Subsurface radon gradient in parts of tremor-prone, north-central Nigeria

Arabi Suleiman (asabdullahi.geo@buk.edu.ng)
Bayero University Kano Department of Geology

Zainab Tukur
Bayero University

Idris I. Isa Funtua
Ahmadu Bello University

Ali A. M.
Bayero University

Ewa Kurowska
Poznan University of Life Sciences: Uniwersytet Przyrodniczy w Poznaniu

Musa Abdulhamid S.
Bayero University

Murtala A. S.
University of Jos

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Abstract

Radon is a natural gas that originates from geogenic and cosmic material as a part of the natural decay process of uranium and thorium. Radon is reported to have been the second leading cause of lung cancer in the United States. The US-EPA estimates that about 21,000 people die each year from radon-related (inhaled/ingested) lung cancer. Radon can escape from basement and soils where they are formed and build up indoors where they are eventually inhaled. In this study, radon activity concentration was measured from subsurface at a depth of 0.33m, 0.66m and 0.99m below ground level from 130 locations that covered the entire Federal Capital territory, Abuja-Nigeria and reported. The results obtained showed that the minimum, maximum and mean radon activity concentration (Bq/m^3) from soil at 0.33, 0.66 and 0.99m below ground level are 15.20, 48,500.00 and 4,257.47 at 0.33m, 15.20, 59,600.00 and 5,061.19 at 0.66m and 10.02, 81,200.00 and 9,993.15 at 0.99m, respectively. Minimum, maximum and mean radon diffusion length (m) recorded at 0.003m are 0.05, 159.63 and 14.01m. At 0.66 and 0.99m, the values calculated are 0.005,19.62 and 1.67, and 0.003, 26.73 and 0.32, respectively. These results indicate that radon concentration increases with depth and characterized by “high” radon concentration in areas covered by biotite granite, undifferentiated schist, undifferentiated gneiss and porphyroblastic gneiss, “medium” in areas covered by coarse porphyritic biotite and medium to coarse grained biotite and “low” in areas covered by migmatite and marble. Most of the values obtained suggest health burden especially in the study areas where massive excavations for construction of housing units is going on and the likelihood of radon entering homes through opening and cracks created as building/structure settles with time.

1.0 Introduction

Radon is a naturally occurring radioactive noble gas that is part of the uranium decay chain, and is the daughter of radium. As radium decays, radon is formed and is released into pore spaces or groundwater resident between soil and rock particles. When this happens within radon’s diffusion length of the soil surface, the radon may be released to ambient air (EPA 2003). Radon content is not a direct function of the radium concentration of the soil, but radium an important indicator of the potential for radon production in soils and bedrock. Radon that is present within solid grains are unlikely to become available for release to the atmosphere, owing to their very low diffusion coefficients in solids. However, if radon emanates into the interstitial space between grains, they may diffuse to the surface. Hence, the release of radon from subsurface geologic materials to the atmosphere take place when; radon atoms formed from the decay of radium escape from the grains (mainly because of recoil) into the interstitial space between the grains (emanation), when diffusion and advective flow cause the movement of the emanated radon atoms through the residue or soil profile to the ground surface (transport) and when radon atoms that have been transported to the ground surface and then exhaled to the atmosphere (exhalation) (Fig. 1). Radon migration models have been elaborated in Etiope and Martinelli, 2002; Kristianson and Malmqvist, 1982; Rogers and Nielson, 1991.

Radon account largely to the public exposure to natural ionizing radiation. Humans are constantly exposed to radiation originating from various sources, including air, soil, rocks, water etc (Zhong *et al.,* 2020). According to UNSCEAR, 2008, worldwide estimated average value for annual exposure to the various forms of natural radiation indicates that radon alone contribute as much as half the overall radiation dose reaching values of about 1.15 *mSv/y* per capita. Radon exposure is largely due to its accumulation within confined environments with less or no air ventilation, which leads to the inhalation of potentially hazardous amounts of airborne alpha-emitters in gaseous and particulate form with very well recognized epidemiological noxious effects (UNSCEAR 2006; WHO 2008). The total effect of many factors, such as lithology, geomorphology, geotectonics, types of building materials as well as living habits, lead to indoor radon accumulation and its inherent health burden (Pors- tendö rfer, 1994).

Indoor concentrations as high as 74,000 Bq/m^3 have been observed in certain locations in the United States (EPA 2008). Based on the National Residential Radon Survey, EPA estimates that the average indoor radon level is 46.25 Bq/m^3 in the United States (EPA 1993; 2011; Marcinowski *et al.,* 1994); however, several locations in the country have been documented where the average indoor air levels are several times greater than the national average (Field *et al.,* 2000; Steck *et al.,* 1999).

About eleven studies of radon-exposed underground miners, including detailed estimates of exposure per year, have already been published. In each of these studies, exposure to radon was associated with an increased risk of lung cancer. A detailed analysis of data from these studies revealed conclusively that exposure at high levels of radon is associated with increased risk of lung cancer (Lubin *et al.,* 1994).

