Journal of the Nigerian Association of Mathematical Physics
Volume 62, (October – Dec., 2021 Issue), **pp63 – 70**

ASSESSMENT OF SOIL RADON POTENTIAL OF EKITI STATE, NIGERIA, USING A 10-POINT EVALUATION SYSTEM

Mansur Zangina[1], Idris Ahmad[2], Murtala Uba Muhammed[3] and Muhammed Ahmad[4]

[1,2]Department of Physics, BUK, Nigeria
[3,4]Department of Geography, BUK, Nigeria

Abstract

The colorless odorless radioactive gas radon, produce from uranium and thorium bearing minerals which are common in the upper layer of the Earth's crust, was discovered to be the second highest cause of lung cancer mortality in the world. High potentiality of radon poses this radiological hazard as witnessed by the increased cases of lung cancer among non-smokers in Nigeria. In this research, ten-point radon potential system was used in assessing and mapping the radon prone areas of Ekiti State, Nigeria. It was found that 41.90% of Ekiti state was occupied by low radon potential, 56.82% was occupied by medium radon potential and 1.27% was occupied by high radon potential. The locations of these high radon potential are lat(7.925N to 7.960N) to long(5.353E to 5.411E), lat(7.755N to 7.813N) to long(5.191E to 5.240E), and lat(7.471N to 7.602N) to long(5.284E to 5.329E) in Ekiti state. Comparison with other in literature work, 10-point radon potential analysis, confirmed that Ekiti State has three categories of radon potential (Low, Medium and High) with majority of the total land mass occupied by low and medium radon potential and very small area was occupied by high radon potential. The results of this research shows that less than 2% of Ekiti state has high radon potential, this is because the areas were occupied by granite and fault which are two major sources of radon concentration and radon potential. It can therefore deduced that the radon safety measure should be taken in the locations of high radon potential.

Keywords; Radon Potential, radon concentration, fault, ten-point system, ArcGIS,

1. INTRODUCTION

Cancer is estimated to be an increasingly important course of morbidity and mortally across the globe. The international agency for research on cancer (IARC) estimates that by 2030, over 24 million people will be diagnosed with cancer and 13 million will die from cancer every year. Radiation exposure from the radionuclides in the uranium and thorium decay series together with the non-series potassium-40 nuclide, contribute to this effect. However, exposure from these sources causes either stochastic health effects or non-stochastic health effects. Stochastic effects are effect associated with long-term, low-level exposure to radiation such as cancer and mutation while non-stochastic health effects are effect associated with Short term, high-level exposure such as burn, radiation sickness and death. Radon which decays through alpha emission can be produced from uranium and thorium bearing minerals, which are common in the upper layer of the Earth's crust was discovered to be the second highest cause of lung cancer mortality apart of cigarette smoking [1, 2].

This threat posed to health by radon is generating a growing attention by national and international authorities aimed at assessing the exposure of people to this radioactive gas and identifying those geographical areas where high radon potential are more likely to be found [3]. Two approaches have been developed by the researchers on their effort to minimize its effect

Corresponding Author**:** Mansur Z., Email: manzangina1@gmail.com, Tel: +2347025433802

and delineate the radon prone areas. Some adopted experimental approach; in which measurement of radon concentration in soil gas, underground drinking water, indoor and outdoor air were used in assessing and delineation of radon prone areas, for instance radon potential have been assessed and mapped into low, medium and high potential in southwest England, Switzerland, Korea, northwest Spain, southwestern part of Nigeria and so on, using this approach [4-9]. While others adopted theoretical approach; investigation shows that, there is strong statistical evidence that areal variation of radon levels depend on geological variation and other site-related parameters [3, 10-15]. Hence, many scientists consider these parameters and developed many model or system that can be used to assess and map the radon prone areas. For instance, radon potential have been assessed and mapped into low, medium, and high potential, using ten-point evaluation system in Germany and Hong-Kong, China [16,17] similarly, using geostatistical simulations with nested model in Italy [18].

