



Measurement of Radionuclides Concentration and Radiological Health Assessment of Some Selected Table Waters in Ilorin

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ABSTRACT

In order to ensure radiation monitoring and protection, an investigation and assessment of radiological risks that may be associated with the consumption of table waters commonly consumed in Ilorin, Nigeria, was carried out. The activity concentration level of ²³⁸U, ²³²Th, and ⁴⁰K was determined using thallium activated 3"×3" [NaI(Tl)] detector connected to ORTEC 456 amplifier. The radiological risks due to the consumption of the samples were then estimated. The highest annual effective dose (AED) values were obtained from VW and the minimum was obtained from UW water. The AED decreases in the order VW>HW>IW>MW>DW>UW. This implies that VW water constitutes more radiation exposure followed by HW, IW, MW, DW, and then UW Water. The values estimated for MW, DW, and UW water were all lower than the world average value of 1 mSv/y and hence pose no serious radiation hazard. While the values estimated for VW, IW, and HW waters were slightly higher than the recommended threshold value, suggesting a possible risk of radiation exposure to customers. The Excess Lifetime Cancer Risks corroborated the findings of the AED, implying that the probability of developing cancer is high for most of the water samples. Since the values of the estimated hazard parameters were mostly higher than the recommended limits for all age groups, it is recommended that public water system should be monitored and efforts should be made to educate and enlighten the public on radiation exposure, its health effects, and remedial actions necessary to reduce radionuclides concentration in drinking water.

Keywords: Radioactivity, Gamma Spectrometry, Table water, Effective Dose, Ionizing radiation.

1. INTRODUCTION

Water is an indispensable requirement for human existence on earth. It is used for drinking, domestic, agricultural, industrial, and allied purposes. It can contain

radionuclides and other elements that originate from the soil it runs over or through (CHEC, 2002; Isikwue et al., 2009; Orosun et al., 2018; Orosun et al., 2020). Radionuclides are atoms with unstable nucleus, which in the process of radioactive decay can emit gamma ray(s) and/or subatomic particles such as Alpha and Beta particles that are ionizing radiations. Exposure to excess level of these ionizing radiations can cause stochastic and genetic effects that tend to damage critical and/or radiosensitive organs of the body, and can even lead to death (Avwiri et al., 2014; Orosun et al., 2017; Ajibola et al., 2021; Orosun et al., 2022). Radionuclides that emit these radiations occur naturally (e.g., during the decay series of ^{238}U , ^{235}U , ^{232}Th and a non-series decay of ^{40}K) or artificially (by human activities e.g., from medical or industrial uses) in the environment. Radionuclide can reach the surface of the water in several ways and therefore necessary to investigate/monitor the quality of water in all communities because of the presence of these primordial radionuclides in the earth's crust (IAEA, 1989; Taskin, et al., 2009).

Radionuclides may possibly be added to water through intentional or unintentional releases of radioactive matter from hospitals, research institutes, manufacturing plants or nuclear reactors (ATSDR, 2004; IAEA, 1989; Orosun et al., 2022a). Overexposure ionizing radiations from these radionuclides could bring about some harmful effects like genetic malformations, leukemia, DNA damage, cancers, among others as stated earlier (Hudson 2003; Henry, 2005; WHO, 2011; Orosun et al., 2021; Orosun et al., 2021a). Earlier investigations on the effect of Uranium in underground water revealed that the presence of radioactive elements in water causes neurological and reproductive damage to developing babies when it is ingested through the placenta (Isikwue et al., 2009; USEPA, 1982, 2000). In Nigeria, most work carried out showed results that were lower than the International Commission on Radiological Protection (ICRP, 1994) maximum permitted limit and therefore have no significant radiological health burden on the environment and the populace (Avwiri et al., 2014; Orosun et al., 2017; Omeje et al., 2021; Omeje et al., 2022; Morakinyo et al., 2022).

Nevertheless, owing to persistent human and industrial activities, constant environmental monitoring needed to be put in place to ensure consumer products like table waters are safe for drinking. This work then focus on investigation and assessment of radiological risks that may be associated with the consumption of table waters commonly consumed in Ilorin, Kwara State in order to ensure radiation monitoring and mitigation.