Several studies on radon activity concentration in groundwater and indoor radon have been conducted in different parts of Nigeria (Oni *et al.,* 2014; Olise *et al.,* 2016; Ajiboye *et al.,* 2018; Oni *et al.,* 2019; Hauwau Kulu *et al.,* 2020; Arabi *et al.,* 2016; 2017) but not a single study from Abuja and environs despite being the federal capital of Nigeria, with a rapidly increasing population, massive construction and quarrying activities, influx of people into the capital territory on daily basis and frequent tremor that characterize this part of the country in recent times whose resultant effects might include the tainting of groundwater by radon gas, increased radon activity concentration in indoor and outdoor air from subsurface fractures resulting from earth movements. Apart from inhaling radon during excavations/construction, after construction, radon from subsurface can enter homes through construction joints, cracks in the solid floors, cavities inside walls, gaps around service pipes and suspended floors, cracks in the walls and through water supply (Fig. 2) (Nelson B., 2008).

The diffusion of radon in dwellings is a process determined by the radon concentration gradient across the building material structure between the radon source and the surrounding air, and can be a significant contributor to indoor radon inflow. Radon can originate from the deeply buried deposit beneath homes and can migrate to the surface of earth. Radon emanates to the surfaces mainly by diffusion processes from the point of origin following the decay of ^{226}Ra in subsurface soil and building materials used, in the construction of floors, walls, and basement (Narula *et al.,* 2009). The isolation of buildings against radon, especially in radon prone areas, shows an inclining interest in different parts of the world. Higher

radon concentrations indoors usually depend on the possibility, that radon can penetrate from the surrounding soil.

To complement to radon activity data of the federal capital territory (Abuja-Nigeria), this study measured radon concentrations at different subsurface depth (0.33, 0.66 and 0.99meters below ground surface) of the entire federal capital territory.

The area is geographically located at the center of Nigeria (Fig. 3) between latitude 7° 20' 00" and 9° 25' 00"N north of the equator and longitude 6° 40' 00" and 7° 40' 00"E east of the Greenwich meridian with a land mass of approximately 7,315 km^2 and estimated population of 3,464,000 (UN world population prospects, 2019). It is situated within the Savanah region with moderate climatic conditions.

Geologically, the area lies within the Precambrian basement complex. It is underlain by migmatitic gneiss complex, Schist, Pan African granitoids mostly on the east, northeast and southeastern part of the area, the younger granite on the on the north and central portion and the cretaceous sedimentary rocks of the lower Turonian on the western part (Fig. 3). The rocks are commonly acidic/felsic, enclosing modal and normative hypersthene, as well as normative corundum.

1.0 Materials And Methods

1.1 The study area

The study area covered the entire Federal Capital Territory (FCT). Abuja, Nigeria is geographically located between latitude 7° 20' 00" and 9° 25' 00"N of the equator and longitude 6° 40' 00" and 7° 40' 00"E. It is strategically at the center of Nigeria (Fig. 3). It has a land mass of approximately 7,315 km^2 and an estimated population of 3,464,000 with a growth rate of 5.67% as of 2021 (UN World population prospects 2019). It is situated within the Savanah region with moderate climatic conditions. The study area was hit six times by earth tremors between 2010 to 2020. Some stakeholders in earth and physical sciences were quick to attribute the tremors to activities such as quarrying of construction aggregate, constructions activities, mining, and over abstraction of groundwater in the north-central zone. To date, those claims have not been scientifically proven. Apart from destructions of lives and properties and panic, Earth movements have implications on groundwater dynamics, quantity and quality. It also has some radiological implications on health due to tremendous radon entry points that ensures when rocks are fractured and movement occur along those weak points. Radioactive gas (Radon) is released into the air, groundwater bodies and as a result, these media become highly vulnerable.

1.2 Radon measurement at different depths

1.2.1 The setup

The set up for soil radon measurement consist of a probe with pointed tip, an extension, both with rod inserts, a T-handle and a barbed hose adapter. There are two couplers, one for the T-handle and the other

between the extension and the probe. The two rod inserts also have a coupler to join them together. In addition, a water shut-off valve and vacuum gauge assembly, a plastic tubing, an adapter, and a roll of Teflon tape. The teflon tape is wrapped around the threads of the 14” probe and one end of the 36” long extension and the two are Join together (airtight) with the coupler. An adapter is attached to the end of the probe, and then attach the T-handle. Using the T-handle, the probe is forced into the ground to the required depth after which the T-handle is remove and the ground is tamped down around the probe to prevent fresh air from leaking down the outside of the probe. The setup is then connected to a dehumidifier then to the inlet of the radon measurement devise (RAD 7) as provided in figure 4.

1.2.2 Measurement

In this study, the GRAB protocol as provided in RAD 7 manual was adopted. Before the beginning of each measurement, the RAD7 was purged for five minutes with dry, fresh air, before connecting the probe to get rid of any residual radon gas in the detection chamber. The protocol is then set to “Grab” and the measurement commences after pressing the “start” button. The RAD7 pump then runs for five minutes after which the instrument waits another five minutes and then count for four five-minute cycles. At the end of the half-hour period, the RAD7 prints out a summary of the measurement, including an average radon concentration in the soil gas from the four 5-minute cycle measurements. Measurements from each location bean with a 0.33m depth probe after which the push down to 0.66m depth, then 0.99m depth. Between each depth, the RAD 7 is purged for five minutes before commencement of measurements.

