Nigerian Journal of Theoretical and Environmental Physics (NJTEP)
ISSN Print: 3026-9601
DOI: https://doi.org/10.62292/njtep.v2i2.2024.43
Volume 2(2), June 2024

Assessment of Indoor and Soil-Gas Radon Concentration of a Quarry Site in Eiyekorin, Kwara State

[1]Aremu, A. A., [1]Ismail, A. A. *[1]Oni, E. A., [2]Oladapo, O. O., [1]Olajide, T. A. and [1]Oni, O. M.

[1]Department of Pure and Applied Physics, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.
[2]Department of Science Laboratory Technology, Ladoke Akintola University of Technology, Ogbomoso, Nigeria.

*Corresponding author's email: eaoni53@lautech.edu.ng

ABSTRACT

The toxic health effect of human exposure to radon gas which is radioactive in nature has attracted extensive research attention worldwide. Since direct experiments on the effect of earthquakes on radon release are difficult to conduct, a possible alternative is to use man-made explosions as an earthquake surrogate and investigate the corresponding effect on radon concentration. This study aims at investigating the soil-gas radon concentration in an active quarry site and areas outside the quarry, and the infiltration of the gas into the indoor environment was measured in order to access the occupational exposure risk. Soil gas radon concentration was taken at 30 random locations within the quarry and areas outside the quarry using RAD7, likewise 10 indoor radon gas in offices and homes were measured using an active radon detector manufactured by Durridge Incorporation in USA and comparative analysis of the difference between the two locations were done. The mean of the soil-gas radon concentration in the quarry site is 24968.84 ± 6913.204Bq/m^3 while that of outside the quarry is 9664.67 ± 4992.86 Bq/m^3. The result shows higher values of radon-gas concentration in the quarry site compared with area outside the quarry and when compared to the International Commission on Radiation Protection (ICRP) suggested value of radon concentration in soil and sediment, which is in the range of 0.4 to 40 KBqm^{-3}, result shows that most location within the study area are higher than these limits. Also, the radon in air indoor and outdoor was taken at the offices located within the quarry and occupational exposure risk was carried out. The average of radon in air indoor and outdoor was found to be 31.12 Bqm^{-3} and 10.12 Bqm^{-3} respectively with higher values found indoor. However, the values are found to be below the recommended value of 300 Bq/m^3 by ICRP publication for homes and workplaces.

Keywords:
Radon concentration,
Earthquakes,
Infiltration,
Quarry,
Soil.

INTRODUCTION

Quarry operations to extract some quarry products cause radioactive contamination of the soil surface, food crops, and local aquatic environment, which is then transferred to water, air, plants, and other living organisms (Nduka *et al.*, 2022). It also leads to considerable environmental devastation through deforestation, destruction of adjoining agriculture lands with stone pebbles, gaseous pollution from the use of explosives, and the release of hazardous metals into the surrounding environment, among other things. Other sources of environmental risk include natural radiations from granitic masses and other geological formations (Tsepav *et al.*, 2018).

The phrase "quarry products" refers to a diverse range of natural rocks with varying mineral compositions that are crushed into various sizes at quarries. This includes various geological elements such as gneiss, granite, diorite, granodiorite, and other rocks that, following an industrial process, are appropriate for use as construction materials and ornamental rocks. The presence of naturally occurring radionuclides in construction materials derived from quarry products expose people to radiation both inside and outside of buildings. This is primarily due to ^{40}K gamma radiation and uranium and thorium decay series members both abundant in soil and rocks of the earth's crust (Gbenu *et al.*, 2016).

Exposure to radiation can be external or internal. External exposure is most commonly produced by gamma radiation from radionuclides in the ^{238}U and ^{232}Th families, as well as ^{40}K. Higher levels of radiation are connected with igneous rocks such as granite and tuff, while lower levels are associated with sedimentary rocks. Internal exposure is associated with radionuclide ingestion; however the primary cause is inhalation of ^{222}Rn and its short-lived decay products (Marchetti *et al.*, 2004). Radon (^{222}Rn) is a byproduct of naturally occurring radioactive decay of radium in the 238U decay series generated in the crust. It is a naturally occurring, odorless, colorless, radioactive noble gas with a half-life of 3.82 days. Radon is found both outside and inside and can degrade into a multitude of radioactive short-lived compounds (Chen *et al.*, 2018).

