Anchor University Journal of Science and Technology (AUJST)
A publication of the Faculty of Science and Science Education, Anchor University Lagos
URL: journal.aul.edu.ng
Vol. 1 No 1, June 2020, Pp. 1 - 9

Residential indoor radon concentrations mapping using solid state nuclear track detectors in some parts of Lagos Nigeria

Abodunrin O. P.*[1], Akinloye M.K.[2], Ode G.O.[3]

[1]Department of Physical Sciences, Bells University of Technology, Ota, PMB 1015

[2]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria. PMB 4000

[3]Department of Surveying and Geoinformatics, Bells University of Technology, Ota. Nigeria

***Corresponding author:**

Abodunrin O. P.,

Phone: +2348038163335,

E-mail: sayopeter@yahoo.co.uk

Submitted 9 March, 2020

Accepted 22 April, 2020

Competing Interests: The authors declare no competing financial interests.

ABSTRACT

Background: There is need for efforts geared towards the continuous indoor radon monitoring programme that will engender setting-up of the national radon reference level.
Objectives: This study was carried out to determine concentrations of radon in the indoor environments of residential buildings.
Methods: Multi-stage sampling protocol was employed in selecting buildings for measurement. Solid state nuclear track detectors (CR-39) mounted in buildings were used for the measurements.
Results: The mean indoor radon concentrations obtained was 7.13 ± 0.09 Bq m-3. It is lower than that obtained from a similar study in Nigeria and those reported from other countries, except India. It is as well lower than the national action level for existing and new buildings in many countries, and the recommended limit of 200 Bq m-3 for mitigation.
Conclusions: This study has made available the baseline data which suggest that the environments assessed are safe from radon problems. The results obtained were used to generate radon map for the study area.

Keywords: Radon indoor concentrations; solid state nuclear track detectors (CR-39); radon map

INTRODUCTION

Sources of radon are present everywhere. These include soil, building materials, rock, groundwater and natural gas. Lack of information on exposure due to radon gas in many indoor environments in Nigeria is a cause for concern, as radon may be the cause of hazard to the health of the residents. In many parts of the world, radon concentrations in residential buildings, schools and workplaces are constantly monitored (USEPA, 1993; EC, 1995; Field *et al.*, 2002; Darby *et al.*, 2004; Synnott and Fenton, 2005a & 2005b; UNSCEAR, 2006; WHO, 2007 & 2009; IAEA, 2012; Matiullah, 2013; Collignan and Powaga, 2017; Gaskin *et al.*, 2018). The strength of any national policy is strongly dependent on the availability of data, and especially its diversity, drawn from local studies and in comparison with foreign and widely accepted references. In Nigeria, available data on environmental radon monitoring (Obed *et al.*, 2010; 2011; Oni *et al.*, 2012; Ojo *et al.*, 2013; Afolabi *et al.*, 2015; Ademola *et al.*, 2015; Abodunrin and Akinloye, 2020), especially from residential buildings (Obed *et al.*, 2012) is not sufficient to establish the reference level. A reference level (RL) defines the accepted average annual radon concentration in a residential building (WHO, 2009). It represents an important component of a national radon programme and cannot be established without obtaining a dataset for radon concentrations in many parts of the country. The initial step in the process of obtaining a representative distribution of the radon concentration within the country starts with an assessment of residential buildings from one part to another. The data obtained in this study will provide, in addition to the existing literature, essential information needed to make informed policy and reorientation of the entire population in Nigeria on radon and associated radiological risk in the immediate environment.

There have been extensive controversies over legislation and regulations to establish standard RL in many countries (HPA, 2009). A useful overview of legislation and national guidelines has been reported by Åkerblom (1999). Ireland, USA and Luxemburg use 200 Bq m^{-3}, 148 Bq m^{-3} and 150 Bq m^{-3} respectively, as RL for residential buildings. Many European countries employ the value, 200 Bq m^{-3} for new buildings and 400 Bq m^{-3} for existing buildings (UNSCEAR, 2000). Also, international organizations have different RL: EPA (148 Bq m^{-3}), WHO (100 Bq m^{-3}), EEC (400 Bq m^{-3}) and ICRP (200 – 600 Bq m^{-3}). Report by Synnott and Fenton (2005b) indicated that the majority of countries from a list of 20 have RL (200 and 400 Bq m^{-3}) for residential buildings. A wider report (WHO, 2007) involving 35 countries shows that more countries have RL for residential buildings, though with varying level of legislation. Morocco, the only African country on the list was reported to have embraced the IAEA-BSS limits (WHO, 2007).

Investigations into radon concentrations are now gradually on the rise in Africa, subject primarily to the increasing concern on the rising trends in death caused by cancer in smokers and more importantly, non-smokers (Seltenrich, 2019). However, it must be noted here that no African country has set RL using data drawn from experimental or simulated approach for radon in residential buildings. Setting an effective RL enhances the classification of buildings with regards to radon concentrations level. This study aimed at determining concentrations of radon in the indoor environments of some residential buildings in Lagos, and has contributed to the framework for continuous indoor radon monitoring that will engender setting of an effective national reference level and the establishment of a national radon programme in Nigeria.

