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Measurement of Radon-222 Concentration in Soil-Gas of Ogbomoso Southwestern Nigeria using RAD7

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ABSTRACT: *Radium-226 in the earth's crust is the main source of radon-222 in the global environment which is the gaseous radionuclide that is highly mobile everywhere in the universe. Radon-222 concentration in soil-gas is a known radioactive gas, contributing the highest exposure of ionizing natural radiation to the public. Its health hazards are well known. It's origination from soil contribute to its concentration level in air, water and other consumables originated from soil. To identify its concentration levels at different locations in Ogbomoso Southwestern Nigeria, an investigation was carried out using measurement techniques for the first time in the locality with electronic active radon detector (RAD7) manufactured by Durridge Company, USA. Experimentally, 13 feasible locations within the study area and four different depths of 20cm, 40cm, 60cm and 100cm were considered for measurement. The results obtained showed that, the highest concentration of radon-222 at 20cm depth was 4,450±695Bqm^{-3} found in location 8($8^0$10.058'N/ $4^0$11.930'E) and that of 100cm depth was 25,640±2035Bqm^{-3} found in location 2($8^0$7.437'N/ $4^0$15.519'E)while the lowest concentration at 20cm was 720±389Bqm^{-3} found in location 13($8^0$5.489'N/ $4^0$19.850'E) and that of 100cm depth was 7,370±1139Bqm^{-3} found in location 5($8^0$8.455'N/ $4^0$14.021'E). The mean value of radon concentration of all the 13 locations considered were calculated to be 2,715.386Bqm^{-3}, 5,920.760Bqm^{-3}, 7,786.923Bqm^{-3} and 20,581.539Bqm^{-3} for 20cm, 40cm, 60cm and 100cm respectively and the average mean of all the 13 locations was calculated to be 9251.154Bqm^{-3}. Inferentially, a model was derived using regression analysis for further study on radon-222 concentration in soil-depths. Thus, the concentration level of radon-222 identified at different soil-depths in the study area provides information on probable level of radon in air, water and other consumables originating from soil in the study area. It is the needed fact in assessing radiological health risk and as other environmental indicator. A derived model could be a yardstick for further studies on soil-gas radon-222 in Nigeria, especially in the study area, Ogbomoso Southwestern Nigeria. Also, comparisons made with other investigators around the globe showed that this present investigator's region results were within the limited range, when compared with other regions of the investigations with higher value around the globe.*

KEYWORD*: Concentration, Probable, Radionuclide, Ubiquitous, yardstick,*

I. INTRODUCTION

Radium-226 in the earth's crust is the main source of radon-222 in the global environment. Radon is ubiquitous throughout the geosphere, biosphere and atmosphere, since radium-226 is present everywhere and the gaseous radionuclide is highly mobile [1]. The major source of radiation in the earth crust that is ionizing in nature and continuously exposed the human being is uranium, thorium and their offspring in the environment [2 & 3]. Human exposure to radiation is mainly natural and the highest percentage is from radon-222 [4].Radon is a chemical element with symbol Rn and atomic number 86. It is a radioactive, colourless, odourless, tasteless noble gas, occurring naturally as an indirect decay product of uranium or thorium found within the soils and rocks of the Earth(Table 1)[5]. Its most stable isotope, ^{222}Rn, has a half-life of 3.8 days. Radon is one of the densest substances that remain a gas under normal conditions. It is also the only gas under normal conditions that only has radioactive isotopes, and is considered a health hazard due to its radioactivity. Studies in many developed countries on exposure to radon have revealed the carcinogenic ability of radon [5]. Radon in air and water is from soil. The concentration of radon in air and water depends largely on the type and other characteristics of the soil. Radon in soil emanates, migrates and diffuses through the soil interstitial spaces to the air, when inhaled in high concentration has been reported to be the second cause of lung cancer after smoking [6]. Also, radon in soil dissolved in underground water. Research activities have reported that when radon contaminated water is ingested, there is an associated high risk of stomach and colo-rectal cancer. However, studies on radon in Nigeria are very scanty. In Nigeria, no previous studies have been reportedly undertaken relating radon concentration in air to

varying soil parameters. As shown in Table 1, radon-222 which is a naturally occurring radioactive isotope, that occurs in the uranium-238 decay chain.
Its immediate parent is radium-226, and radon-222 itself decays by alpha particle emission through a series of short - lived decay products (mainly isotopes of polonium, lead and bismuth) to lead-210 and on eventually to stable lead-206. [7]. Two other isotopes of radon occur in nature; radon-220, which occurs in the thorium-232 decay chain and radon-219 in the uranium-235 chain [7]. Both of these isotopes have half-lives of under a minute and are less important than radon-222 which is the subject of this research. In this work, *in-situ* measurement of soil-gas radon-222 concentration was carried out to identify its concentration levels and its dispersal in soil-gas in Ogbomosho southwestern Nigeria of Africa using electronic active radon detector (RAD-7) of Durridge Company, USA. Knowing the Radon-222 concentration in soil-gas at different soil depth determines the concentration level of radon in outdoor/ indoor air, water and other consumables originating from soil, which is a needed fact in assessing radiological health risk and as other environmental indicator.