1.3 Parameter calculations

1.3.1 Radon diffusion length

The in-situ radon diffusion lengths were determined by analysing the depth profile of radon concentration in the residue matrix. the schematic diagram of the measurement set-up is shown in fig. 4. Radon concentrations were measured at different depths from 0.33 to 0.99m, using the soil probe, according to diffusion theory, the radon concentration $C(z)$ at depth z follows the equation (Moed, B. A. et al., 1988; Shafik S. S. and Aamir A. M., 2013).

$$C(z)=C\infty(1-\exp(-z/Lr)) \quad \text{equation 1}$$

Where:

C_∞ is the radon concentration at great depth (Bq/m^3); z is the thickness of the material (m); and L_r is the radon diffusion length (m).

2.0 Results And Discussion

Radon profiling at different depth (0.33, 0.66 and 0.99m) within the subsurface was conducted at 130 locations that covered the entire Federal Capital Territory FCT), Abuja Nigeria. The results are presented

as supplementary data (Table 1) (Appendix I). Annual Equivalent Dose (WLM/y) and radon diffusion length (m) were also calculated and presented (Table 1).

2.1 Radon activity concentrations

Radon activity concentration in soil at a depth of 0.33m (33cm) ranged from 15.20 to 48,500.00 Bq/m^3 with an average value of 4,257.47 Bq/m^3. At a depth 0.66m (66cm) below ground surface, the values obtained ranged from 15.20 to 59,600.00 Bq/m^3 with a mean of 5,061.19 Bq/m^3 while at 0.99m (99cm) below ground surface, the values recorded ranged from 10.02 to 81,200.00 Bq/m^3 with a mean value of 9,993.15 Bq/m^3. About 88.5% of the values recorded were observed to have exceeded the 200 Bq/m^3 action level recommended by International Commission on Radiological Protection (ICRP). This suggest the fact that should this level of radon find its way into homes, most of the homes around the FCT would be requiring some mitigative actions to reduce radon exposure. This also is an indicator toward health burden associated with radon for construction workers that engage in manual excavation during housing and other construction activities. The study area is a rapidly developing federal capital with heavy activities going on in the construction housing units, roads, industries etc. High radon activity concentration coupled with the downward increase in radon within the subsurface may also be a pointer to the effect of seismic activities experienced in the study area in recent times. Earth tremors recently experienced in the area might have caused some openings (fractures) within the basement rocks which eventually serves as radon entry points into groundwater and the overburden. Naturally radon from the basement will travel upwards into the overburden and this might manifest in the form of radon increase with depth as depicted in the result obtained (Fig. 5). Figure 5 clearly indicate how radon activity concentration in the area increases with depth.

	RADON AT 0.33m (Bq/m3)	RADON AT 0.66m (Bq/m3)	RADON AT 0.99m (Bq/m3)	IN-SITU RADON DIFFUSION LENGTH AT 0.33 *(m)*	IN-SITU RADON DIFFUSION LENGTH AT 0.66 *(m)*	IN-SITU RADON DIFFUSION LENGTH AT 0.99 *(m)*
Min	15.20	15.20	10.02	0.005	0.005	0.003
Max	48,500.00	59,600.00	81,200.00	15.96	19.62	26.73
Ave	4,257.47	5,061.19	9,993.15	1.40	1.67	3.29

2.2 Radon diffusion length

Minimum, maximum and mean values calculated for radon diffusion length at the different depth (0.33, 0.66 and 0.99m) are 0.005, 0.005 and 0.003m as minimum, 15.96, 19.62 and 26.73m as maximum and 1.40, 1.67 and 3.29m as mean values, respectively. In general, the diffusion length is in the range of 0.3 to 2673cm.

The transport phenomenon of radon through diffusion is a significant contributor to indoor radon entry. The diffusion of radon in dwellings is a process determined by the radon concentration gradient across the building material structure between the radon source and the surrounding air. Radon diffusion and transport through different media is a complex process and is affected by several factors (Narula *et al.,* 2009). For any material medium the porosity, permeability and the diffusion coefficient are the

parameters, which can quantify their capability to hinder the flow of radon soil gas. An increase in porosity will provide more air space within the material for radon to travel, thus reducing resistance to radon transport. The permeability of material describes ability to act as a barrier to gas movement when a pressure gradient exists across it and is closely related to the porosity of material. The radon diffusion coefficient of a material quantifies the ability of radon gas to move through it when a concentration gradient is the driving force. This parameter is proportional to the porosity and permeability of the medium (Narula *et al.,* 2009).

A plot of radon activity concentration against in-situ radon diffusion length indicate a positive linearity between the parameters (Fig. 6).