Though the risk of ingesting radon through water is lower than the risk of inhaling radon from the air, the risk posed by this cannot be overlooked (Oni & Adagunodo, 2019). Because radon is odourless, colourless, and tasteless, its concentration and production are not uniform. It is a radioactive element with distinct properties because it is the only one that exists as an inert gas under normal temperature and pressure conditions. Because radon is chemically inert, it may easily escape from the earth's crust into the atmosphere. Once created, it goes through the ground to the atmosphere, while some of it dissolves in water and remains below the Earth's surface and flows beneath the ground surface. When radon decays, it generates ionizing radiations in the form of alpha particles, as well as short-lived decay products (Francisca *et al.*, 2023).

Despite the fact that humans are constantly exposed to background ionizing radiation (UNSCotEoA & Annex, 2000), the exposure levels at the quarry site cannot be compared to those found in regular surroundings. Internal exposure to radionuclides linked with quarry products can also occur as a result of unintentional ingestion within mining/excavation pits and dust particle inhalation during quarrying (Echeweozo & Ugbede, 2020). Although there is no area on Earth that is completely free of radioactivity, soil containing naturally occurring radionuclides that are above the maximum allowable exposure limit can be exceedingly harmful and have a major impact on the health of individuals who live in that environment (Adewoyin *et al.*, 2022). As a result, this study compares the amount of radon concentration at an active quarry site to that of non-quarry sites. The study aims to examine and measure the background radiation absorbed dose rate in the area's air. The recorded radon concentration is then used to compute the annual effective dose received by workers. The exposure is also linked to an Excess lifetime cancer risk (ELCR). The study's findings are compared to the standard recommended value to determine the radiological health implications.

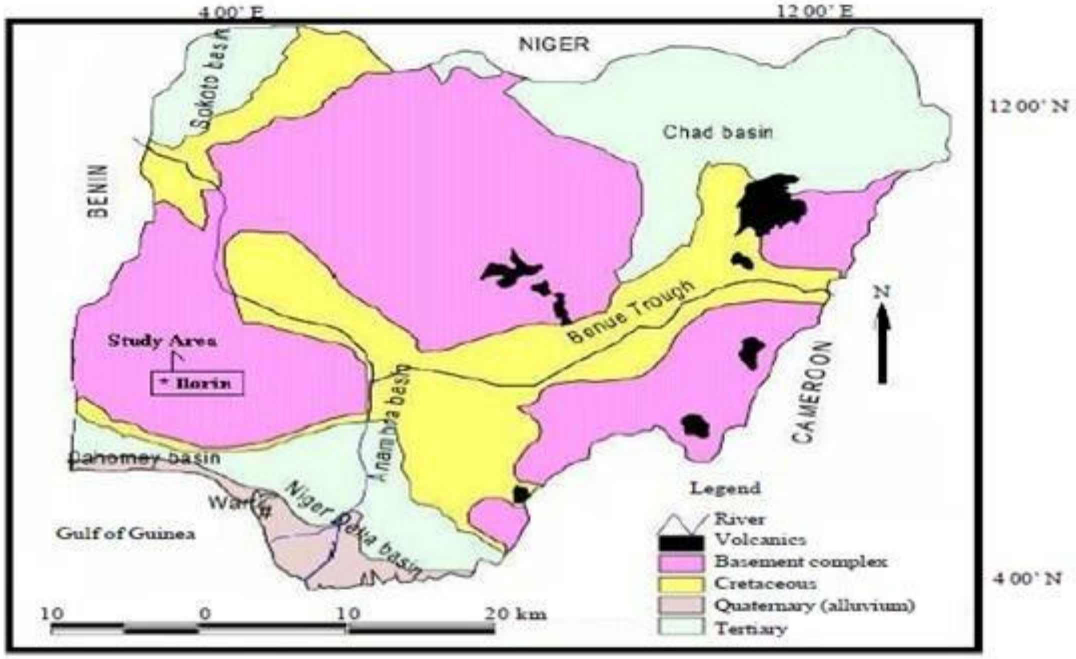

Figure 1: Geological map showing the study area (Orosun *et al.*, 2016)

