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Computational Model for Prediction of Soil-Gas Radon-222 Concentration in Soil-Depths and Soil Grain Size Particles

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Abstract**—**Percentage of soil-gas radon-222 concentration (^{222}Rn) from soil-depths contributing to outdoor radon atmospheric level depends largely on some physical parameters of the soil. To determine its dependency in soil-depths, survey tests were carried out on soil depths and grain size particles using in-situ measurement method of soil-gas radon-222 concentration at different soil depths. The measurements were carried out with an electronic active radon detector (RAD-7) manufactured by Durridge Company USA. Radon-222 concentrations (^{222}Rn) in soil-gas were measured at four different soil depths of 20, 40, 60 and 100 cm in five feasible locations. At each soil depth, soil samples were collected for grain size particle analysis using soil grasp sampler. The result showed that highest value of radon-222 concentration (24,680 ± 1960 Bqm^{-3}) was measured at 100 cm depth with utmost grain size particle of 17.64% while the lowest concentration (7370 ± 1139 Bqm^{-3}) was measured at 100 cm depth with least grain size particle of 10.75% respectively. A computational model was derived using SPSS regression package. This model could be a yardstick for prediction on soil gas radon concentration reference to soil grain size particle at different soil-depths.

Keywords**—**Concentration, radon, porosity, diffusion, colorectal, emanation, yardstick.

I. Introduction

THE percentage of soil-gas radon-222 concentration contributing to outdoor radon atmosphere level depends on some physical parameters of the soil such as soil moisture, porosity, pore size and number, radium concentration, grain size particle and shape, atmospheric condition and soil temperature as well as atmospheric pressure [1]. Radon-222 is a known carcinogenic gas [8]. It is a radioactive, colorless, odorless, tasteless noble gas that is naturally occurring as progeny of uranium and thorium exist in the soils and rocks of the Earth [3].

Radon in air and water comes from soil [3]-[9]. The concentration of radon in air depends on the type and other characteristics of the soil. Radon in air, when inhaled in high concentration, has been reported to be the second cause of lung cancer after smoking [2]. Also, radon in soil dissolves in water under the ground. Previous research work revealed that when water contaminated with radon is ingested, there is tendency and risk of having stomach and colorectal cancer [2]. According to [1], there has been no published quantitative experimental work examining the effect of granular pores on radon emanation. This is likely due to difficulties in quantifying the size and number of pores of various types of materials.

Radon emanation and diffusion through the soil interstitial space to the global environment depends on the soil geophysical formation (Fig. 1). Therefore, to provide essential information on the level of radon concentration in soil, water and air, quantitative research work to ascertain emanation, diffusion and movement of soil-gas radon concentration through soil interstitial spaces is required. Thus, having fundamental needs of knowledge on soil-gas radon-222 concentration and its dependency on some soil geophysical formation at different soil-depths provides probable information on the apparent level of radon concentration in air, which is one of the needed facts in assessing radiological health risk and as other environmental indicator.

The formation of radon from rocks and soils released to the surrounding water or air is partially. Some percentage of radon migrates and diffuses through pore spaces to the nearby surrounding. Its principal mechanism of transportation is through convection and general flow of air and water.

High level of porosity increases its diffusion rate. Moisture modest also improves the release of radon but, high level of modest reduces diffusion processes and hence, decreases radon levels [4]-[6]. Most of the air contaminant present in the soil is based on the permeability and density of the soil. Radon diffuses from nearby soil particles or migrates from more distance radon richen materials. Its concentration in soil gas decreases as it migrates to the surface to the open air above the ground. Related models have been developed based on the experimental studies of soil-gas radon to further research on radon.

In this research, *in-situ* measurement of soil-gas radon (^{222}Rn) concentration was carried out in some locations of Ogbomoso Southwestern Nigeria (bounded within latitude 8.04362 – 8.17045°N and longitude 4.14302 – 4.26700°E) (Fig. 2) [10], using electronic active radon detector (RAD-7) manufactured by Durridge Company, USA, specially made for Radon and Thoron.

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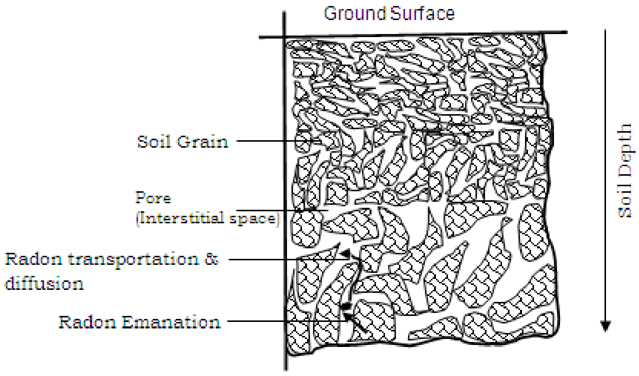