Recent researches have shown a sharp increase in reported cases of lung cancer among non-smokers in Nigeria, which may be traceable to the ingestion and inhalation of ^{222}Rn in underground drinking water, indoor and outdoor air [9, 19]. However, the inadequate data for radon potential zones in Nigeria that can be used to resolve the spatial distribution of radon- prone areas, and difficulties arises due to lack of accessibility of using radon detectors, new method of producing radon potential map was needed. Ten-point radon potential system was used in assessing and mapping the radon prone areas of Ekiti State, Nigeria. The system was proposed by [20] while the validation of the system was done by [16] where they presented figures of soil radon potential and concentration mainly from Quaternary to Cretaceous materials in Germany which shows a strong correlations (R^2 = 0.94–0.99) between experiment and 10-point radon potential system, Similarly a correlations was also found between 10-point radon potential and the soil radon concentration in Hong-Kong China, particularly in the places of relatively homogenous geology with medium value of radon potential, on their effort of revalidating the system[17].

2. METHODOLOGY

2.1 A 10-Point Radon Potential System

The system involves the inspection of in situ geogenic and anthropogenic factors such as geology, relief, vegetation cover, tectonics, soil sealing and traffic vibrations (Table 1). Assessing each of the sampling site or geological unit with points of the five controlling parameters and summing up all the points in each sample site the resulting score ranges from 0-10 points whereby $P \leq 3$ represent low radon potential, $3 \leq P \leq 6$ represent medium radon potential and $6 \leq P \leq 10$ represent high radon potential respectively.

As long as only the soil radon in rural and natural areas is concerned, the effect of traffic vibration and soil sealing are not considered in this study. This is because the study area was characterized as rural area and the impact of vibrations on soil gas radon concentration was studied by [21] and found that the strongest vibrations and the most striking impact on the ^{222}Rn concentrations in soil gas were observed in the vicinity of construction sites. In particular, when metal panels were rammed into the ground, a doubling of ^{222}Rn concentrations close to the vibration source (10 m) were measured. Even at a distance of 60 m, the concentrations were increased by about 30%. Much weaker vibrations were generated by road traffic which resulted in a smaller effect on soil ^{222}Rn potential. Hence it should be neglected.

Similarly, sealing of soils result in a reduction of exhalation, but an increase in ^{222}Rn concentrations beneath the sealing, It is well known that the study areas has no effect of natural soil sealing by frost and snow cover and investigation conducted by [20, 22] shows that the effect of artificial sealing (e.g. roads, squares and buildings) is very high in urban areas and least in rural areas. Hence, it can also be neglected.

Table 1: Ten Point Radon Potential System [17]

SN	Parameters		Rating Points
1	**Origin of soil**	(1) undisturbed soil or backfill<2 m (go to 2.1)	2
		(2) backfill>2 (go to 2.2)	0
2	**Geology**	**2.1 Variety of rocks**	
		Sediment: black shale, phosphorite, bauxite	3
		Magmatic rock: (a) silicic rocks (e.g. granite, granodiorite, syenite, monzonite, Rhyolite, rhyolite lava, dacite, pumice, pegmatite), (b) Alkaline rocks (e.g. phonolite, nephelinite)	
		Volcanic rock: crystal tuff	
		Metamorphic rock: orthogneiss, greisen	
		Sediment: gravel, clay, pelite, carbonate rock, loess, mudstone, Metasiltsone, metaconglomerate, metasandstone, eutaxite	1
		Magmatic rock: intermediate rocks (e.g. diorite, andesite)	
		Volcanic rock: trachyte, tuff, tuffite	
		Metamorphic rock: clay schist, mica schist, paragneiss, granulite, marble	
		Sediment: sand, sandstone, conglomerate, evaporite, silstone, silicified sandstone	0
		Magmatic rock: (a) mafic rocks (e.g. gabbro, basalt, diabase) (b) ultramafic rocks (e.g. peridotite)	
		Metamorphic rock: quartzite, amphibolite, eclogite, serpentinite, metasediments	
		2.2 Type of back fill	
		High226 Ra conc.: slags, ashes, sewage sludge, tailings (ore mining)	3
		Low226 Ra conc.: sand, gravel, soil aggradation, rubble, tailings(coal mining)	0

3	**Relief**	Upper part of hill	1
		Lower part of hill	0
		Plain	0
4	**Vegetation**	Grass, field, meadow or no vegetation	1
		Forest, bush, scrub, mixed plantation	0
5	**Local Parameters**	Tectonic elements: fault, mining subsidence	1
		Soil sealing>50 % e.g. urban area	1
		Strong traffic vibration (trains or trucks)<10 m distance	1
		Maximum points	10

2.2 Origin of Soil Data analysis

The study area was characterized as rural, land used data of Nigeria and the clip layer were inputted into ArcMap software, and the data were thoroughly investigated, but no backfill was discovered in the study area, only one mining subsidence area was discovered. Hence, the study area was considered undisturbed.