MATERIALS AND METHODS

Geology of the Study Area

Understanding an area's geology is critical for analyzing possible mineral resources, finding groundwater sources, and assessing geological dangers. The research region is wholly within the basement rocks in western part of central Nigeria, bordered by longitudes 4.36'-4.39' E and latitudes 8.27'-8.30' N. It is located in the northwestern part of Ilorin, Nigeria's semi-arid zone. Ilorin's geology consists of a Pre-Cambrian foundation complex with elevations ranging from 273 m to 333 m in the west and 200 m to 364 m in the east, with an isolated hill (Sobi hills) of around 394 m above sea level. According to Oyegun (1985) sedimentary rock covers a substantial portion of Ilorin, including both primary and secondary laterites and alluvial deposits. The heterogeneity of basement complex rocks results in a wide number of ferruginous soil group. Thus, the main soil type of Ilorin is ferrallitic, with a deep red color and a significant clay concentration. The major river in Ilorin is Asa, which flows North-South direction dividing the plain into two, Western and Eastern parts. The eastern part is generally steeper than the western part with height ranging from 900 – 1200 feet in some part and peaking at isolated landforms.

Sample Measurements

The measurement was carried out with consideration for sites with little or no human disturbance such as farming, drilling or construction of any form. Thirty (30) measurements of the radon concentration were randomly taken within and outside the quarry site while indoor measurement were taken in offices located within the quarry site. The soil gas radon concentration was measured at 80cm depth using RAD7, an active radon detector manufactured by Durridge Incorporation in USA which converts the energy of an alpha particle emitted by ^{218}Po in secular equilibrium with ^{222}Rn directly into electrical signal.

At every location, the Rad7 unit was first purged for several minutes to ensure that the relative humidity in the measurement chamber is 8% or less as specified by the manufacturer, this is done by pumping air into the sampling cell. Before the air reaches the cell, it is allowed to pass through a desiccant (drierite) to lower the humidity in the sample cell of the detector.

Each measurement runs for four times with each repetition taking five minutes, using a constructed and calibrated pilot Rod and Hammer, the steel soil Gas Probe was inserted into the soil in such a way that a reasonable seal exists between the probe shaft and the surrounding soil so that ambient air does not descend around the probe and dilute the soil gas sample, the soil gas radon flow through a tube to a desiccant ($CaSO_4$) filter tube which dries off any moisture in the radon gas, and then to the Air-inlet probe (pore size - 1µm) that blocks fine dust particles from entering the radon detector (RAD-7). The RAD-7 displays the results, which was stored in the detector memory for later use. The Annual Effective Dose, Annual Working Level, Working Level Month (WLM) and the Excess Lifetime Cancer Risk were calculated using.

Estimation of Radiological Indices

Annual Effective Dose (mSvy-1)

The annual effective dose D_{RN} (mSvy^{-1}) is the relative detriment associated with each irradiated tissue or organ and its response is expressed as if the whole body were irradiated, its relationship to the indoor radon concentration was calculated using equation (i) by (Al-Hamidawi & Husain, 2016).

$$\text{Annual Effective Dose } D_{RN} = E_f \times C_f \times O_f \times C_{RN} \times T \qquad (1)$$

Where E_f is the equilibrium factor (0.5), C_f is the coefficient factor (9 × 10^{-6} mSvh^{-1}/Bqm^{-3}), C_{Rn} is the ^{222}R concentration (Bqm^{--3}), O_f is the occupancy factor (0.8), T is the indoor occupancy time (1920 hy^{-1}).