MATERIALS AND METHODS

Description of Study Area

The study area for this work is within Lagos State, Nigeria. Lagos State was chosen because of the commercial activities as well as its economic importance to Nigeria. The State is highly industrialized with various kinds of diagnostic centres, hospitals and industries including metallurgy, automobile, gas, chemicals, petrochemicals, machine tools, mining tools, aeronautics, furniture, large dumpsite and waste sites. Lagos State is densely populated with approximately 12 million people (NBS, 2018). The State is located in the South-Western part of Nigeria, on the narrow plain of the Bight of Benin; lying approximately within longitudes 2° 30' and 4° 30'E, and latitudes 6° 00' and 6° 30'N. It is bounded in the North and East by Ogun State, and in the West by the Republic of Benin and stretches over 180 kilometres along the Guinea Coast of the Bight of Benin. Below its Southern borders lies the Atlantic Ocean, a transnational transport route.

Delineation of Study Area and Sampling Protocol

To minimize the resources available for the study, a multi-stage sampling protocol was employed in selecting the sampling locations. Hence, in the first stage, the study area was stratified into three according to the administrative boundaries (Padraic, 2008). In the second stage, one local government area (LGA) was selected at random from each stratum; these being Badagry, Epe and Ikorodu. Digitized data from google earth 2018 used to obtain the number of buildings in these LGAs recoreded 117,216, 16,171 and 56,523 respectively for Badagry, Epe and Ikorodu. At the base of the protocol, Community Development Areas (CDAs) whose number of buildings are usually 200 – 400, were selected randomly. The sampling was done at an approximate rate of one in every seven buildings. The map of Lagos showing the selected sampling sites is shown in Figure 1.

Purposive technique was also applied in selecting the buildings for measurement to ensure buildings with similar constructional, structural and architechtural characteristics were selected. The buildings were bungalow type, single family units constructed with cement and sand (mortar). This type of building are very common in these environments. The reason for this was that these environments are less industrialized but greatly residential compared to many other parts of Lagos State.

Reconnaissance Survey and Scoping Exercise

Reconnaissance survey and scoping exercise involved field familiarization, orientation of the general public and distribution of informative materials on radon and associated health risks. In each sampling site, at least five terrain masters