2. MATERIALS AND METHOD

2.1. The Study Area

Ilorin the area of the study lies entirely within the basement rocks in the western part of central Nigeria and bounded by longitudes 4°36' – 4°39' E and latitudes 8°27' – 8°30' N. The study area falls within the North –central, a semi-arid region of Nigeria. The major river in Ilorin is Asa, which flows North-South direction dividing the plain into two namely: 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. Ilorin city is one of the fastest growing cities in Nigeria with a tropical wet and dry climate with mean annual rainfall of 1,200mm (Orosun et al., 2020; Ajibola et al., 2022). Its average annual temperature is 26.2 °C; it peaks at about 30 °C in March which marks the hottest month. Wet season is experienced from April to October and dry season from November to March. Figure 1 shows the map of Nigeria indicating the study area “Ilorin”.

The study area consists of Precambrian basement of south-western Nigeria. The soils are formed from metamorphic and igneous rocks which are about 95%. The metamorphic rocks consist of quartzite, augite gneiss, granitic gneiss, biotite gneiss and banded gneiss (Orosun, 2021). The assortment of basement complex rocks bring about large number of ferruginous groups of soils. Therefore, ferrallitic soil type (generally deep red in colour with high clay content) is the major type of soil in Ilorin (Oyegun, 1985).

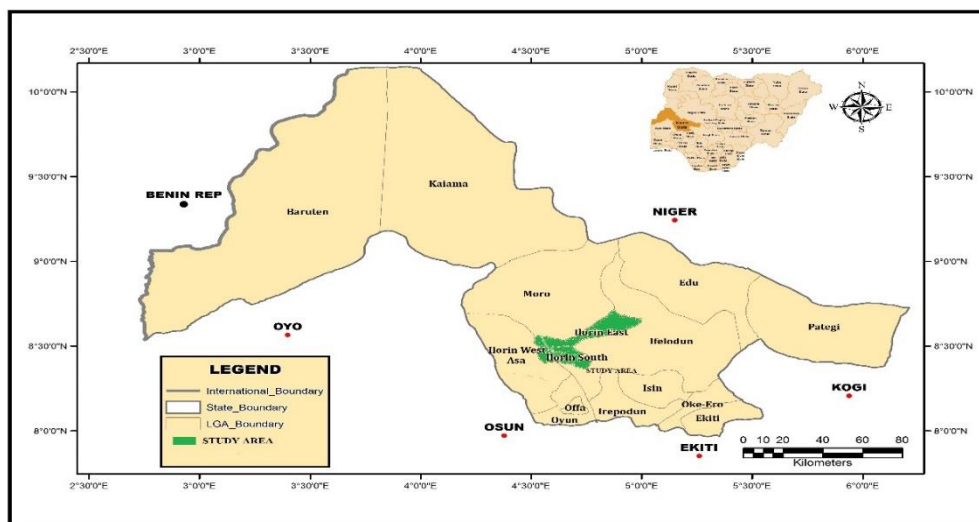


Figure 1. Map of Nigeria showing the study area Ilorin.

2.2. Sample Collection and Preparation

Three (3) water samples each were collected from six table water production factories namely VW, IW, HW, MW, DW, and UW water in Ilorin, Kwara state, Nigeria. The samples making a total of 18 samples were collected using clean 1 liter plastic bottles. The samples were acidified with 11 M HCl at a rate of 10 ml per liter to prevent adsorption of water with the wall of the containers. 200 ml of each sample were then sealed with adhesive tape and kept for at least 28 days (Ajibola et al., 2022; Olomo et al., 1994). This was done in order to allow for radium and its short-lived progenies to reach secular radioactive equilibrium prior to gamma spectroscopy (Olomo et al., 1994; Augustine, 2015). Secular equilibrium is reached when the half-lives of the daughter radionuclide is equivalent to one half-life of the parent radionuclide. After secular equilibrium had been attained, gamma counting was then carried out.