Annual Working Level

The risk from radon inhalation is closely related to the energy imparted by the short-lived daughter of radon in the radiosensitive cells of the respiratory system. By convention, the concentration of radon daughter is measured in Working Level (WL). The occupational exposure best estimated by the Potential Alpha Energy Concentration (PAEC) was accessed using equation (ii) by (Obed *et al.*, 2010).

$$PAEC(WL) = \frac{C_{RN} \times C_f}{100} \qquad (2)$$

Where C_{RN} is the mean radon concentration (pCi) and C_f = 0.5 is the equilibrium factor

Working Level Month (WLM)

Working level month (WLM) means a unit of exposure used to express the accumulated human exposure to radon decay products. It is calculated by multiplying the average radon progeny concentration in working levels to which a person has been exposed by the number of hours exposed and dividing the product by one hundred seventy hours per month. This calculation is known as the Working Level Month (WLM). The number of hours in a working month is 170. This is based on 8 hours a day for 21 working days per month. The calculation was done using equation (iii) by (Council, 1999)

$$WLM = \frac{8760 \times T\ (hy^{-1})}{170hours}\ X\ WL \qquad (3)$$

Where T is the indoor occupancy time (hy^{-1}) and WL is the working level.

Excess Lifetime Cancer Risk

The Excess Lifetime Risk (ELCR) associated with exposure to indoor radon was calculated taking into consideration the estimates of lifetime excess absolute risk of lung cancer associated with radon and radon concentration as reported by (Ajayi & Olubi, 2016) is

$$\text{Excess Lifetime Cancer Rick (ELCR)} = \text{ELCR} = D_{RN} \times DL \times RF \quad (4)$$

Where DL is the average duration of life (70 years) and RF is risk factor (Sv^{-1}), which is the fatal cancer risk per Sievert.

RESULTS AND DISCUSSION

The results of the measured radon concentration within and outside the quarry site, and the calculated Annual Effective Dose, Annual Working Level, Working Level Month and Excess Lifetime Cancer Risk of the radon in air both outdoor and indoor are presented in Table 1, Table 2 and Table 3.

Table 1: The concentration of radon gas, within and outside the quarry site

S/N	Quarry (Bq/m^3)	Off-Quarry (Bq/m^3)
1	15500.91	9580
2	15431.24	10600
3	27112.54	11600
4	26479.47	11300
5	37883.83	13600
6	34955.87	15300
7	38723.54	15900
8	40385.3	15600
9	12474.76	16000
10	24853.16	17900
11	23486.44	19100
12	22218.27	16700
13	25392.43	2130
14	26717.6	5000
15	26163.3	1670
16	10734.07	1310
17	21865.69	4070
18	23004.05	4600
19	25324.45	4470
20	23022.22	4480
21	26128.4	9900
22	25870.14	10500
23	26274.36	10400
24	26976.28	9480
25	25293.56	6830
26	25799.51	8150
27	27523.78	7060
28	27156.3	7710
29	17230.92	10600
30	19082.78	8400

Table 2: Radon in air outdoor and its' calculated Annual Effective Dose, Working Level, Working Level Month and Excess Lifetime Cancer Risk

Offices	Outdoor (Bq/m^3)	Annual Effective Dose	Working Level	Annual Exposure WLM	Excess Lifetime Cancer Risk
A	7.5	0.065	0.0010	0.0114	6
B	13.5	0.117	0.0018	0.0206	6
C	13.5	0.117	0.0018	0.0206	10
D	8	0.069	0.0011	0.0122	10
E	8.1	0.070	0.0011	0.0124	6

Table 3: Radon in air indoor and its' calculated Annual Effective Dose, Working Level, Working Level Month and Excess Lifetime Cancer Risk

Offices	Indoor (Bq/m^3)	Annual Effective Dose	Working Level	Annual Exposure WLM	Excess Lifetime Cancer Risk
A	38.4	0.332	0.0052	0.0585	29
B	38.8	0.335	0.0052	0.0592	30
C	32.1	0.277	0.0043	0.0489	24
D	16.2	0.140	0.0022	0.0247	12
E	30.1	0.260	0.0041	0.0459	23