Also, superimposed 3-dimention spatial maps of radon activity concentration at the different depth across the study area (Fig. 7) indicates that radon health burden increases with depth, despite the fact that fewer locations were measured at 0.99m because of the increase in compactness or hardness at depth which prevented measurement at some locations. This trend can be observed in the supplementary data provided were data at certain locations especially at 0.66 and 0.99m.

3.0 Conclusion

This study sets out to investigate radon activity concentration (Bq/m^3) at different depth that covered the federal capital territory (FCT) Abuja and environs. Radon activity concentration values at different depths was utilized to calculate radon diffusion length with the aim of ascertaining the levels and trend. This suggest that those working especially in the construction industries that entails excavation for foundation during construction of housing units, roads etc around the FCT might be exposed to high radon concentration during the course of work. This high radon activity concentration might also end up in homes after construction if proper radon mitigation measures are not put in place. Long term exposure to radon coupled with other lifestyles might result to inhabitants experiencing some health burden that are related to radon exposure in their life time.

The results also indicate that radon concentration increases with depth. Other factors observed indicates that areas characterized by “high” radon concentration are areas covered by biotite granite, undifferentiated schist, undifferentiated gneiss and porphyroblastic gneiss, “medium” in areas covered by coarse porphyritic biotite and medium to coarse grained biotite and “low” in areas covered by migmatite and marble.

It is hereby recommended that measures that would reduce radon entry into homes be put in place during construction of housing unit around the FCT and radon status of houses be determined after construction and mitigation measures be put in place in home where values exceeding the ICRP recommendation are discovered.

Declarations

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DECLARATION OF INTEREST

The authors wish to declare that there is no conflict of interest with regard to this wok

CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

Abdullahi Arabi Suleiman: is the principal investigator of the project, he drafted the original manuscript. **Idris Isa Funtua, Zainab Tukur, Ewa Kurowska and Mohammad A. Ali** are co-researchers on the project that reviewed and edited it, while **Musa Suleiman Abdulhamid** and **Adamu Murtala Suleiman** are postgraduate student that are working on the project as part of manpower development. Both have actively taken part in the acquisition of data from the field and other laboratory activities.

APPENDIX A

Supplementary data attached separately

Results of all data collected from the field and those calculated is hereby attached as supplementary document Table 1)

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Appendix

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Figures

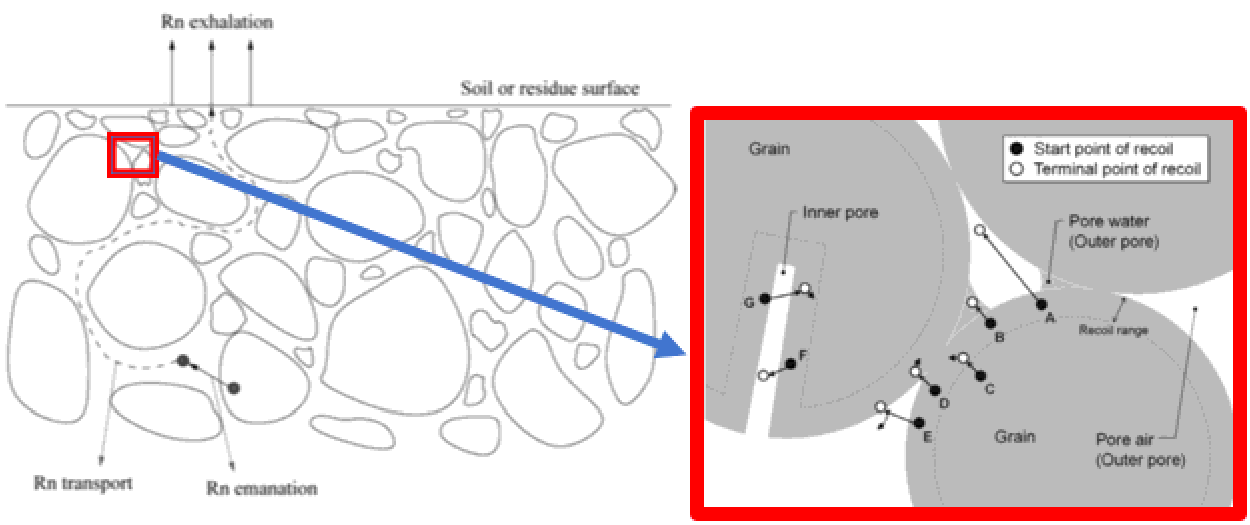

Figure 1

A sketch of how radon is recoiled, emanated, transported and exhaled from subsurface material to the surface of the earth (modified after Ishimori et al., 2013)