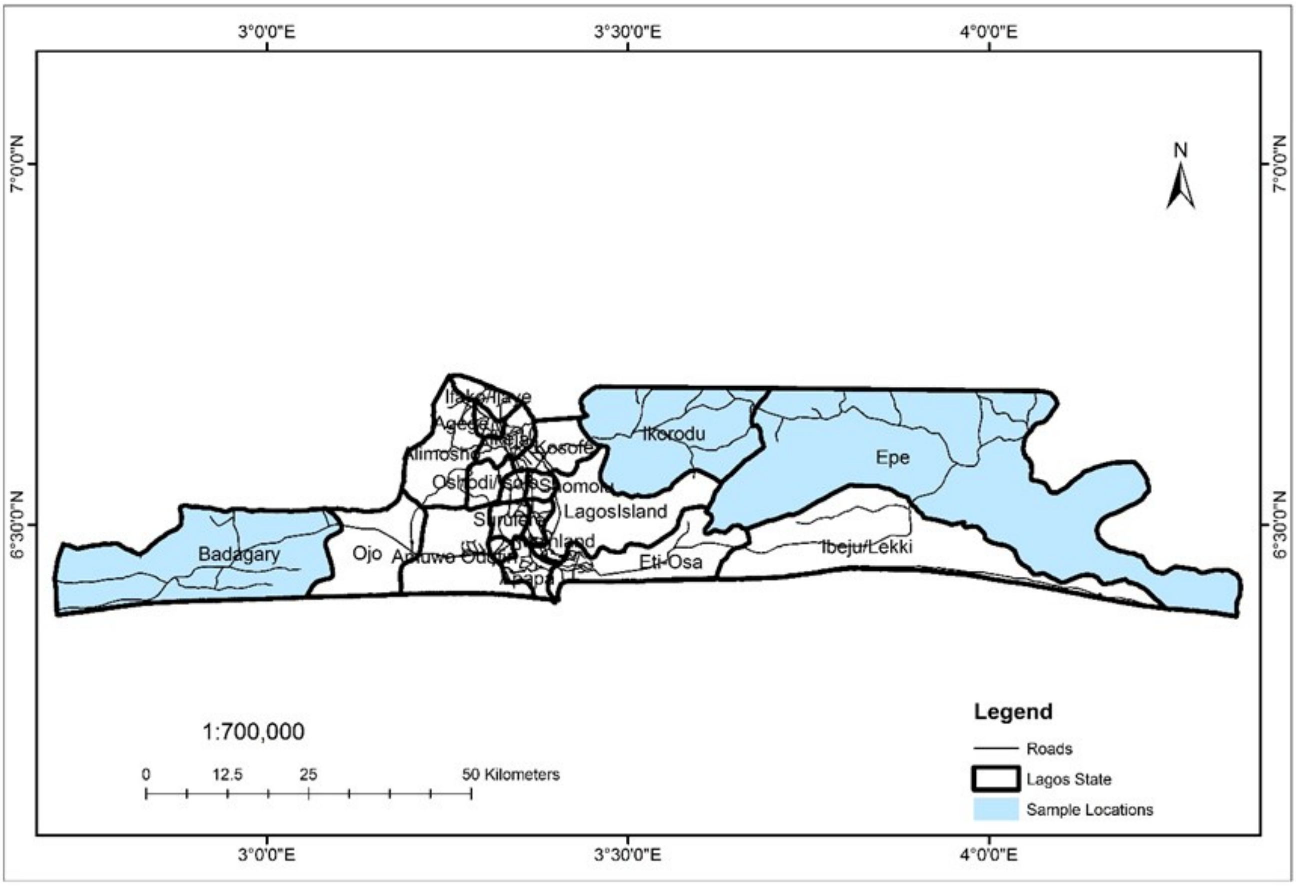

Figure. 1 Map of Lagos State showing the Study Sites

were coopted to facilitate easy access to members of the community. The orientation was undertaken from street to street and through religious centres and CDA meetings, and a total number of 135 volunteers were raised at 45 per sampling area. The volunteers raised were properly informed on the handling of the detector during the measurement period.

Indoor Radon Measurement

A total number of one hundred and twenty-nine (129) buildings were selected for measurement with the sampling protocol stated above. The remaining six (6) buildings were rejected due to inappropraite response from the volunteers. The CR-39 solid state nuclear track detectors with 1 x 1 cm were used. They were mounted with RSK diffusion chamber within each building at the height of approximately 2 m above the floor representing the typical breathing zone, 25 cm from other objects to allow normal airflow around the detector, 40 cm from the wall and 50 cm from the window, and in an area with least possible disturbance by inhabitants (EPA, 1992; Zunic *et al.*, 2006; Health Canada, 2008; Baluci *et al.*, 2013; Ademola *et al.*, 2015). Locations near excessive heat, such as fireplaces or in direct sunlight, and areas of high humidity were avoided as specified by the supplier. The detectors were exposed for six months to determine the long term average. The period following the deployments of detectors was used for the follow-up of volunteers and continued orientation; through mass text messages, phone calls and frequent visitations to ensure that the detectors were maintained in position and reassure the volunteers of the essence of the research. Hence, only three (3) detectors were not retrievable. The detectors were withdrawn in phases depending on the date of deployment, kept separately in aluminum foil to ensure accuracy of the result. Finally, the results obtained were discussed with the occupants on individual bases to clarify each volunteer's inquisitions.

Etching and Counting of Tracks

The detectors were etched with 6.25 M of NaOH solution in a water bath at 70 ^{o}C for 3 hours, which has been reported to yield satisfactory results (Abodunrin and Akinloye, 2020). The detectors were subsequently washed with running water for 10 minutes and soaked in distilled water for 15 minutes, to remove the etchant residue from the pits and thereafter dried in the laboratory at room temperature. The tracks on the detectors were counted using an image analysis system consisting of Charge Coupled Devices (CCD) camera connected to a PC and an optical microscope of 40x objective lens.

Determination of Radon Concentrations

Radon concentration, C_{Rn}, in Bq m^{-3} was computed using Eq. 1 (Matiullah, 2013), where CF represents the calibration factor, T is the exposure time and T_D is the track density. The calibration factor supplied by the manufacturer for RSK-type diffusion chamber was employed since the study commenced within the manufacturer's stipulated period of 9 months.

$$C_{Rn} = \frac{T_D(track\ mm^{-2}) \times CF\left(\frac{Bq\ h\ m^{-3}}{track.mm^{-2}}\right)}{T(h)} \quad 1$$

The track density, T_D, is the ratio of the average number of tracks to the area (A) of the field of view (FOV) which was determined using Eq. 2 (Ahmad *et al.*, 2014):

$$T_D = \frac{\sum_i N_i}{nA} \quad 2$$

where N_i is the total number of tracks per detector and n is the total number of FOVs.

RESULTS AND DISCUSSION

Radon concentrations obtained in the buildings range from 3.63 – 9.90 Bq m^{-3}; 5.08 – 12.80 Bq m^{-3} and 4.09 – 11.08 Bq m^{-3} with mean of 6.25 ± 0.08 Bq m^{-3}, 7.67 ± 0.09 Bq m^{-3} and 7.43 ± 0.09 Bq m^{-3} respectively for Badagry, Epe and Ikorodu (Table 1). The results indicate that Epe and Badagry recorded the highest and lowest indoor radon concentrations respectively. Epe having the highest mean also recorded the lowest deviation (Table 1). Arithmetic mean and standard deviation of 7.13 ± 0.09 Bq m^{-3} was obtained for the study area. This mean is distinctively lower than the results obtained from similar work in Nigeria; 257 Bq m^{-3} for Oke-Ogun area in Oyo State (Obed et al., 2012). The mean from this work is also lower than the average value reported from other countries (Table 2). The result is however higher than the mean of 6.3 Bq m^{-3} obtained from Bangalore, India (Ravikumar and Somomashekar, 2015).