Fig. 1 Mechanisms of radon emanation and diffusivity in soil-depth

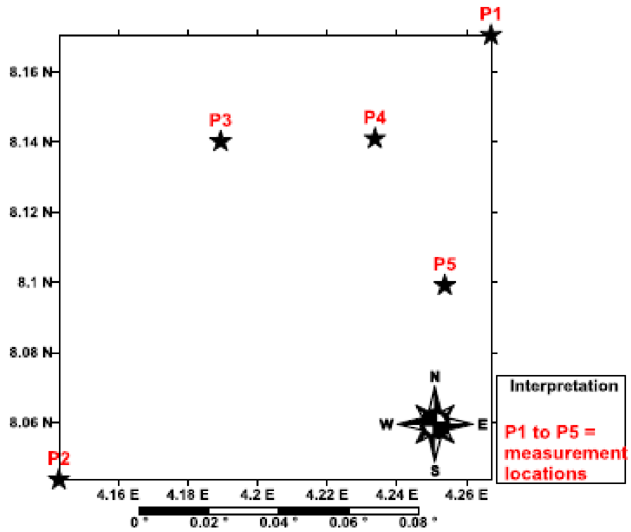

Fig. 2 Measurement locations in the study area (Ogbomoso SW Nigeria) [10]

II. Methodology

A. Measurement Techniques

For this work, measurement of soil-gas Radon-222 concentration at different soil-depths was done using Soil Gas Probe of the electronic active radon detector (RAD-7) manufactured by Durridge Company, USA (Fig. 3). The measurements were done with a calibrated pilot rod hammered to the required depth and soil gas probe was inserted and through tube connection to the RAD-7, the soil-gas radon concentration was measured. Four different depths of 20, 40, 60 and 100 cm were considered for the measurement. At each soil-depth in a particular location, the soil-gas radon-222 concentration was measured four times. At each measurement depths, soil samples were obtained for further laboratory test on soil grain size particles using a constructed Soil Grasp Sampler (SGS) (Fig. 4).

B. Grain Size Analysis

The grain size test was conducted to determine the percentage of different grain sizes contained within a soil at different soil depth. Four different sieve sizes of 50, 56, 63 and 1600 µm were used. The equipment (apparatus) used in this determination are: balance, set of sieves, cleaning brush, sieve shaker and timing device. For each sample, weight of each sieve as well as the bottom pan used were measured and recorded and the weights of each dry soil samples were also measured and recorded. Furthermore, it was ensured that all the sieves were cleaned and assembled in ascending order of sieve numbers and the bottom pan was placed below last sieve. Carefully, the soil samples were poured into the top sieve and the cap was placed over it. Furthermore, the sieves were stack in the mechanical shaker and shake for 10 minutes. The stack was later removed from the shaker and thoroughly weighed and recorded the weight of each sieve with its retained soil. In addition, the bottom pan was also weight with its retained fine soil and the data collected were recorded for further analysis.

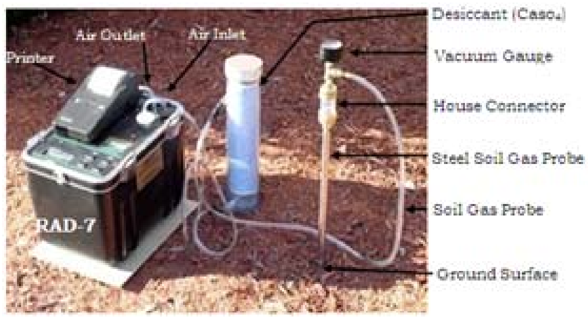

Fig. 3 Setup of the Radon-222 measurement equipment

Fig. 4 Soil Grasp Sampler

The mathematical relation for grain size analysis was done using (1), to calculate the percentage of soil sample retained as:

$$\%\, retained = \frac{Mass\ retained}{Total\ mass}\ X\ \frac{100}{1} \tag{1}$$

and percentage of the soil sample passing was calculated as:

$$\%\, passing = 100 - x_1, (100 - x_1) - x_2, ((100 - x_1) - x_2)) - x_3, \dots \dots - x_n. \tag{2}$$

where; x is the total mass of the soil sample, $x_1, x_2, x_3, \dots \dots \dots x_n$, is mass retained on each sieve. Hence, quantity of soil passing is:

$$\text{Total mass – Mass retained i.e. } x - x_1, (x - x_1) - x_2, (x - x_1) - x_2) - x_3, \ldots\ldots\ldots\ldots . x_n \quad (3)$$

(a) (b)

Fig. 5 Grain Size Analysis Materials (a) Set of Sieve Stack in Mechanical Shaker & (b) Electronic Scale and Weighed Soil Sample

Fig. 6 Electronic Scale, Weighing Balance and Weighed Soil Sample

C. Statistical Test

With the results of radon-222 concentrations measured and that of laboratory test for grain size particles obtained at each measurement depths, mean values of radon-222 at 20, 40, 60 and 100 cm were calculated for the analysis. Computationally, using SPSS statistical package, a computational model was derived for this work. The model derived could be a yardstick for further study in prediction on soil-gas radon concentration at different soil depths with reference to soil grain size particles.