The radon concentration in 30 random locations within the quarry and outside the quarry, and radon in air outdoors and indoors of the offices was measured using a radon RAD7 detector. Table 1 presents the radon concentration value at those locations while Table 2 and 3 presents the radon in air outdoors and indoors respectively. The annual effective dose, working level, working level month, and excess lifetime cancer risk for radon in air outdoors and indoors were calculated and results are presented in Table 2 and 3.

Results show that the radon concentrations within the quarry site is higher than those outside the quarry site with maximum value of 40385.3Bq/m^3 and minimum value of 10734.07Bq/m^3 within the quarry site. The radon concentration outside the quarry has maximum value of 19100Bq/m^3 and minimum value of 1310Bq/m^3. The mean value of the radon concentration in the quarry site is 24968.84±6913.204Bq/m^3 while that of off quarry site is 9664.67±4992.86Bq/m^3. The acquired results when compared to the International Commission on Radiation Protection (ICRP) suggested value of radon concentration in soil and sediment, which is in the range of 200 to 800 Bqm^{-3} (Amin *et al.*, 2017) shows that most location within the study area are higher than these limits.

The outdoor radon in air in different offices varies from 7.5 to 13.5Bq/m^3 as shown in Table 2 with minimum value of 7.5Bq/m^3 obtained in office A and maximum value of 13.5Bq/m^3 in office B and C. Likewise, the indoor radon in air in different offices of A, B, C, D and E varies from 16.2 to 38.8Bq/m^3 as shown in Table 3 with minimum value of 16.2 Bq/m^3 obtained in office D and maximum value of 38.8Bq/m^3 in office B. The average indoor radon in air level is below the action level (300 Bq/m3) recommended by ICRP publication for homes and workplaces (Pervin *et al.*, 2022). Outdoor levels are usually assumed to be small in comparison with indoor levels. Result of this study yields a mean value 31.12 Bqm^{-3} for indoor radon and 10.12 Bqm^{-3} for outdoor radon. The highest levels of indoor radon are recorded in offices with insufficient ventilation. Some factors influencing indoor radon concentration, includes soil gas radon concentration, radium concentration, emanation coefficient, and ventilation rate (Mehta *et al.*, 2014). Radon concentrations were found to be higher in poorly ventilated rooms than in well-ventilated rooms. As a result, it was clear that a bad ventilation system causes higher radon concentrations than a good ventilation system, which is also confirmed by literature data (Karim *et al.*, 2016).

The associated annual effective dose, working level, working level month and excess lifetime cancer risk for outdoor radon in air and indoor radon in air were calculated and shown in Table 2 and 3 respectively. It was found that the highest annual effective dose is 0.117 Bq/m^3 for outdoor and 0.335 Bq/m^3 for indoor. The value of the annual effective dose of this study was found to be below the ICRP recommended range of 3–10 mSv/y for exposure to ^{222}Rn at workplaces (Sherafat *et al.*, 2019). The calculated value of ELCR ranged from 6-10 outdoor and 12-30 indoor, and it was found that two values of ELCR are lower than the action level of ELCR recommended by the US-EPA (Azhdarpoor *et al.*, 2021).

CONCLUSION

In this paper, the results of radon concentration in a quarry site was presented and compared with that of non-quarry site. The radon measurements were taking using an electronic active radon detector, RAD7. The radon in air within the offices (indoor) and outside the offices (outdoor) were also taken and the associated annual effective dose, working level, working level month and excess lifetime cancer risk was calculated. Comparing the results of the radon concentration, the value is higher in quarry site compared to that of non-quarry site. This can be due to the bedrock and the blasting activities within the quarry. The measured radon concentrations in most of the studied places are higher than the recommended action level, thus, the areas are not safe from radon exposure and associated hazards. However, locations within and outside the offices are safe because the radon in air measured around this area are lower than the recommended action. Overall, this study provides baseline data on soil-gas radon from a quarry and a non-quarry location, as well as radon in air from indoor and outdoor sources. In the future, the offered data may be useful for ^{222}Rn source identification and national mapping.