The results obtained from this study are lower than the recommended limit (200 Bq m^{-3}) for mitigation in existing residential buildings (Health Canada, 2008) and the reference level (30 Bq m^{-3} in the Netherlands, 50 Bq m^{-3} in Norway and 100 Bq m^{-3} in Switzerland respectively) for new buildings (WHO, 2009). It is also much lower than the recommended upper limit of 300 Bq m^{-3} (ICRP, 2010), and national RL for the 35 countries listed in WHO (2007).

Table 1. Indoor Radon Concentrations (Bq m^{-3}) for the Study Area

Location	Sampling size	RADON CONCENTRATIONS			
		Min	Max	Mean	SD
Badagry	38	3.63	9.90	6.25	1.35
Epe	45	5.08	12.80	7.67	0.75
Ikorodu	43	4.09	11.08	7.43	1.03
Not retrievable	3				
Total	129				

Most of the radon-induced lung cancer deaths occur at exposures to radon concentrations well below 200 Bq m^{-3} and most of them in areas other than those designated as Radon Affected Areas (HPA, 2009). Observably, cancer incidence in Nigeria is a double pandemic, affecting both the low and high class of the social web. This is a material public health issue. This study recommend continuous indoor radon monitoring programmes in Nigeria, the result of which can be applicable to set up the national reference level.

In a situation in which radon concentrations are as low as the results obtained in this study, the main source has been attributed to radon from air or emissions from building materials (HPA, 2009). If the underlying rock is covered with clay, then radon is unlikely to be able to escape to the surface as it could if the covering was of a more porous material (HPA, 2009). The geology of the Lagos area has been reported to be dominated by continuous and monotonous repetition of clayey and sandy horizons (Olatunji, 2010). Also, the results obtained are higher than the natural concentrations of radon in ambient outdoor air, a value of 10 Bq m^{-3} (WHO, 2010) in 9 locations representing 7.14% of the total sampling locations; while the results from 117 locations representing 92.86% of the total sampling locations were lower than this value. Hence, this study suggests that building materials used for construction rather than the soil in the study area may be the main contributor to the indoor radon concentrations. It further suggests the use of radon protective measures to ensure that radon concentrations in homes are kept consistently low. The normal distribution curve of radon concentrations obtained from all the buildings is shown in Figure 2.

Table 2 Mean Indoor Radon Concentration (Bq m^{-3}) from different parts of the World

Country	Arithmetic mean	Reference
Argentina	40.5	WHO (2009)
Australia	11.0	IAEA (2012)
Iceland	10.0	IAEA (2012)
India, Bangalore	6.3	ICRP (2010)
Japan	16.0	IAEA (2012)
Jordan	48.0	Abumurad (1994)
New Zealand	22.0	IAEA (2012)
Nigeria, Lagos	7.1	Current study
Republic of Korea	53.0	IAEA (2012)
Sweden	108.0	Swedjemark (1993)
United Kingdom	20.0	IAEA (2012)
USA	46.0	IAEA (2012)
Worldwide average	39.0	Seltenrich (2019)

