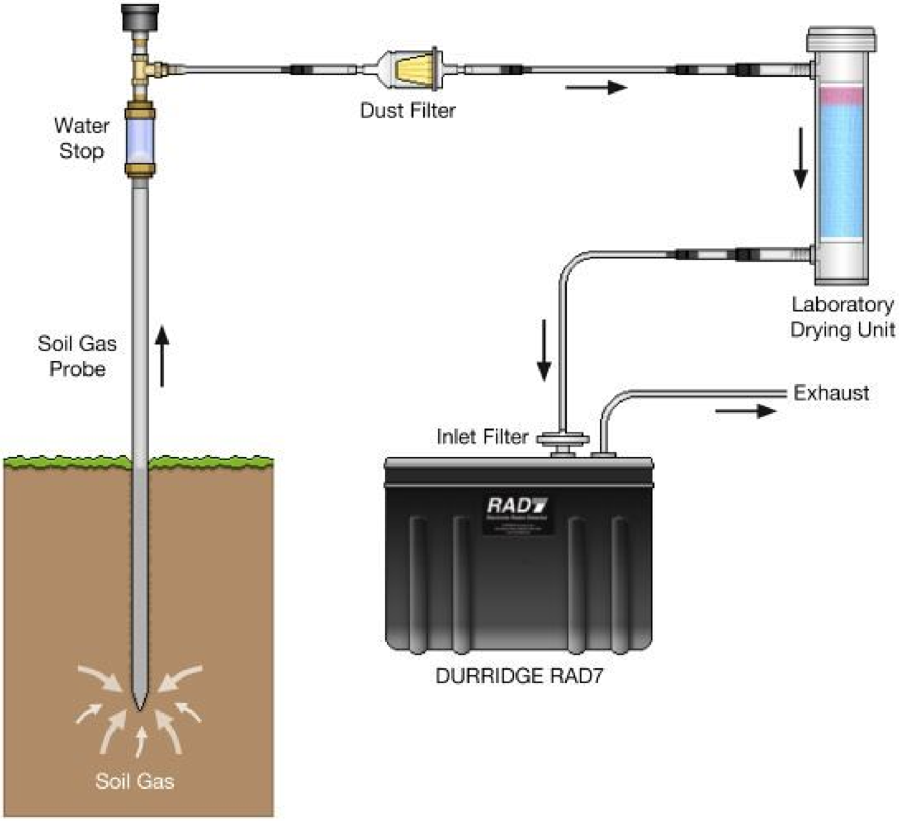

Figure 1

Set-up for soil-gas radon concentration measurement at 1m depth (Durridge, 2010)