Table 1: Uranium – 238 Decay Chain [7]

Element	Radiation	Half – life
Uranium – 238	Alpha	4,460,000,000 years
Thorium – 234	Beta	24.1 days
Protactinium – 234	Beta	1.17 minutes
Uranium – 234	Alpha	247,000 years
Thorium – 230	Alpha	80,000 years
Radium – 226	Alpha	1,602 years
Radon – 222	**Alpha**	**3.82 days**
Polonium – 218	Alpha	3.05 minutes
Lead – 214	Beta	27 minutes
Bismuth – 214	Beta	19.7 minutes
Polonium – 214	Alpha	1 microsecond
Lead – 210	Beta	22.3 years
Bismuth – 210	Beta	5.01 days
Polonium – 210	Alpha	138.4 days
Lead – 206	None	Stable

II. MATERIALS AND METHODS

Brief about Study Area: Ogbomosho is a city in Oyo State, southwestern Nigeria. It's located between latitude 8˚06′70″ and 8˚06′98.7″North and between longitude 4˚14′28.2″ and 4˚14′56.9″ East [8]. It was founded in the mid-17th century and the population was approximately 645,000 in 1991 [9] by March 2005, it was estimated at around 1,200,000 [10]. The City is considered one of Nigeria's largest urban centers. The majority of the people are members of the Yoruba ethnic group. Yams, cassava, maize, and tobacco are some of the notable agricultural products of the region [9], which are directly or indirectly originating from soil that are classified to be the source of radon in the global environment. The soil, which is the main sources of uranium and thorium, is also the main sources of the agriculture products of the study area. Measurement of radon concentration at different locations

and different soil-depths provides information on the probable level of radon concentrations in the locality, especially on the radon concentration in air, water and other consumables originating from soil.

Experimental Measurements: Measurement of soil-gas radon-222 concentration at different soil-depths was done using soil gas probe extending from steel soil gas probe in the soil depth through a desiccant to the electronic active radon detector (RAD-7) manufactured by Durridge Company, USA. The detailed setup of the radon equipment used for the radon measurement is shown in Fig. 1.

With the setup (Fig. 1), measurements were done at 13 locations chosen within the study area (Fig. 2). At every location, with a calibrated pilot rod hammered to the required depth, a soil gas probe inserted through tube connection to the RAD-7 and the soil-gas radon concentration was measured. Four different depths of 20cm, 40cm, 60cm and 100cm were considered for the measurement. At each soil depth in a particular location, the soil-gas radon concentration was measured four times in Bqm^{-3} at every location and recorded. Being a pilot study, the work was limited to a size-able and feasible geo-coordinates permissible within the study area, with the field work took place between 15th of February to 4th march, 2015. It was dry season period with mean ambient temperature usually between 35^0C to 55^0C.