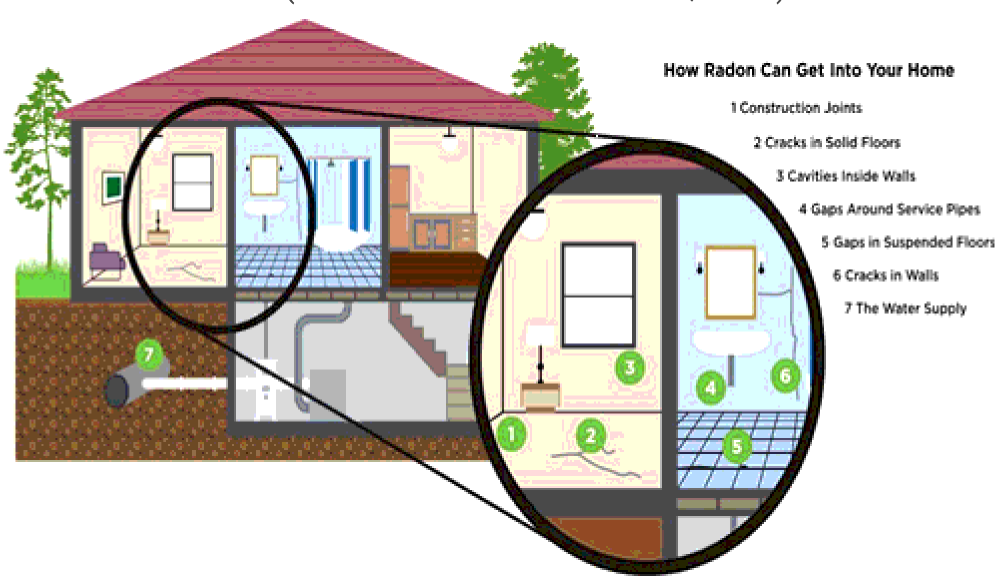

Figure 2

How radon gas gets into our homes (Nelson Bill, 2008, visited 22nd January, 2021)

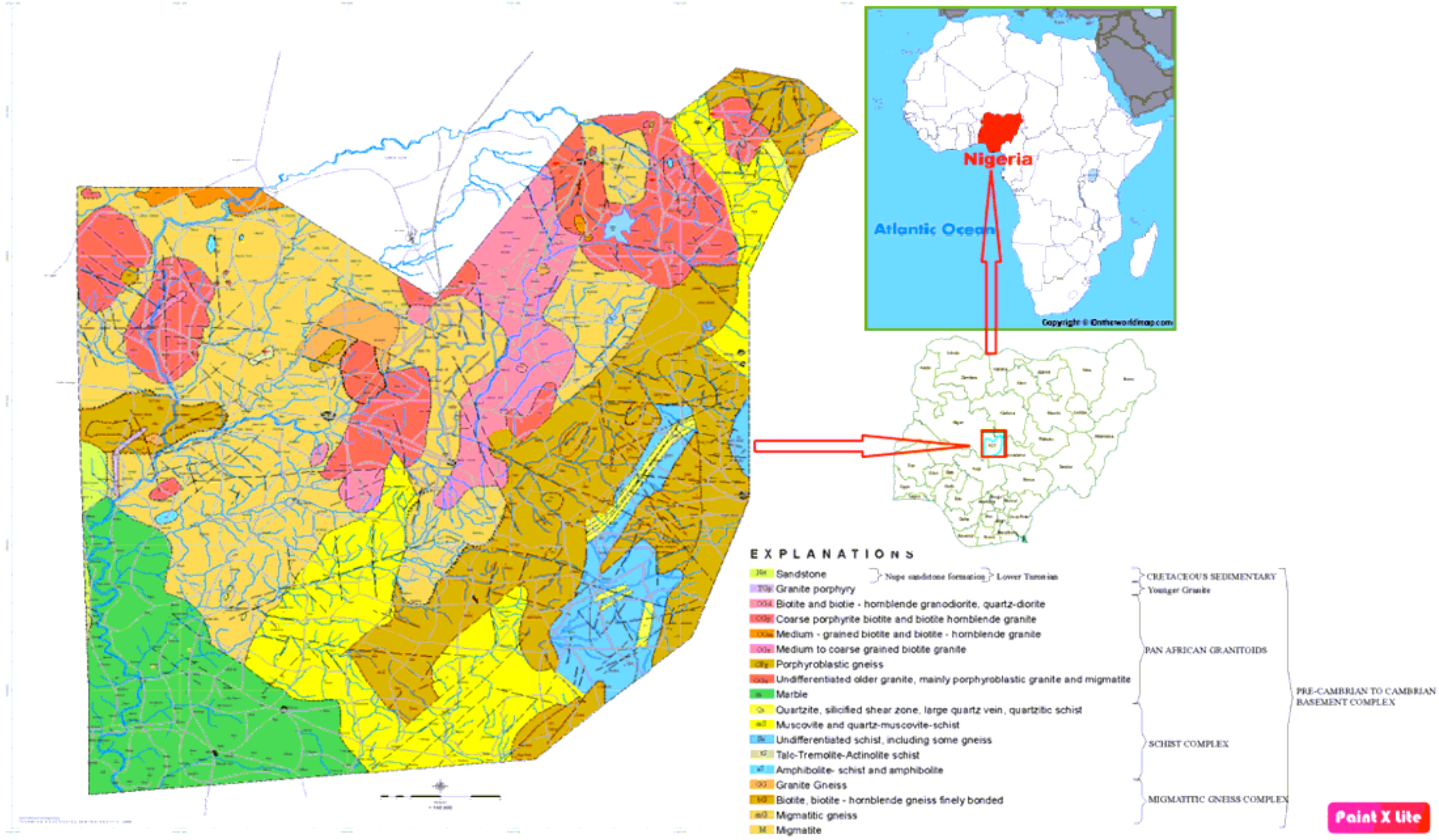

Figure 3

Geologic map of the Federal Capital Territory (GSNA, 2006)