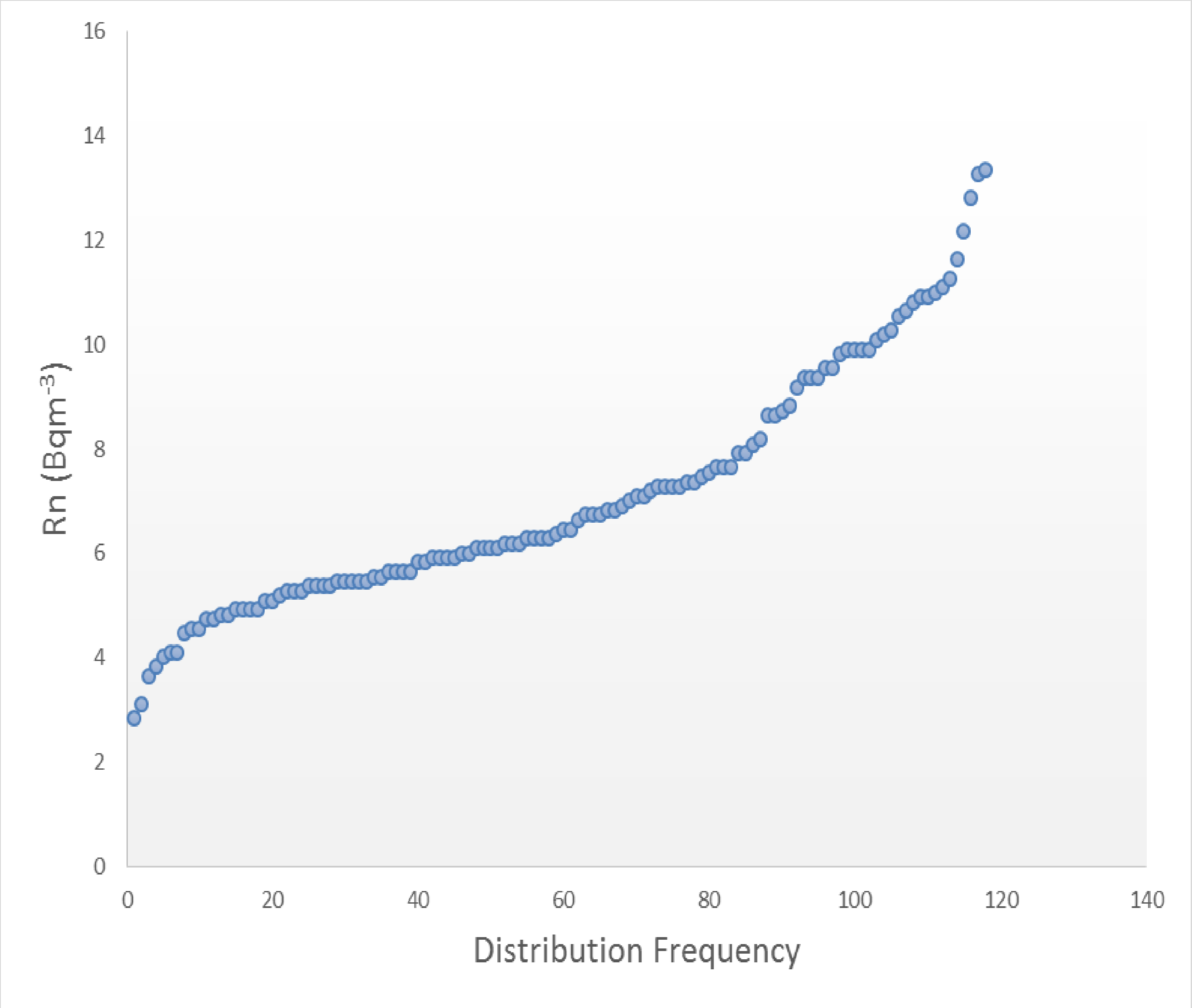

Figure. 2 Normal Distribution Curve of Radon Concentrations in the Study Area

Radon Maps

Radon map was generated by importing the image of an existing map of the study area to ArcGIS. The map was geo-referenced and digitized to convert the analogue data into digital format. The coordinates obtained with the use of GPS at the various locations were charted on the base map. The measured indoor radon concentrations from the corresponding locations were then overlaid on the map of the study area. The radon maps (Figure 3, 4 and 5) showed the spatial distribution of radon in the indoor environment and were generated for specific environments where measurements were carried out to enhance the magnification. The use of these radon maps will facilitate easy identification of the locations that have been measured. This will also aid data comparison with future studies for easy detection of any rise in radon concentrations within the study area. Any resident of the study area can explore the map to know the present indoor radon concentrations of his/her building, using the northing and easting value. The use of these radon maps will help the implementation of a national radon policy in Nigeria.

CONCLUSION

The concentrations of radon in some indoor environments of Lagos State have been measured as an integral part of the effort needed to set the pace for dedicated continuous radon monitoring leading to setting up of a national action level. Passive measurement method which incorporate CR-39 solid state nuclear track detectors was employed to determine the long term average. A multi-stage sampling protocol was developed for the study area. The volunteers were raised through an awareness campaign in the selected areas. Radon concentration measurement was carried out within each building for six months. The results obtained followed the lognormal distribution observed in similar studies. Also, the results obtained are lower than the known natural concentrations of radon in ambient outdoor air in 93.0% of the total sampling locations. This finding suggests that building