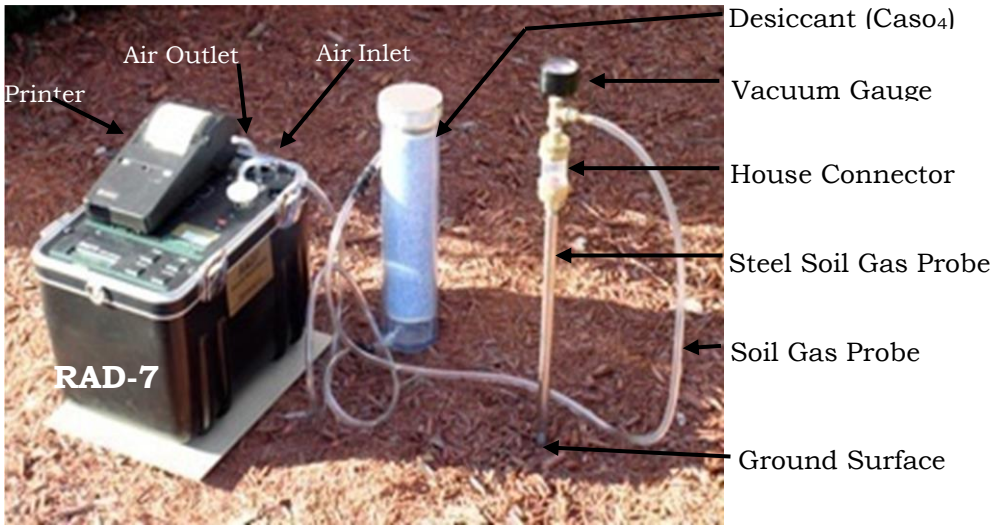

Figure 1: Detail setup of the radon-222 measurement equipment

Statistical Analysis: With the results of radon concentration measured in all the 13 locations considered, the mean values of radon at 20cm, 40cm, 60cm and 100cm were calculated. Inferentially, a model was derived using regression analysis. Also, a comparative test was done with other investigators around the globe and the mean value of radon-222 concentration of all the 13 locations considered for this work was also calculated and recorded.

III. RESULTS

The results of soil-gas radon-222 concentration measured within the study area, Ogbomoso North and South Local Government Area of Oyo state were tabulated and presented (Table 2). Also presented (Table 3), are the average mean values of radon-222 concentration calculated at 20cm, 40cm, 60cm and 100cm respectively. Based on the average mean values, a model equation was derived (Equation1) for further study on soil-gas radon concentration in soil-depths. The constants estimated values for model equation were also presented (Table 4).

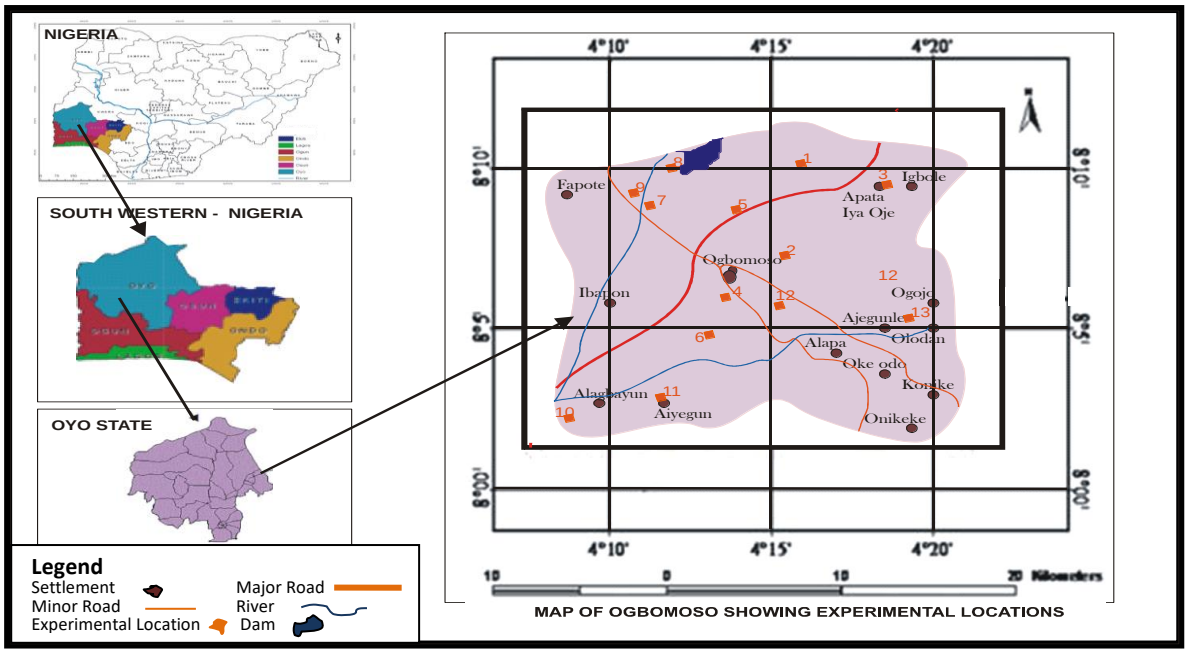

Figure 2: Map of Ogbomoso showing radon-222 experimental locations [Modified after 11, 12 &13]