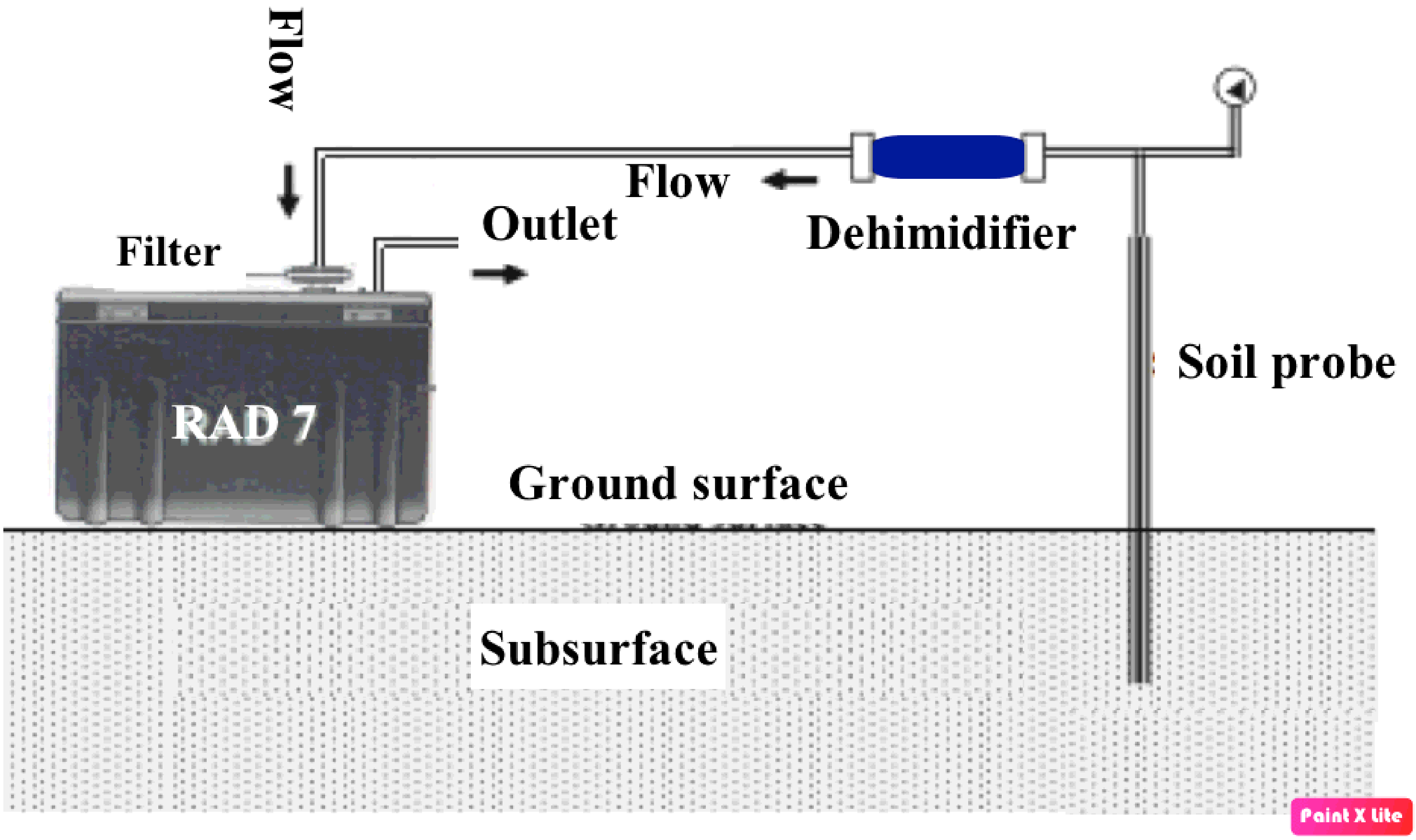

Figure 4

Setup for soil radon depth profiling

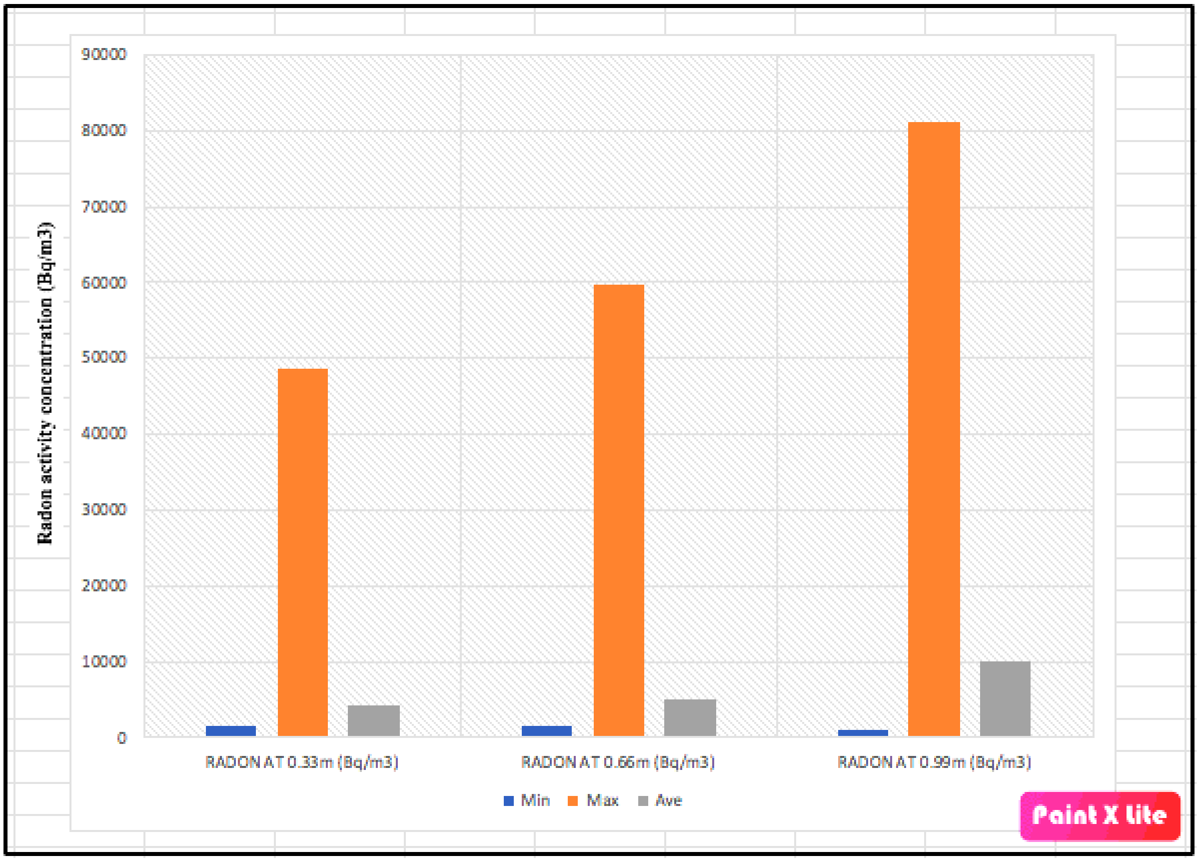

Figure 5

Minimum, maximum and Average radon activity concentration at different depths of the subsurface