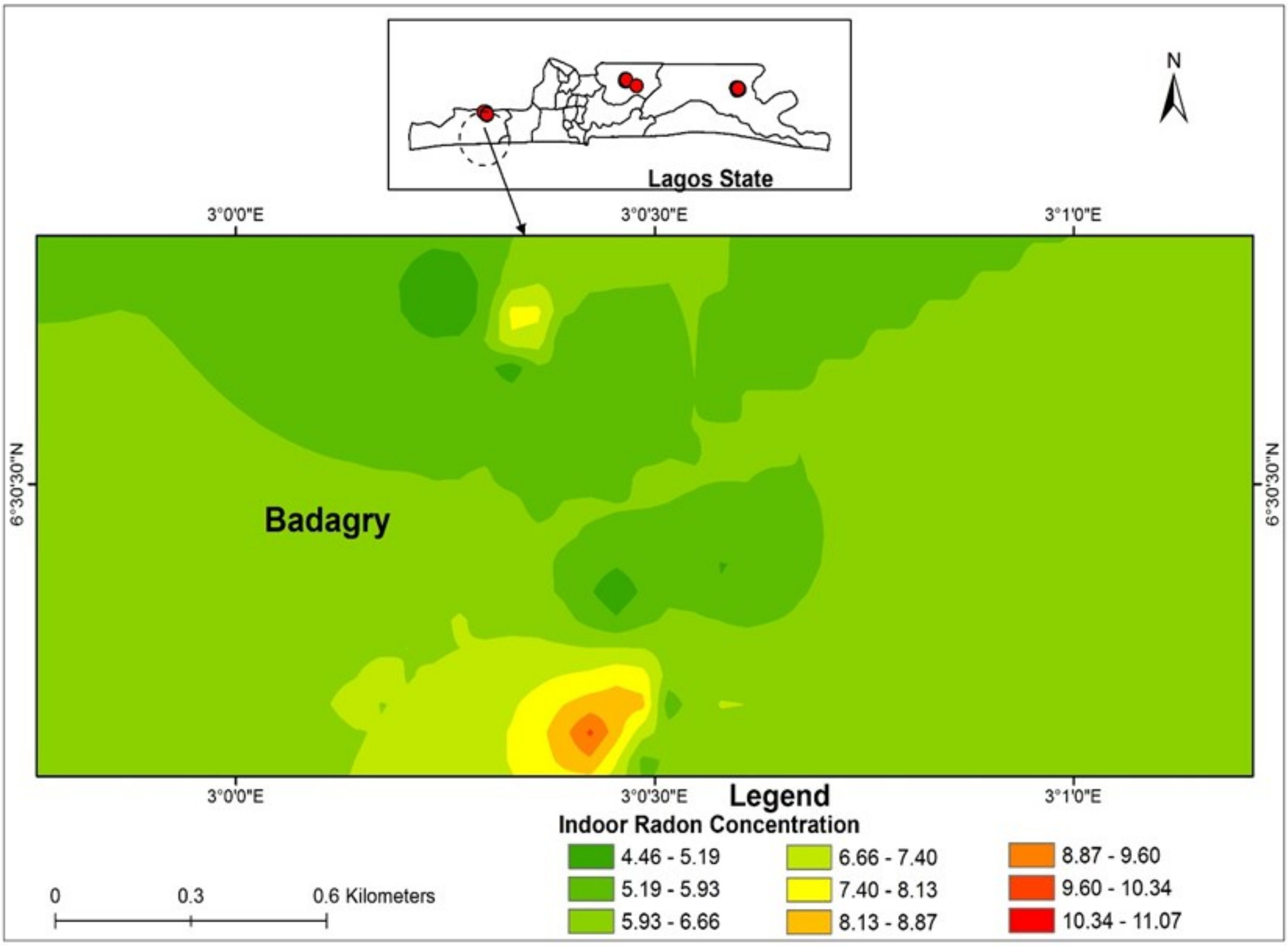

Figure. 3 Radon Map of Badagry

materials used for construction rather than the soil in the study area may be the main contributor to the indoor radon concentrations. The results showed that indoor radon concentrations vary from one building to another, and from one environment to another as found in other studies. The results obtained from this study are lower than the established national action level for existing and new residential buildings in many countries around the world. This study recommend continuous indoor radon monitoring programmes in Nigeria, the result of which can be applicable to set up the national action level.

Public awareness campaigns undertaken through this study has generated an increased number of residents who desire to have their homes tested for radon.