Table 2: Radon-222 Concentration Measured at Definite Soil-depths

Sample Location	Latitude and Longitude	Sampling Depth (cm)	Radon concentration (Bqm^{-3})	Range
Location 1	8^0 10.227′ N 4^0 16.02′ E	20	2920 (±368)	3290 – 2480
		40	8760 (±840)	10220 – 7140
		60	13800 (±1090)	15100 – 7280
		100	24680 (±1960)	30842 – 12500
Location 2	8^0 7.437′ N 4^0 15.519′ E	20	3180 (±401)	3590 – 2800
		40	6240 (±882)	11550 – 8020
		60	14260 (±1126)	16050 – 8780
		100	25640 (±2035)	32480 – 11070
Location 3	$8^0$9.531′N $4^0$18.415′E	20	2050 (±334)	3110 – 1290
		40	8180 (±803)	9980 – 6840
		60	10510 (±1057)	14970 – 8200
		100	23910 (±1894)	28660 – 10840
Location 4	8^0 6.223′ N 4^0 13.639′ E	20	2620 (±1580)	4000 – 549
		40	6970 (±2360)	8790 – 3520
		60	5380 (±2140)	8360 – 3570
		100	21800 (±10990)	30120 – 12655
Location 5	8^0 8.455′ N 4^0 14.021′ E	20	2360 (±651)	3480 – 659
		40	680 (±392)	970 – 540
		60	4220 (±894)	5640 – 2850
		100	7370 (±1139)	9140 – 4060
Location 6	$8^0$4.965′ N $4^0$12.938′ E	20	3740 (±1775)	4070 – 1230
		40	5230 (±561)	7020 – 4800
		60	3980 (±1320)	6560 – 1590
		100	20060 (±10562)	26630 – 60050
Location 7	8^0 8.407’ N 4^0 11.365’ E	20	3520 (±342)	3840 – 2300
		40	7630 (±730)	8560 – 5980
		60	9100 (±1232)	1020 – 7800
		100	22680 (±1872)	28400 – 5800
Location 8	8^0 10.058′ N 4^0 11.930′ E	20	4450 (±695)	5800 – 2040
		40	9720 (±722)	10030 – 6880
		60	11040 (±1223)	15090 – 8530

		100	23850 (±1503)	29550 – 6100
Location 9	8^0 9.000′ N 4^0 11.000′ E	20	3670 (±432)	4020 – 2100
		40	6200 (±709)	7950 – 4800
		60	8960 (±1235)	9440 – 6060
		100	21670 (±1955)	29600 – 5980
Location 10	8^0 2.617′ N 4^0 8.581′ E	20	890 (±433)	1530 – 225
		40	2950 (±730)	3670 – 1170
		60	3530 (±807)	3760 – 3420
		100	18400 (±1765)	25100 – 6320
Location 11	8^0 2.951′ N 4^0 11.972′ E	20	1070 (±776)	1580 – 320
		40	4090 (±667)	5820 – 1290
		60	6640 (±834)	7785 – 3550
		100	19770 (±1800)	2535 – 7750
Location 12	8^0 5.943’ N 4^0 15.226’ E	20	4110 (±1950)	5590 – 1360
		40	6520 (±586)	7200 – 5830
		60	4400 (±1370)	6050 – 2940
		100	20700 (±10900)	29500 – 5860
Location 13	$8^0$5.489′ N $4^0$19.850′ E	20	720 (±389)	1480 – 200
		40	3800 (±690)	4605 – 1100
		60	5410 (±780)	3770 – 3400
		100	17030 (±1730)	24110 – 5710

*** Values in parentheses represent the standard deviation.**

Table 3: Mean Radon-222 Concentration at Definite Soil-Depths

Sampling Depth (cm)	**Radon Concentration (Bqm^{-3})**
20.00	2715.386
40.00	5920.766
60.00	7786.923
100.00	20581.539

Based on the mean radon-222 concentration at definite soil-depths (Table 3), a derived model (equation 1) at each definite soil-depth is as follows;

$$\widehat{R_n} = \hat{\alpha} + \widehat{\beta_1} d + \widehat{\beta_2} d^2 + \widehat{\beta_3} d^3 \qquad R^2 = 1 \qquad \text{(Equation 1)}$$

As shown (Equation 1), $\hat{R}_n$ is the estimated value of radon-222 concentration at definite soil depth, $\hat{\alpha}$, $\widehat{\beta_1}$, $\widehat{\beta_2}$ and $\widehat{\beta_3}$ are the constant estimated variables of the model at different soil-depths d considered for the measurement. However, the following conditions satisfied the applicability of the equation 1;

(i) $\hat{R}_n$ is positive and valid only, when 20cm ≤ d ≤ 100cm and

(ii) $\hat{R}_n$ is negative when d ≤ 0cm and invalid when d < 20cm

The above conditions satisfied the depths of 20cm and 100cm because, the modeled variables ranges between 20cm and 100cm soil-depths.