REFERENCES

Adewoyin, O., Maxwell, O., Akinwumi, S., Adagunodo, T., Embong, Z., & Saeed, M. (2022). Estimation of activity concentrations of radionuclides and their hazard indices in coastal plain sand region of Ogun state. *Scientific reports*, *12*(1), 2108. DOI: 10.1038/s41598-022-006064-3

Ajayi, O., & Olubi, O. (2016). Investigation of indoor radon levels in some dwellings of Southwestern Nigeria. *Environmental Forensics*, *17*(4), 275-281. DOI: 10.1080/15275922.2016.1230909

Al-Hamidawi, A. A. A., & Husain, A. A. (2016). Radiation hazards due to radon concentrations in dwellings of Kufa Technical Institute,'Iraq'. *Phys Int*, *7*(1), 28-34. **DOI:** https://doi.org/10.3844/pisp.2016.28.34

Amin, S., Al-Obiady, A., & Alwan, A. (2017). Radon level measurements in soil and sediments at oil field area and its impact on the environment. *Engineering and Technology Journal*, *35*(1B), 1-7. https://doi.org/10.30684/etj.35.1B.1

Azhdarpoor, A., Hoseini, M., Shahsavani, S., Shamsedini, N., & Gharehchahi, E. (2021). Assessment of excess lifetime cancer risk and risk of lung cancer due to exposure to radon in a middle eastern city in Iran. *Radiation Medicine and Protection*, *2*(03), 112-116. https://doi.org/10.1016/j.radmp.2021.07.002

Chen, Z., Li, Y., Liu, Z., Wang, J., Zhou, X., & Du, J. (2018). Radon emission from soil gases in the active fault zones in the Capital of China and its environmental effects. *Scientific reports*, *8*(1), 16772. DOI: 10.1038/s41598-018-35262-1

Council, N. R. (1999). Evaluation of Guidelines for Exposures to Technologically enhanced Naturally occurring radioactive materials. DOI: 10.17226/6360

Echeweozo, E., & Ugbede, F. (2020). Assessment of background ionizing radiation dose levels in quarry sites located in Ebonyi State, Nigeria. *Journal of Applied Sciences and Environmental Management*, *24*(10), 1821-1826. DOI: 10.4314/jasem.v24i10.17

Francisca, D. D., Iramina, W. S., Ayres da Silva, A. L. M., & de Tomi, G. (2023). New Evaluation Method of Exposure to Radon Gas in Mining Environments. *Minerals*, *13*(7), 897. **https://doi.org/10.3390/min13070897**

Gbenu, S., Oladejo, O., Alayande, O., Olukotun, S., Fasasi, M., & Balogun, F. (2016). Assessment of radiological hazard of quarry products from southwest Nigeria. *Journal of Radiation Research and Applied Sciences*, *9*(1), 20-25. https://doi.org/10.1016/j.jrras.2015.08.004

Karim, M. S., Daroysh, H. H., & Mohammed, A. N. (2016). Assessment of Indoor Radon C Concentrations in Dwellings for Baghdad Governorate by Using RAD-7 Detector. DOI: 10.4236/detection.2016.42006

Marchetti, E., Trevisi, R., Tonnarini, S., Orlando, C., Bruno, M., Amici, M., . . . Nappi, F. (2004). *Natural radioactivity exposure: risk assessment of workers in Italian quarries.* Paper presented at the 11 th International Congress of the International Radiation Protection Association.