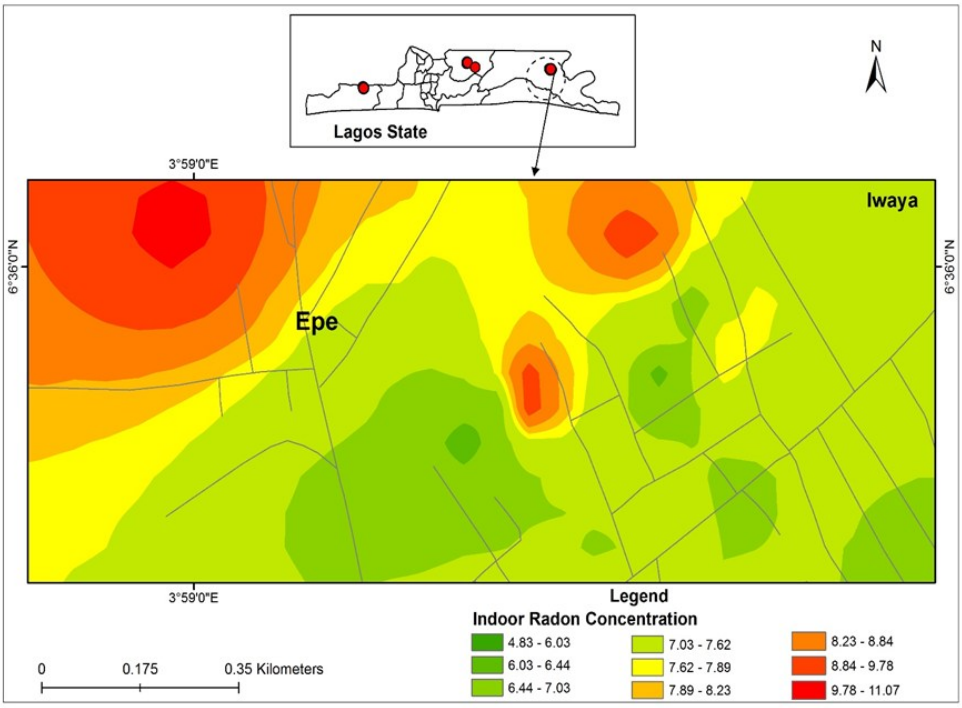

Figure. 4 Radon Map of Epe

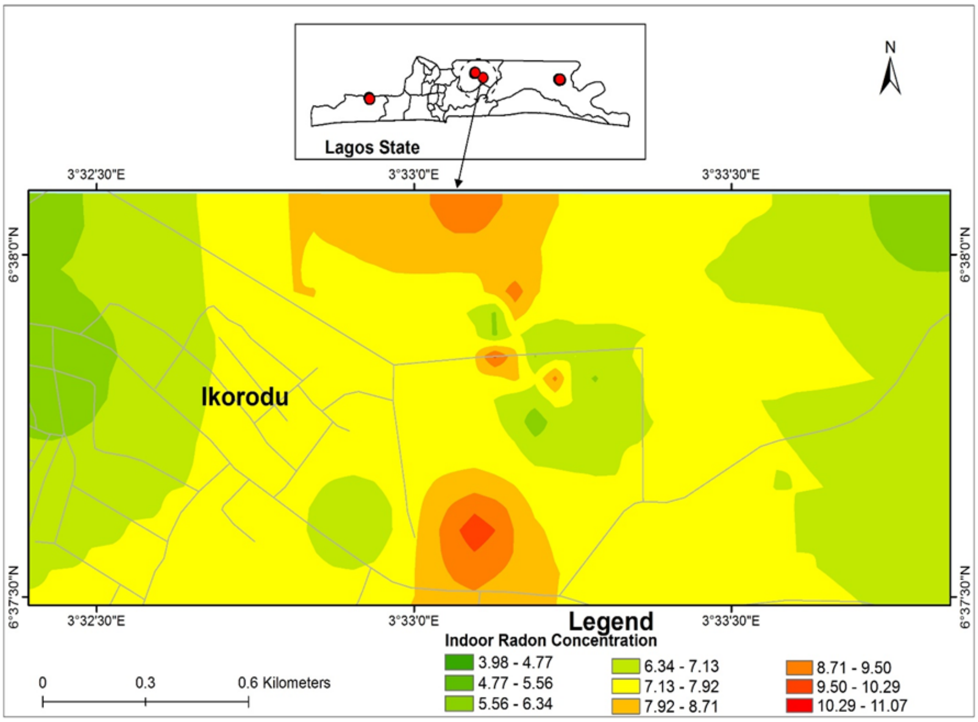

Figure. 5 Radon Map of Ikorodu

REFERENCES

Abodunrin O. P. and Akinloye M. K. (2020) Determination of radon exhalation rates from soil around buildings in Lagos environments using passive measurement technique. *Journal of Environmental Health Science and Engineering*. DOI 10.1007/s40201-020-00446-3.

Abumurad K, Kullab M, Al-Bataina B, Ismail A, Lehlooh A (1994) Estimation of Radon Concentration Inside Houses in Some Jordanian Regions. *Mu'tah J. Res. Stud.*. 9(5): 9–21.

Afolabi O. T., Esan D. T., Banjoko B., Fajewonyomi B. A., Tobih J. E., and Olubodun B. B. (2015) Radon level in a Nigerian University Campus. BMC Research Notes, 8:677. Doi: 10.1186/s13104-015-1447-7.

Ahmad N., Jaafar M. S., Khan S. A., Nasir T., Ahmad S. and Rahim M. (2014) Measurement of radon exhalation rate, radium activity and annual effective dose from bricks and cement samples collected from Dera Ismail Khan. *American Journal of Applied Sciences*, 11(2): 240-247. doi:10.3844/ajassp.2014.240.247.

Åkerblom G. (1999) Radon Legislation and National Guidelines, Swedish Radiation Protection Institute, Stockholm. Rep 99: 18.

Baluci, C. et al, (2013). National mapping survey of indoor radon levels in the Maltese Islands. Malta Medical Journal, 25(4), 33-39.

Collignan B. and Powaga E. (2017) Impact of ventilation systems and energy savings in a building on the mechanisms governing the indoor radon activity concentration. DOI.org/10.1016/j.jenrad.2017.11.023.

Darby S., Hill D., Auvinen A., Barros-Dios J. M., Baysson H., Bochicchio F., Deo H., Falk R., Forastiere F., Hakama M., Heid I., Kreienbrock L., Kreuzer M., Largarde F., Makelainen I., Muirhead C. Oberaigner W., Pershagen G., Ruano-Ravina A., Ruosteenoja E., Schaffrath A., Tirmarche M., Tomasek L., Whitley E., Wichmann H. E. and Doll R. (2005) Radon in homes and risk of lung cancer: collaborative analysis of individual data from 13 European case studies. *British Medical Journal*, 330: 223 – 228. DOI: 10.1136/bmj.38308.477650.63

EC (1995) European collaborative action: indoor air quality and its impact on man. *Environment and quality of life*, report no 15, radon in indoor air. EUR 16123EN.

Field R. W., Smith B. J., Steck D. J. and Lynch C. F. (2002) Residential radon exposure and lung cancer: variation in risk estimates using alternative exposure scenarios. *Journal of Exposure Analysis and Epidemiology*, 12:197 – 203.

Gaskin J., Coyle D., Whyte J. and Krewksi D. (2018) Global estimate of lung cancer mortality attributable to residential radon. DOI.org/10.1289/EHP2503.

Health Canada (2008) Guide for radon measurements in residential dwellings (homes). www.hc-sc.gc.ca (14/07/2015).

HPA (2009) Health Protection Agency. Radon and Public Health. Report of the independent advisory group on ionizing radiation (radon, chemical and environmental hazards). RCE-11.