2.2.2 Geology Data Analysis

The state boundary map of Nigeria and the geological map of the study area were inputted, and the geological map was georeferenced to match the exact geographic location. Two parameters were assessed using this georeferenced geological map; variety of rocks and fault.

Variety of Rocks

The shapefile for digitization was created where the geological map was digitized into polygons and new field was added where the variety of rocks was assessed based on the dominant category of rocks in each geological unit, and where there are two variety of rocks belonging to two different categories, the geological unit was assess with the point of variety of rock having high point. The point of undisturbed was added to the assessed field of the variety of rocks of geological map. The vector map was converted into raster with the assessed field. This implies that, the raster map obtained contain the point of undisturbed and the points of the variety of rocks cumulatively. Then, the raster map and polygon shapefile was unchecked leaving the georeferenced geological map.

Local Parameter (Fault)

New shapefile for digitization was created and then the fault lines in the geological map were digitized into polyline and then new field was added in the attribute table of the shapefile and the point of fault was assigned in the field. Then, the shapefile was converted into density map.

2.2.3 Shuttle Radar Topographic Mission (SRTM) Data Analysis

The SRTM of Nigeria was imported then relief map of the study area was extracted. The extracted relief map was reclassified into three (3) using Reclassify and then new field was added in the attribute table of reclassified relief map. The smallest range class was assign the point of a plain land, the medium range class was assign the point of a lower part of the hill and highest range class was assign the point of upper part of the hill.

2.2.4 Land Use Data Analysis

The clipped land used data of the study area was displayed and then, new field was added in the attribute table where the vegetation was assessed based on the dominant variety of vegetation in each geological unit. In addition, a point of mining subsidence (as one of the local parameters) was added in the field of assessed extracted land used data of Ekiti state. Finally, the vector map of the study area was converted into raster map.

2.2.5 Weighted Sum

Weighted sum was used in summing the four assessed raster maps with their assessed field into a single map that contain all the information of other maps. This single map was reclassified into low, medium and high radon potential using reclassify. The final map obtained is the radon potential map.

2.2.6 Interpolation

Ekiti soil gas data was inputted and interpolated using Inverse Distance Weighted interpolation procedure. The interpolated map was also reclassified as low for $[Rn] < 10\ KBqm^{-3}$, medium for $10 < [Rn] < 100KBm^{-3}$ and high for $[Rn] > 100KBm^{-3}$ [17].

3. RESULT AND DISCUSSION

After assessing the variety of rocks together with origin of soil, fault, relief and vegetation cover, the following results were obtained and shown in figure 1-4.