Table 4: Model Estimated Values

$\hat{\alpha}$	$\widehat{\beta_1}$	$\widehat{\beta_2}$	$\widehat{\beta_3}$
-5099	560.4	-9.849	0.068

Table 5: Comparison of Radon-222 Concentration Measured with other Investigators around the Globe [14].

Region	Radon concentration in soil - gas ($kBqm^{-3}$) Range	Mean	References
Islamabad, Pakistan	17.34 – 72.52	45.08	Ali *et al* (2010)
Murfree, Pakistan	0.61 – 3.89	1.70	Ali *et al* (2010)
Southern Punjab, Pakistan	0.42 – 3.56	-	Mujahid *et al* (2010)
Budhakeda, Tehri Garhwal, India	1.10 – 31.80	7.46	Prasad *et al* (2008)
Hamirpur district, HP, India	0.03 – 2.28	0.46	Mehra and Bala (2013)
Garhwal Himalaya, India	0.01 – 2.33	0.30	Bourai*et al* (2013)
Upper Siwaliks, India	11.50 – 78.47	-	Singli*et at* (2010 a, b)
Malwa belt, Punjab, Indiia	1.90 – 16.40	-	Kumar *et al* (2011)
Tusham ring complex, Haryana, India	42.80 – 71.50	61.00	Bajwa*et al* (2010)
Kangra district, HP, India	1.10 – 82.20	-	Singli*et al* (2006)
Sri Ganganagar district, Rajasthan, India	0.09 – 10.40	-	Vikas Duggal *et al* (2014)
Ogbomoso southwestern Nigeria	**0.20 – 32.48**	**9.25**	**Present investigation**

IV. DISCUSSIONS OF RESULTS

As shown in Table 1, the highest concentration of radon at 20cm soil-depth was 4,450±695Bqm^{-3} and that of 100cm soil-depth was 25,640±2035Bqm^{-3} while the lowest concentration at 20cm was 720±389Bqm^{-3} and that of 100cm depth was 7,370±1139Bqm^{-3}. The mean value of radon concentration of all the 13 locations considered were calculated (Table 3) and the average mean value was estimated to be 9251.153Bqm^{-3}. Furthermore, a derived model (Equation 1) with its $R^2 = 1$ uphold that the model is reliable and its applicability for further prediction on soil-gas radon-222 concentration in soil-depths is justified. The conditions stated satisfied the depths at 20cm and 100cm because, the modeled variables ranges between 20cm and 100cm soil-depths. Also showed in Table 4 are the constant estimated values derived for the modeled (Equation 1). These constant values are peculiar to the model and does not change or modify for any condition. Also presented in Table 5 is the comparison table showed the result of present investigator and those reported by other investigators around the globe with the mean value of 9.25$kBqm^{-3}$. This showed that this present investigator's region, Ogbomoso southwestern Nigeria is within the limited range of radon-222, when compared with other regions of the investigations with higher value around the globe.

V. CONCLUSION

Radon-222 concentration in soil-gas is a known radioactive gas, contributing the highest exposure of ionizing natural radiation to the public. The results of the field experimental measurement to determine its concentration level for this work showed that, the highest concentration of radon in Bqm^{-3} at 20cm depth was found in location 8($8^0$10.058′N/ $4^0$11.930′E) and that of 100cm depth was found in location 2($8^0$7.437′N/ $4^0$15.519′E) while the lowest concentration at 20cm depth was found in location 13($8^0$5.489′N/ $4^0$19.850′E) and that of 100cm depth was found in location 5($8^0$8.455′N/ $4^0$14.021′E). Thus, known the concentration of radon-222 at different soil-depth in Ogbomoso metropolis will provide information on the probable concentration level of radon in outdoor/ indoor air, water and other consumables originating from soil in the locality. It is a needed fact in assessing radiological health risk and as other environmental indicator. However, studies on radon in Nigeria are very scanty. In Nigeria, no previous studies have been reportedly undertaken presenting measurement results on radon-222 using electronic active radon detector (RAD-7) in the study area. Being the first of its type in the study area to use RAD-

7 for radon measurement, history had been made for measurement of soil-gas radon-222 concentration in soil-gas of Ogbomoso Southwestern Nigeria using RAD-7 and this also presents Ogbomoso to be among world radon research area, it also provides opportunity to evaluate the performance of radon measurement device (RAD-7) for measuring radon in soil as compared with other researchers in the globe. Based on the measurements and data obtained, a model developed (equation 1) could be a yardstick for further study on radon-222 concentration predictor in Nigeria, especially in the study area, Ogbomoso southwestern Nigeria.

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