2.3. Gamma Counting

The experiments for radioactivity measurement of the water samples were carried out at the National Institute of Radiation Protection and Research (NIRPR) University of

Ibadan using a thallium activated Canberra vertical high purity 3"×3" Sodium iodide [NaI(Tl)] scintillation detector connected to ORTEC 456 amplifier. The detector was connected to a computer program MAESTRO window that matched gamma energies to a library of possible isotopes. The detector was shielded by 15cm thick lead on all four sides and 10cm thick on top. The energy resolution of 2.0keV and relative efficiency of 33% at 1.33MeV was achieved in the system with the counting time of 27000 seconds. The standard International Atomic Energy Agency (IAEA) sources were used for calibration. From the counting spectra, the activity concentrations of ^{238}U , ^{232}Th and ^{40}K was determined using computer program. The peak that corresponds to 1460 keV (^{40}K) for ^{40}K , 1764.5 keV (Bi-214) for ^{238}U and 2614.5 keV (Th-208) for ^{232}Th were considered in arriving at the activity levels (BqL^{-1}). The activity concentration (C) of the radionuclide was calculated using equation (1) after subtracting the background peak area from the sample peak areas.

$$C_s = \frac{N_a}{P_\gamma \left(\frac{M_s}{V_s}\right) \varepsilon_\gamma t_c} \quad (\text{Bq L}^{-1}) \quad (1)$$

Where, C_s = Activity concentration in the Sample, N_a = Net peak area (sample peak area – background peak area), ε_γ = Efficiency of the detector for a γ -energy of interest, V_s = volume of the water sample, t_c = total counting time, P_γ = gamma yield and M_s is the mass of the given sample.

2.4. Radiological Impact Parameters

These are parameters used to determining the radiation hazards that could be incurred from the consumption of the selected water. Calculating the effective dose is usually the first major step for evaluating the health risk. With regard to biological effects, the radiological and clinical effects are directly related to the absorbed dose rate (Orosun et al., 2018; Ramasamy et al., 2011).

2.4.1. Annual effective dose (AED)

Effective Dose takes into account the type of radiation and the nature of each organ or tissue being irradiated, and enables summation of organ doses due to varying levels and

types of radiation. The annual effective dose for ingested radionuclide from water was calculated using equation (2) given by UNSCEAR (UNSCEAR, 2008).

$$AEDE = \sum C_i \times I \times 365 \times D_i \quad (2)$$

Where, C_i is the activity concentration of ^{40}K , ^{238}U and ^{232}Th , I is the daily intakes of water which was assumed to be 2L d^{-1} for adults, 1 l d^{-1} for lower ages and 0.5 L d^{-1} for infants (WHO, 2011) and D_i is the ingestion dose coefficient of ^{40}K , ^{238}U and ^{232}Th .

2.4.2. Excess lifetime cancer risk (ELCR)

The Excess Lifetime cancer risk was calculated using equation (3) (Avwiri et al., 2014):

$$ELCR = AED \times DL \times RF \quad (3)$$

Where, AED is the Annual Equivalent Dose Equivalent, DL is the average duration of life (estimated to be 70 years), and RF is the Risk Factor (Sv^{-1}), i.e. fatal cancer risk per Sievert. For stochastic effects, ICRP uses RF as 0.05 for public (Avwiri et al., 2014). Average value of ELCR is given as 0.2×10^{-3} (UNSCEAR, 2000).

3. RESULTS AND DISCUSSION

The results of the gamma-ray analysis of eighteen table water samples from 6 production factories are presented in table 1. The radionuclides observed belong to the decay chains of ^{238}U (^{226}Ra) and ^{232}Th with a non-series decay of ^{40}K . For the results obtained for the radiological parameters in table 2, the annual effective dose for adult calculated using in equation (2) is presented in column 2 and the excess lifetime cancer risk calculated using equations (3) is presented in column 3 respectively.

The result of the gamma spectrometry analysis is presented in table 1. The mean activity concentration of ^{40}K , ^{238}U and ^{232}Th were 24.47, 12.80 and 7.03 Bq/l respectively for HW water; 15.7, 22.49 and 6.43 Bq/l for VW water; 9.00, 6.96 and 3.61 Bq/l, for MW water; 22.28, 5.03 and 2.09 Bq/l, for UW Water; 16.47, 18.64 and 5.47 Bq/l, for IW Water and 18.25, 6.15 and 3.29 Bq/l, respectively for DW water.

Table 1. The Spectrometry Result of Radionuclides in the Selected Table Waters.