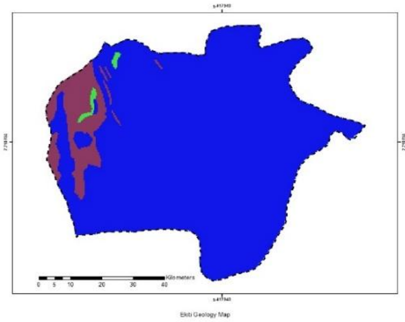

Figure 1: Assessed Map of Variety of Rocks Together with Origin of Soil

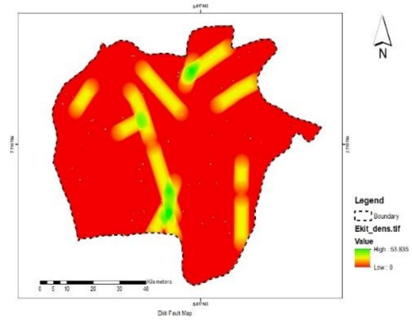

Figure 2: Assessed Fault Map

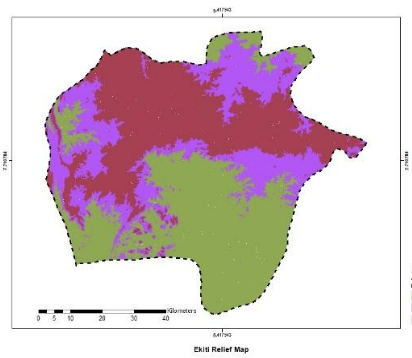

Figure 3: Assessed Relief Map of Ekiti

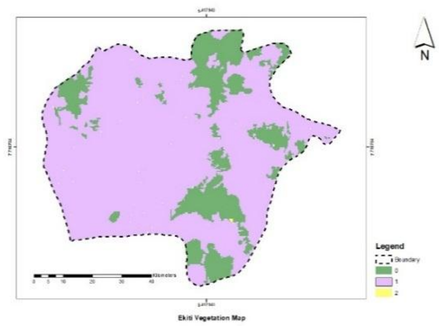

Figure 4: Assessed Vegetation Map of Ekiti

After summing the above raster data and classify the results into low, medium and high. The following final radon potential map was obtained

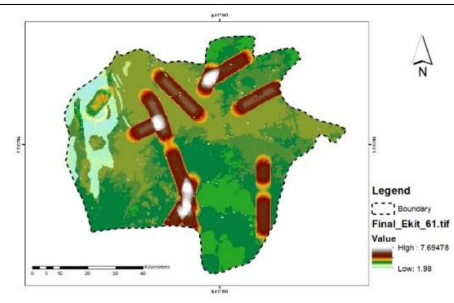

Figure 5: Unclassified Radon Potential Map Ekiti

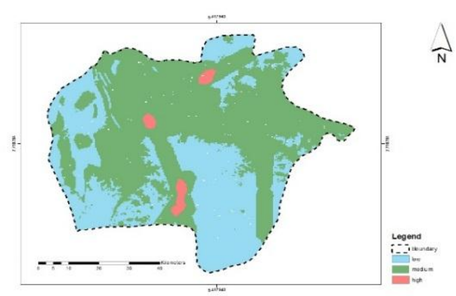

Figure 6: 10-Point Radon Potential Map of Ekiti

3.1.2 Soil Gas Radon Potential Map

After interpolated the soil gas data of Ekiti State found in the work of [9], and reclassified the result, The following classified soil gas radon potential map was obtained

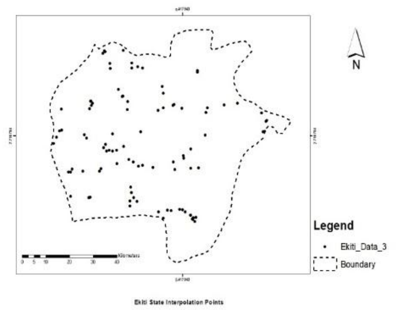

Figure 7: Interpolation Points of Ekiti

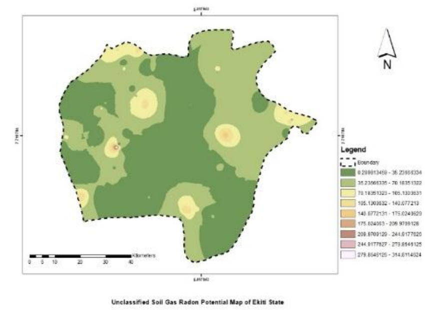

Figure 8: Unclassified Soil Gas Radon Potential Map

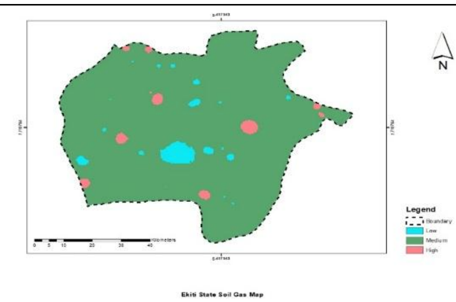

Figure 9: Ekiti Soil Gas Radon Potential map

Table 2: Radon Potential Areas for 10-Point system and Soil Gas of Ekiti State

Method	Low (km^2)	%	Medium (km^2)	%	High (km^2)	%
10-Point system	2662	41.9	3610	56.82	81	1.27
Soil Gas system	171	2.69	6051	95.25	131	2.06