III. Result and Discussion

Shown in Table I are the concentrations of soil-gas radon-222 measured at each soil depths in the locations across the study area. The radon concentration ranged between 680 ± 392 Bqm^{-3} and 24680 ± 1960Bqm^{-3} at 20 cm and 100 cm soil-depths, respectively. At 100 cm depth, the highest concentration of 24680 ± 1960 Bqm^{-3} was found in location 1 and the lowest concentration of 7370 ± 1139Bq.m^{-3} was found in location 4. Also, the percentages of soil grain size particles determined at each soil-depth across the locations within the study area are shown (Table I). The percentages of soil grain size particles in ranged between 03.53% and 17.64% at 20 cm and 100 cm soil-depths respectively. At 100 cm depth, the highest percentage of 17.64% grain size was found in location 1 and the lowest percentage of 10.75% grain size was found in location 4.

With the variations of radon concentration and soil grain particle in the soil (Table I), the highest concentration of radon-222 gas was found in location 1 at 100 cm and, this is also the location found the highest percentage of soil grain size particle at 100 cm soil-depth. Furthermore, the lowest concentration of radon-222 was found in location 4 at 100 cm and, this is also the location found the lowest percentage of soil grain size particle at 100 cm soil-depth. Table II shows the mean concentrations of Radon-222 and soil grain size particles estimated at each measurement soil depths for the computational analysis.

TABLE I
Radon Concentration and Soil Grain Size Particle in Soil-Depths

Sample location & coordinates	Sampling depths (cm)	Radon concentration (Bqm^{-3})	% Grain size particle
Location 1	20	2920 (± 368)	06.66
8^0 10.227′ N	40	8760 (± 840)	09.20
4^0 16.02′ E	60	13800 (± 1090)	11.47
	100	24680 (± 1960)	17.64
Location 2	20	890 (± 433)	04.76
8^0 2.617′ N	40	2950 (± 730)	07.47
4^0 8.581′ E	60	3530 (± 807)	08.17
	100	18400 (± 1765)	14.15
Location 3	20	3520 (± 342)	07.32
8^0 8.407' N	40	7630 (± 730)	09.74
4^0 11.365' E	60	9100 (± 1232)	10.48
	100	22680 (± 1872)	16.96
Location 4	20	2360 (± 651)	07.04
8^0 8.455′ N	40	680 (± 392)	03.53
4^0 14.021′ E	60	4220 (± 894)	08.13
	100	7370 (± 1139)	10.75
Location 5	20	4110 (± 1950)	08.34
8^0 5.943' N	40	6520 (± 586)	09.42
4^0 15.226' E	60	4400 (± 1370)	08.59
	100	20700 (± 10900)	13.16

* Values in parentheses represent the standard deviation.

TABLE II
Mean Radon-222 Concentration and Grain Size Particles at Definite Soil-Depths

Sampling Depth (cm)	Radon Concentration (Bqm^{-3})	% Grain size Particle
20.00	2715.386	06.824
40.00	5920.763	07.872
60.00	7786.923	09.368
100.00	20581.539	14.532

Based on the mean radon-222 concentration and soil grain size particles estimated at each definite soil-depth above

(Table III), computational model was derived (3). This model could be used to estimate radon-222 concentration based on soil grain size particles at definite soil-depths within the study area.

$$\hat{R}_n = \widehat{\beta_1} g + \widehat{\beta_2} d + \alpha R^2 = 99.7\% \quad (4)$$

Note: $\hat{R}_n$is the estimated value of radon-222 concentration, $\widehat{\beta_1}, and \widehat{\beta_2}$ are both constant and model variables for grain size particle (g) derived at different soil-depths (d) of the measurement. To satisfactorily use (4), the following conditions must be considered:

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

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

The above conditions satisfied the depths of 20 cm and 100 cm because, the modeled variables ranges between 20 cm and 100 cm soil-depths. The model estimated values are presented in Table III.

TABLE III
MODEL ESTIMATED VALUES

α	$\widehat{\beta_1}$	$\widehat{\beta_2}$
-14200.513	2632.165	-35.384

IV. CONCLUSION

Radon-222 is a known radioactive gas, contributing the highest level of exposure of ionizing natural radiation to the public [8]. The results of *in-situ* measurement of soil-gas radon-222 concentration for this work showed that highest value of radon-222 concentration measured at 100 cm depth was 24680 ± 1960 Bqm^{-3} with utmost grain size particle of 17.64% found in location 1, while the lowest concentration of radon at 100 cm depth was 7370 ± 1139 Bqm^{-3} with least grain size particle of 10.75% found in location 4 respectively. Computationally using regression procedure of SPSS package, a model was derived (4). This model could be a yardstick for further study in prediction of soil-gas radon-222 concentration reference to soil grain size particle at different soil depths. Thus, the results of this work provide a basis to evaluate the relationship between radon-222 concentration and soil grain size particles at different soil depths. It also provides the results, data and a model that can be useful for further studies on radon-222 concentration in soil-gas, especially in the study area.

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