IAEA (2012) Sources and measurements of radon and radon progeny applied to climate and air quality studies. International Atomic Energy Agency Vienna, 2012. http://www.iaea.org/books STI/PUB/1541.

ICRP (2010) The International Commission on Radiological Protection. Lung cancer risk from radon and progeny. *Annals of the ICRP*. Draft report for consultation.

Matiullah (2013) Determination of the calibration factor for CR-39 based indoor radon detector. *Journal of Radioanalytical Chemistry*, 298:369 – 373. doi 10.1007/s10967-013-2451-9.

NBS (2018) National Bureau of Statistics. Demographic statistics bulletin. Page 7.

Obed R. I., Lateef H. T. and Ademola A. K. (2010) Radon survey in a university campus of Nigeria. *Journal of Medical Physics*, 35(4): 243 – 247.

Obed R. I., Ademola A. K., Vascotto M. and Giannini G. (2011) Radon measurements by nuclear track detectors in secondary schools in Oke-Ogun region, Nigeria. *Journal of Environmental Radioactivity*, 102: 1012 – 1017. doi:10.1016/j.jenvrad.2011.06.012.

Obed R. I., Ademola A. K. and Ogundare P. O. (2012) Radon measurements by nuclear track detectors in dwellings in Oke-Ogun area, South-Western, Nigeria. *Radiation Protection Dosimetry*, 148 (4): 475 – 481. doi:10.1093/rpd/ncr196.

Ojo O. F., Farai I. P. and Jibiri N. N. (2013) Determination and evaluation of radiological risk due to indoor radon concentration levels in offices at a University Faculty in Ibadan Southwestern Nigeria. *Journal of indoor and built environment*, 22(2): 343 – 346.

Olatunji A. S. (2010) Evaluation of groundwater occurrence of Metropolitan Lagos, Southwestern Nigeria In Groundwater Quality Sustainability, XXXVIII IAH Congress, Krakow, 12–17 September 2010, *Extended Abstracts*.

Oni O. M., Ishola G. A., Oladapo O. O. and Oni E. A. (2012) Estimation of lifetime fatality risk from indoor radon in some offices in a Nigeria University. *Res. J. Env. & Earth Sci.*, 4(1): 131 –133.

Padraic Murphy (2008) An overview of primary sampling units (PSUs) in multi-stage samples for demographic surveys. *Section on Government Statistics* – JSM 2008.

Ravikumar P. and Somashekar R. K. (2015) Estimates of the dose of radon and its progeny inhaled inside buildings. *European Journal of Environmental Sciences*, 3(2): 88–95.

Seltenrich Nate (2019) Radon risk: a global estimate of radon's contribution to lung cancer. DOI.org/10.1289/EHP4169.

Swedjemark, G.A., Mellander, H., Mjönes, L. (1993) Radon. In: The indoor climate in Swedish residential buildings (in Swedish with an abstract in English). Editors Norlen, U and Andersson, K. Swedish Building Research Institute. *Report TN:30*.

Synnott H. and Fenton D. (2005a) An evaluation of radon mapping techniques in Europe. European Radon Research and Industry Collaborative Concerted Action (ERRICCA 2). European Commission Contract. FIRI-CT-2001-20142 (www.rpii.ie/reports).

Synnott H. and Fenton D. (2005b) An evaluation of radon Reference Levels and radon measurement techniques and protocols in European countries. European Radon Research and Industry Collaborative Concerted Action (ERRICCA2). European Commission Contract. FIRI-CT-2001-20142 (www.rpii.ie/reports).

USEPA (1992) U.S. Environmental Protection Agency. Indoor radon and radon decay product measurement device protocols. Office of Air and Radiation (6604J). EPA 402-R-92-004, July 1992 (revised).

USEPA (1993) U.S. Environmental Protection Agency. Protocols for Radon and Radon Decay Product Measurements in Homes. EPA 402-R-92-003, EPA, Office of Air and Radiation, Washington, DC. Available at www.epa.gov/iaq/radon/rpp_docs.htm.

UNSCEAR (2000) United Nation Scientific Committee on the Effects of Atomic Radiation, Sources and effects of ionizing radiation. *New York: United Nations.*

WHO (2007) International radon project: survey on radon guidelines, programmes and activities final report. Health security and environment public health and environment radiation and environment health. Geneva, *WHO/HSE/RAD/07.01* English only.

WHO (2009) WHO handbook on indoor radon: a public health perspective. Editors: Hajo Zeeb and Ferid Shannoun.

WHO (2010) World Health Organization Guidelines for Indoor Air Quality: Selected Pollutants. Geneva. ISBN-13: 978-92-890-0213-4. Accessed on 01/02/2020.

Zunic Z. S., Kobal I., Vaupoti J., Kozak K., Mazur J., Birovljev A., Janik M., Celikovic I., Ujic P., Demajo A., Krstic G., Jakupi B., Quarto M. and Bochicchio F. (2006) High natural radiation exposure in radon spa areas: a detailed field investigation in Niska Banja (Balkan region). *Journal of Environmental Radioactivity*, 89(2006): 249 – 260.