Mehta, V., Singh, S., Chauhan, R., & Mudahar, G. (2014). Measurement of indoor radon, thoron and their progeny levels in dwellings of Ambala district, Haryana, Northern India using Solid state nuclear track detectors. *Romanian Journal of Physics*, *59*(7-8), 834-845. D DOI: 10.12691/aees-9-7-2

Nduka, J. K., Umeh, T. C., Kelle, H. I., Ozoagu, P. C., & Okafor, P. C. (2022). Health risk a Assessment of radiation dose of background radionuclides in quarry soil and uptake by Plants in Ezillo-Ishiagu in Ebonyi South-Eastern Nigeria. *Case Studies in Chemical and Environmental Engineering*, *6*, 100269. DOI: 10.1016/j.cscee.2022.100269

Obed, R., Lateef, H., & Ademola, A. (2010). Indoor radon survey in a university campus of Nigeria. *Journal of Medical Physics/Association of Medical Physicists of India*, *35*(4), 242. doi: 10.4103/0971-6203.71760

Oladejo, O. F., Olukotun, S. F., Ogundele, L. T., Gbenu, S. T., & Fakunle, M. A. (2020). Radiological risk assessment of naturally occurring radioactive materials (NORMS) from selected quarry sites in Edo State, South-south, Nigeria. *Environmental Earth Sciences*, *79*, 1-8. DOI: 10.1007/s12665-020-8842-7

Oni, E. A., & Adagunodo, T. A. (2019). *Assessment of radon concentration in groundwater within Ogbomoso, SW Nigeria.* Paper presented at the Journal of Physics: Conference Series. DOI: 10.1088/1742-6596/1299/1/012098

Onwuka, M., Avwiri, G., & Ononugbo, C. (2023). Evaluation of Radionuclide Concentration in Suspended Particulate Matter from Two Quarry Sites in Nigeria. *Asian Journal of Physical and Chemical Sciences*, *11*(2), 29-40. DOI: 10.9734/ajopacs/2023/v11i2199

Orosun, M., Lawal, T., & Akinyose, F. (2016). Natural radionuclide concentrations and radiological impact assessment of soil and water in Tanke-Ilorin, Nigeria. *Zimbabwe Journal of Science & Technology*, *11*, 158-172.

Oyegun, R. (1985). The use and waste of water in a third world city. *GeoJournal*, *10*, 205-210.

Pervin, S., Yeasmin, S., Khandaker, M. U., & Begum, A. (2022). Radon concentrations in indoor and outdoor environments of Atomic Energy Centre Dhaka, Bangladesh, and Concomitant Health Hazards. *Frontiers in Nuclear Engineering*, *1*, 901818. https://doi.org/10.3389/fnuen.2022.901818 .

Regassa, T. N., Raba, G. A., Chekol, B. M., & Kpeglo, D. O. (2023). Assessment of natural radioactivity and associated radiological risks from soils of Hakim Gara quarry sites in Ethiopia. *Heliyon*. DOI: 10.1016/j.heliyon.2023.e19476.

Samuel, O. O. (2018). Radiation exposure level in some granite quarry sites within Ohimini and Gwer-East Local Government Areas of Benue State Nigeria. *Insights Med Phys*, *2*(3), 12. DOI: 10.21767/2574-285X.100019

Sherafat, S., Mansour, S. N., Mosaferi, M., Aminisani, N., Yousefi, Z., & Maleki, S. (2019). First indoor radon mapping and assessment excess lifetime cancer risk in Iran. *MethodsX*, *6*, 2205-2216. DOI: 10.1016/j.mex.2019.09.028

Tsepav, M., Yakubu, A., Gene, A., & Abbas, U. (2018). Assessment of Radiation Related Health Risks of Quarry Sites in the Vicinity of Lapai, North Central Nigeria. *Journal of Scientific & Engineering Research*, *9*(4), 1414-1421.

Ugbede, F. O., & Echeweozo, E. O. (2017). Estimation of annual effective dose and excess lifetime cancer risk from background ionizing radiation levels within and around quarry site in Okpoto-Ezillo, Ebonyi State, Nigeria. *The land*, *7*(12).

UNSCotEoA, R., & Annex, B. (2000). Exposures from natural radiation sources. *New York*, *United Nation*.