3.1.3 Ekiti State Correlation Map

On correlating the locations of high radon potential of 10-point radon potential analysis with radon bearing soil gas analysis of Ekiti state by using extract multi value to point in the ArcToolbox of ArcMap (i.e. extracting raster values of 10-Point system using soil gas point data of Ekiti state) and by considering the coordinates of the location of high radon potential areas of the two analysis only lat(7.755N to 7.813N) to long(5.191E to 5.240E) show high radon potential in both two analysis, but still the two analysis shows that Ekiti State has three potential categories (Low, Medium and High) with majority of the total land mass occupied by low and medium radon potential, and very small area was occupied by high radon potential. The deviation in the location of high radon potential of the two analysis is due to the lack of soil gas data in some locations (Figure 10), experimental error or due to the fact that continues data varies over time.

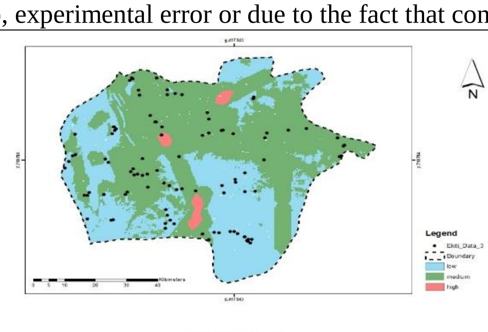

Figure 10: Ekiti State Correlation Map

3.2 Discussion

Table: 2 shows land mass occupied by low, medium and high radon potential with their percentage in both ten-point radon potential analysis and soil gas radon potential analysis of Ekiti States, while Figure 6: is the radon potential map, points to areas, where in unfavorable cases high radon potential are likely to occur, and on the other hand helps to identify regions of exclusion. It was found that 41.90% was occupied by low radon potential, 56.82% was occupied by medium radon potential and 1.27% was occupied by high radon potential in Ekiti state. The locations of these high radon potential are lat(7.925N to 7.960N) to long(5.353E to 5.411E), lat(7.755N to 7.813N) to long(5.191E to 5.240E), and lat(7.471N to 7.602N) to long(5.284E to 5.329E) of Ekiti state. Comparison with result of the data interpolated found in the work of [9], only lat(7.755N to 7.813N)to long(5.191E to 5.240E) shows high radon potential in both radon bearing soil gas analysis and 10-Point radon potential analysis, but still 10-Point radon potential analysis confirmed that Ekiti State has three categories of radon potential (Low, Medium and High) with majority of the total land mass occupied by low and medium radon potential and very small area was occupied by high radon potential.

Radon Risk Assessment

Although risk to tissues poses by radon can occur through ingestion of water with high radon concentration but it's much smaller than those associated with inhalation exposure to radon. International commission of radiological protection (ICRP) considered that simple counter measures would be virtually certain to be justified to avert an effective dose of 10mSv in a year (i.e. the upper bound of the maximum tolerable dose to individuals) and yearly average radon concentration of 200Bqm^{-3} —600Bqm^{-3}.

Similarly, ICRP recommended a radon concentration of 600Bqm^{-3} as that at which action is almost certain to be justified and it expected optimization to suggested action level not lower than 200Bqm^{-3}. While World Health Organization (WHO), established national annual average concentration reference level of 100Bqm^{-3} but said that "if this level cannot be reached under the prevailing country specific conditions, the level should not exceed 300Bqm^{-3}". Bearing in mind, radon content in soil gave more accurate indoor radon predictions than external gamma radiation or ^{226}Ra concentration in soil and the level of indoor radon concentration were far more greater than outdoor radon concentration [7, 15, 17, 20]. From the above statement made by ICRP and WHO, the indoor radon concentration classification that correspond to 10-point radon potential classification and soil gas radon concentration classification can be deduce as $[Rn] < 100Bqm^{-3}$ for low, $100Bqm^{-3} < [Rn] < 360Bqm^{-3}$ for medium and $[Rn] > 360Bqm^{-3}$ for high indoor radon potential.