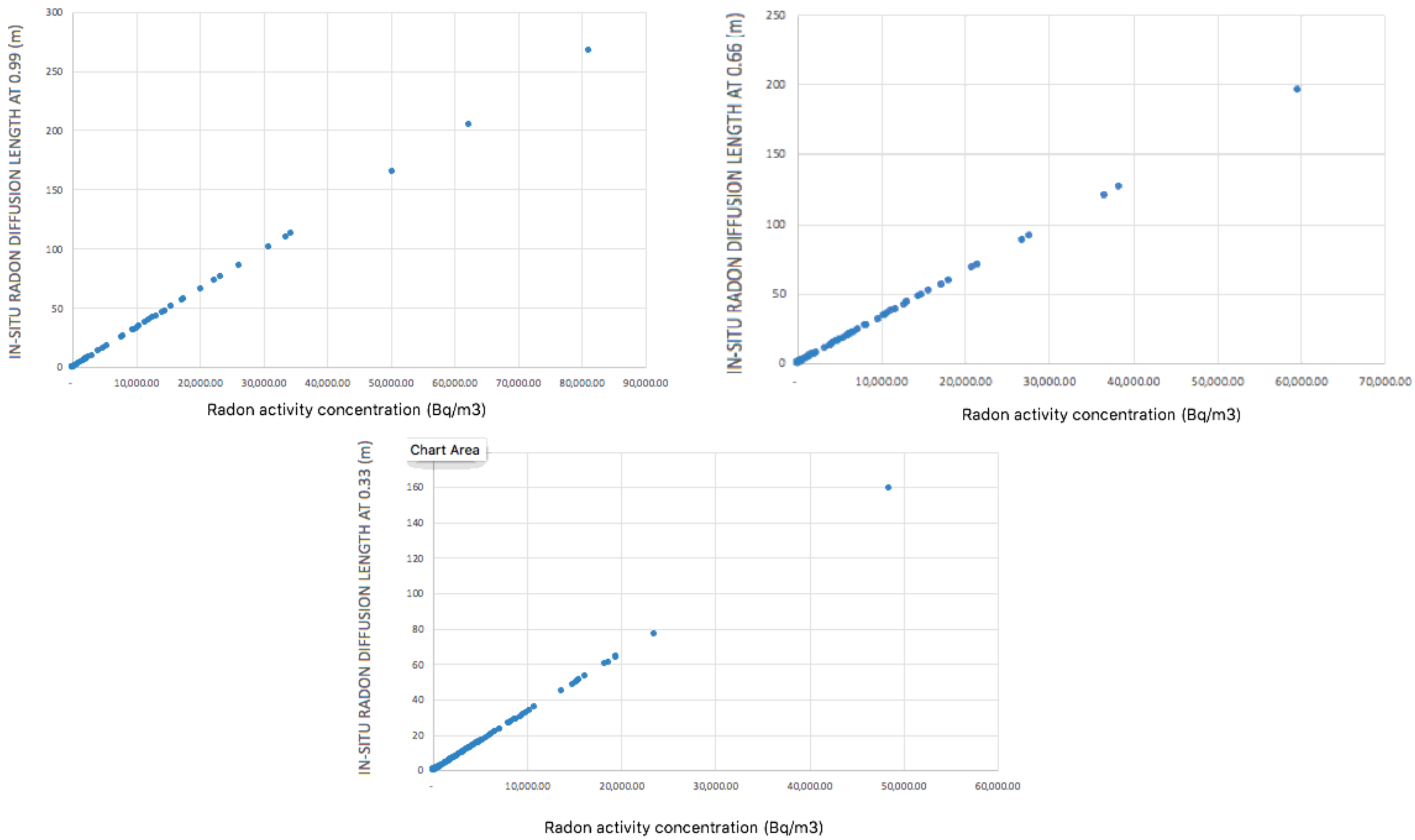

Figure 6

A plot of Radon activity concentration (Bq/m3) against radon diffusion length (x100) (bottom) at 0.33, 0.66 and 0.99m below ground level.

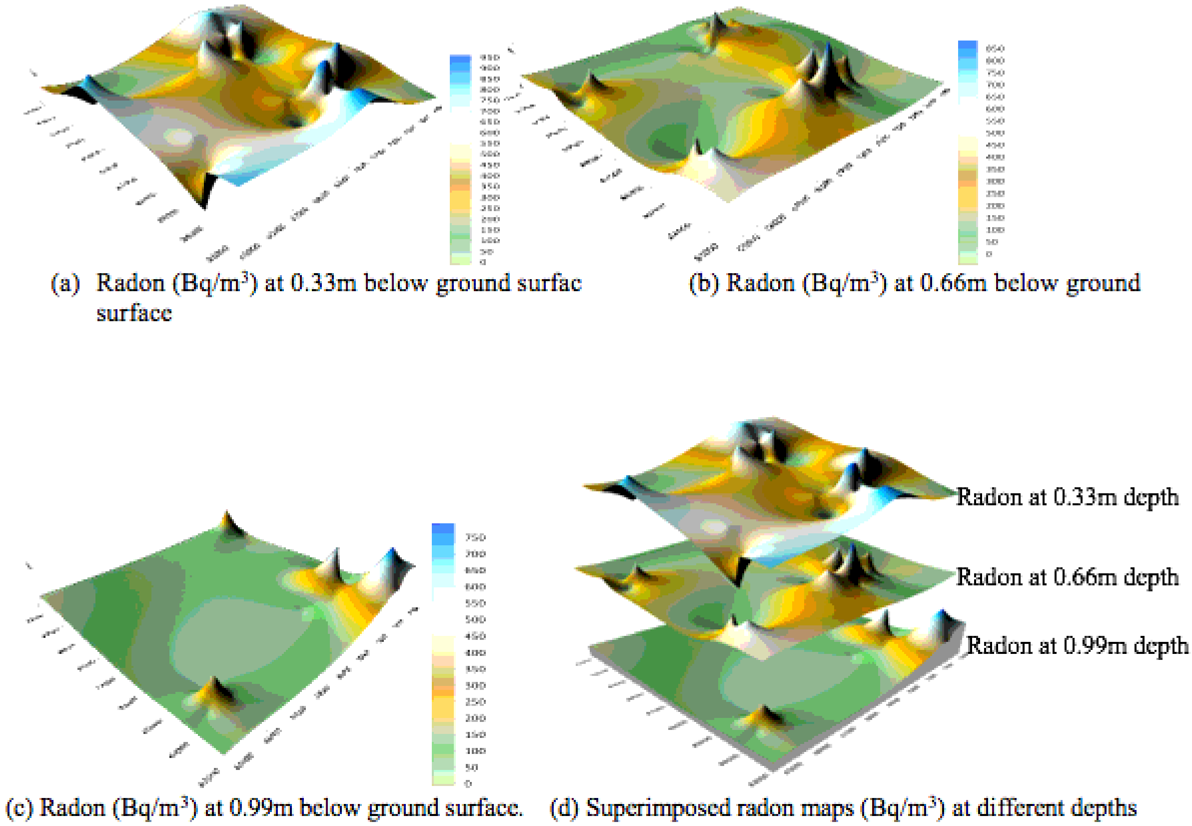

Figure 7

3-dimension spatial maps of radon activity concentration at different depths