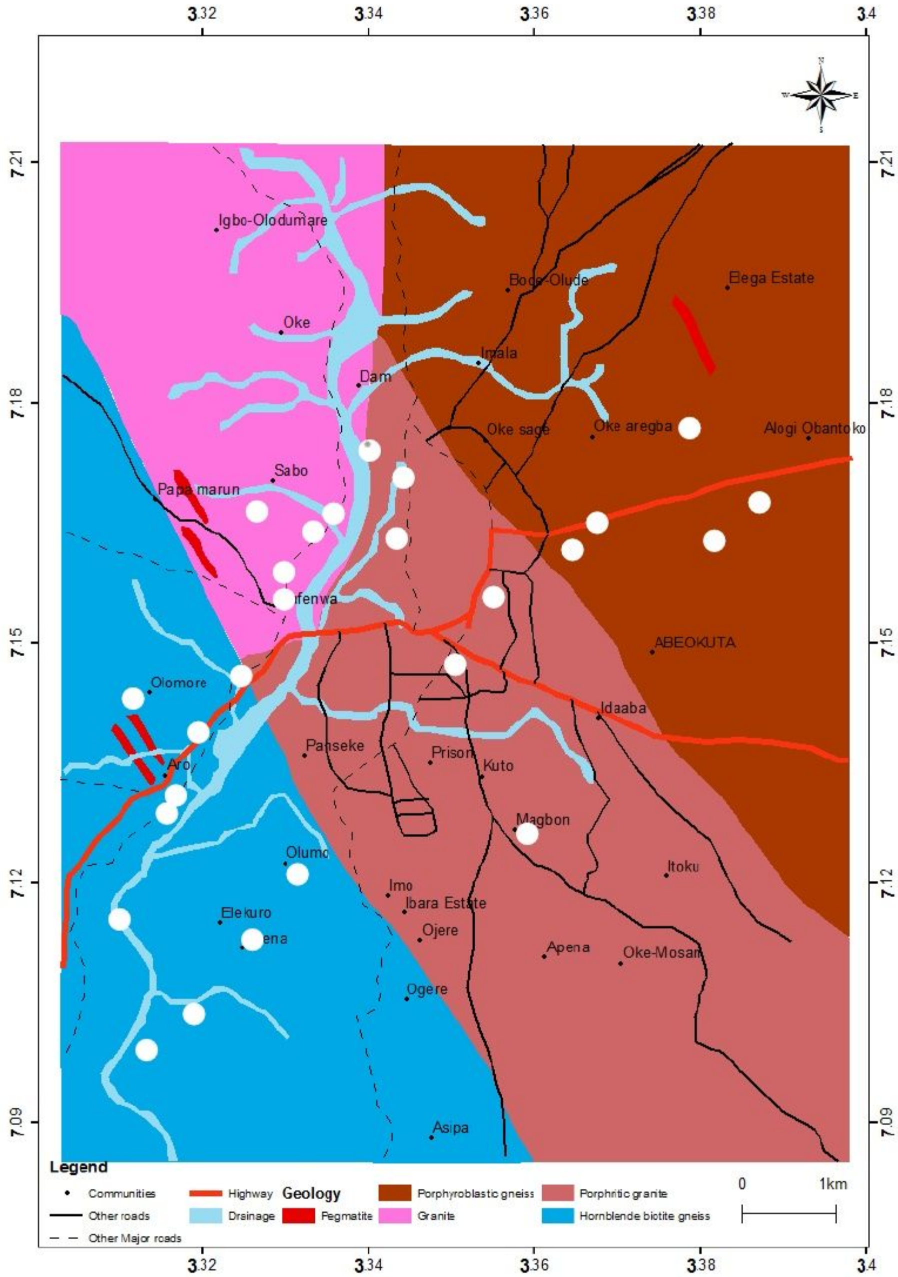

Figure 2

Geological map of Abeokuta showing the points of sampled area (Samuel *et. al.,* 2022)

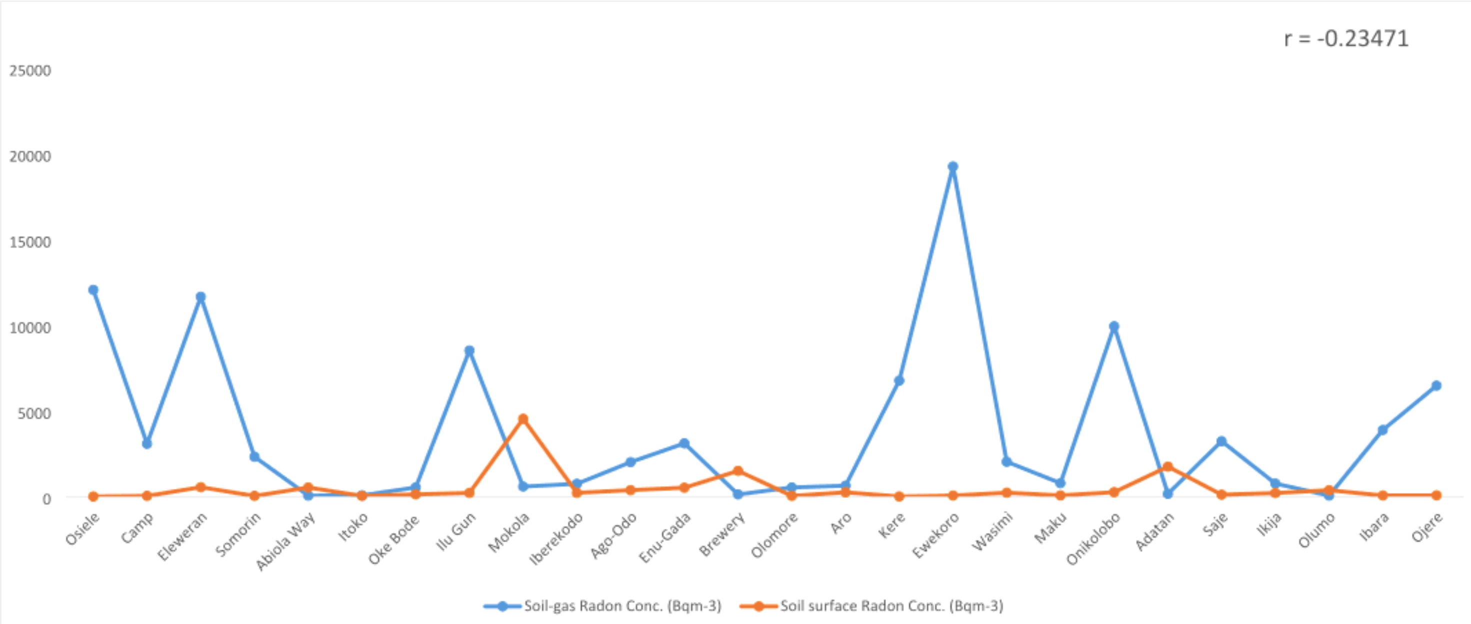

Figure 3

Chart showing the correlation between soil surface and soil-gas radon concentration.