To estimate the total annual effective dose for low, medium and high radon potential areas, considering the ratio of indoor to outdoor radon concentration of 4:1 used in [23]. it is necessary to use dose conversion coefficient 9nSv (Bq h m^{-3})$^{-1}$, indoor and outdoor equilibrium factor 0.4 and 0.6, indoor and outdoor occupancy factor 7000hy^{-1} and 1760hy^{-1} respectively, proposed by [23]. Therefore the effective dose is determine as follows

$$Indoor(mSvy^{-1}) = C_{\mathrm{Rn}}(Bqm^{-3}) \times 0.4 \times 7000hy^{-1} \times 9\mathrm{nSv}\ (\mathrm{Bq\ h\ m^{-3}})^{-1} \times 10^{-6} \quad (1)$$

$$Outdoor(mSvy^{-1}) = C_{\mathrm{Rn}}(Bqm^{-3}) \times 0.6 \times 1760hy^{-1} \times 9\mathrm{nSv}\ (\mathrm{Bq\ h\ m^{-3}})^{-1} \times 10^{-6} \quad (2)$$

Table 4: The calculated indoor, outdoor and total annual effective dose for low, medium and high radon potential areas.

Radon Level	Radon concentration (Bqm^{-3})		Annual Effective Dose (mSvy^{-1})		Total AED (mSvy^{-1})
	Indoor	**Outdoor**	**Indoor**	**Outdoor**	
Low	10	2.5	0.252	0.024	0.276
	50	12.5	1.260	0.119	1.379
	100	25.0	2.520	0.238	2.758
Average	**53.3**	**13.3**	**1.343**	**0.126**	**1.469**
Medium	110	27.5	2.772	0.261	3.033
	200	50.0	5.040	0.475	5.515
	360	90.0	9.072	0.855	9.927
Average	**223.3**	**55.8**	**5.627**	**0.530**	**6.157**
High	370	92.5	9.324	0.879	10.204
	400	100.0	10.080	0.950	11.030
	500	125.0	12.600	1.188	13.789
Average	**423.3**	**105.8**	**10.667**	**1.006**	**11.673**

This implies that the people living in low radon potential areas received total annual effective dose in the range of 0.276 mSvy^{-1} to 2.758 mSvy^{-1} with an average of 1.469 mSvy^{-1} which is far more below the upper bound of the maximum tolerable dose to individuals. The people living in medium radon potential areas received total annual effective dose in the range of 3.033 $mSvy^{-1}$ to 9.927 $mSvy^{-1}$ with an average of 6.157$mSvy^{-1}$ which is also below the upper bound of the maximum tolerable dose to individuals. Whereas the people living in high radon potential areas received total annual effective dose in the range of 10.204 $mSvy^{-1}$ to 13.789$mSvy^{-1}$ with an average of 11.673 $mSvy^{-1}$ which is above the upper bound of the maximum tolerable dose to individuals slated by ICRP, hence radon safety measures need to be taken in the locations of high radon potential.

4. Conclusion

Ten-point radon potential system was used in assessing and mapping the radon prone areas of Ekiti State, Nigeria. It was found that 41.90% was occupied by low radon potential, 56.82% was occupied by medium radon potential and 1.27% was occupied by high radon potential in Ekiti state. Comparison with other in literature work, 10-point radon potential analysis, confirmed that Ekiti State has three categories of radon potential (Low, Medium and High) with majority of the total land mass occupied by low and medium radon potential and very small area was occupied by high radon potential. The results of this research shows that less than 2% of Ekiti state has high radon potential, this is because the areas were characterized and occupied by granite and fault zones which are two major sources of radon concentration and radon potential. Hence radon safety measure should be taken in the locations of high radon potential.

References

[1] S. Darby, D. Hill, and R. Doll, "Radon: A likely carcinogen at all exposures," *Ann. Oncol.*, vol. 12, pp. 1341–1351, 2001.

[2] H. Zeeb and F. Shannoun, "Indoor Radon a Public Health Perspective," *Int. J. Environ. Stud.*, vol. 67, no. 1, p. 108, 2010.

[3] A. Sarra, L. Fontanella, P. Valentini, and S. Palermi, "Quantile regression and Bayesian cluster detection to identify radon prone areas," *J. Environ. Radioact.*, vol. 164, pp. 354–364, 2016.

[4] N. R. Varley and A. G. Flowers, "Indoor radon prediction from soil gas measurements," *Health Phys.*, vol. 74, no. 6, pp. 714–718, 1998.

[5] L. Rybach, D. Bächler, B. Bucher, and G. Schwarz, "Radiation doses of Swiss population from external sources," *J. Environ. Radioact.*, vol. 62, no. 3, pp. 277–286, 2002.

[6] H. K. Je, C. G. Kang, J. Y. Choi, J. S. Lee, and H. T. Chon, "Assessment of soil and soil-gas radon activity using active and passive detecting methods in Korea," *Environ. Geochem. Health*, vol. 29, no. 4, pp. 295–301, 2007.

[7] L. S. Quindós *et al.*, "Indoor radon in a Spanish region with different gamma exposure levels," *J. Environ. Radioact.*, vol. 99, no. 10, pp. 1544–1547, 2008.

[8] O. S. Ajayi and O. E. Olubi, "Investigation of indoor radon levels in some dwellings of southwestern Nigeria," *Environ. Forensics*, vol. 17, no. 4, pp. 275–281, 2016.

[9] Y. Ajiboye, M. O. Isinkaye, and M. U. Khanderkar, "Spatial distribution mapping and radiological hazard assessment of groundwater and soil gas radon in Ekiti State, Southwest Nigeria," *Environ. Earth Sci.*, vol. 77, no. 14, pp. 1–15, 2018.

[10] J. Kemski, R. Klingel, H. Schneiders, R. Siehl, and J. Wiegand, "Geological Structure and Geochemistry Controlling Radon in Soil Gas," *Radiat. Prot. Dosimetry*, vol. 45, no. 1/4, pp. 235–239, 1992.

[11] J. Kemski, R. Klingel, and A. Siehl, "Classification and mapping of radon-affected areas in Germany," *Environ. Int.*, vol. 22, no. SUPPL. 1, 1996.

[12] M. H. Al-Tamimi and K. M. Abumurad, "Radon anomalies along faults in North of Jordan," *Radiat. Meas.*, vol. 34, no. 1–6, pp. 397–400, 2001.

[13] A. A. Adepelumi, T. R. Ajayi, B. D. Ako, and A. O. Ojo, "Radon soil–gas as a geological mapping tool: case study from basement complex of Nigeria," *Environ. Geol.*, vol. 48, no. 6, pp. 762–770, 2005.

[14] J. Kemski, R. Klingel, A. Siehl, and M. Valdivia-Manchego, "From radon hazard to risk prediction-based on geological maps, soil gas and indoor measurements in Germany," *Environ. Geol.*, vol. 56, no. 7, pp. 1269–1279, 2009.

[15] R. J. Watson, M. A. Smethurst, G. V. Ganerød, I. Finne, and A. L. Rudjord, "The use of mapped geology as a predictor of radon potential in Norway," *J. Environ. Radioact.*, vol. 166, pp. 341–354, 2017.

[16] D. Bleile and J. Wiegand, "Checking the '10 point system' for an evaluation of the soil radon potential," *Radioact. Environ.*, vol. 7, no. C, pp. 833–841, 2005.

[17] S. Tung, J. K. C. Leung, J. J. Jiao, J. Wiegand, and W. Wartenberg, "Assessment of soil radon potential in Hong Kong, China, using a 10-point evaluation system," *Environ. Earth Sci.*, vol. 68, no. 3, pp. 679–689, 2013.

[18] C. Cafaro, C. Giovani, and M. Garavaglia, "Geostatistical simulations for radon indoor with a nested model including the housing factor," *J. Environ. Radioact.*, vol. 151, pp. 264–274, 2016.

[19] N. Ezemba, E. E. Ekpe, and J. C. Eze, "Challenges of lung cancer management in a developing country.," *Niger. J. Med.*, vol. 21, no. 2, pp. 214–217, 2012.
[20] J. Wiegand, "A guideline for the evaluation of the soil radon potential based on geogenic and anthropogenic parameters," *Environ. Geol.*, no. 40, pp. 949–963, 2001.
[21] S. Schmid and J. Wiegand, "The influence of traffic vibrations on the radon potential," *Health Phys.*, vol. 74, no. 2, pp. 231–236, 1998.
[22] J. Wiegand and B. Schott, "The sealing of soils and its effect on soil-gas migration," *Nuovo Cim. della Soc. Ital. di Fis. C*, vol. 22, no. 3–4, pp. 449–455, 1999.
[23] UNSCEAR, *2000-Sources and Effects of Ionizing Radiation: Volume I*, vol. I, pp. 107—108, 2000.