<i>Samples</i>	^{40}K (Bq/l)	^{238}U (Bq/l)	^{232}Th (Bq/l)
HW1	15.80±1.21	BDL	3.65±0.38
HW2	41.27±2.95	23.58±5.63	11.66±1.10
HW3	16.36±1.22	14.82±3.87	5.80±0.57
Mean	24.47±1.79	12.80±3.16	7.03±0.68
VW1	7.52±0.61	11.00±2.97	6.92±0.67
VW2	21.96±1.62	28.61±6.50	5.45±0.57
VW3	17.75±1.37	27.86±6.88	6.92±0.69
Mean	15.70±1.20	22.49±5.45	6.43±0.64
MW1	8.04±0.67	3.26±0.83	6.10±0.61
MW2	6.65±0.53	17.61±4.65	4.72±0.48
MW3	12.32±1.03	BDL	BDL
Mean	9.00±0.74	6.96±1.83	3.61±0.63
UW1	17.43±1.33	6.62±1.72	2.28±0.24
UW2	34.03±2.33	6.90±1.86	0.40±0.04
UW3	15.38±1.15	1.58±0.40	4.98±0.52
Mean	22.28±1.60	5.03±1.33	2.09±0.27
IW1	2.78±0.22	22.37±5.71	1.97±0.21
IW2	21.40±1.68	11.18±2.96	8.57±0.83
IW3	25.23±1.89	22.37±5.72	5.47±0.57
Mean	16.47±1.26	18.64±4.79	5.34±0.54
DW1	22.38±1.72	BDL	7.18±0.72
DW2	22.90±1.66	11.84±3.14	1.81±0.19
DW3	9.47±0.81	6.62±1.76	0.89±0.09
Mean	18.25±1.39	6.15±1.63	3.29±0.33

Table 2. The Result of the Mean Impact Parameters.

<i>WATER SAMPLES</i>	<i>AED (mSv/y)</i>	<i>ELCR ($\times 10^{-3}$)</i>
VW	1.889	6.612
IW	1.583	5.541
HW	1.711	5.989
MW	0.875	3.063
DW	0.837	2.929
UW	0.616	2.156
Mean	1.252	4.382

These results shows that some of the table waters have concentration of the radionuclides higher than the world average value of 10, 10 and 1 Bq/l for ^{40}K , ^{238}U and ^{232}Th , respectively (UNSCEAR, 2000). This may be due to the local geology of the factory site and production processes. The mean annual effective dose (AED) estimated for adults is 1.889, 1.583, 1.711, 0.875, 0.837 and 0.616 mSv/y for VW, IW, HW, MW, DW and UW Water, respectively (Table 2). The highest was obtained in VW and the minimum in UW water. The AED decreases is in the order $\text{VW} > \text{HW} > \text{IW} > \text{MW} > \text{DW} > \text{UW}$. This implies that VW water constitutes more radiation exposure followed by HW, IW, MW, DW, and then UW Water. The values estimated for MW, DW and UW water were all lower than the world average value of 1 mSv/y (UNSCEAR, 2000) and hence poses no serious radiation hazard. While, the values estimated for VW, IW and HW water were slightly higher than the world average value and suggests a possible risk.

The Excess Life Cancer risk (10^{-3}) values as presented in table 2 were 6.612, 5.541, 5.989, 3.063, 2.929 and 2.156 for VW, IW, HW, MW, DW and UW Water, respectively. All the values were higher than the world average of 0.2×10^{-3} . Higher ELCR value is as a result of high value of AED caused by specific activity of the radionuclides in the samples collected and the expected duration of life taken to be 70 years. This high value implies that the probability of developing cancer over a lifetime considering seventy years as the average life span of humans is high. VW as expected, have the highest value followed by IW Water, HW Water, MW Water, DW Water and UW Water. Following the dose conversion factors for ingestion of radionuclides given in table 3 and the consumption rate of drinking water that varies among various age groups, the annual effective doses (AED) were then estimated for the various age groups. The result is presented in table 4. The mean AED for the ingested radionuclide in VW, HW, IW, MW, DW and UW waters are: 2.601, 2.612, 2.192, 1.317, 1.291 and 0.950 mSv/y, respectively for infants; 2.295, 2.090, 1.950, 1.036, 1.089 and 0.905 mSv/y, respectively for 1 year old; 1.604, 1.470, 1.359, 0.737, 0.746, and 0.593 mSv/y, respectively for 5 years old;

1.313,1.178,1.106, 0.598, 0.587 and 0.452 mSv/y, respectively for 10 years; 1.180, 1.022, 0.989, 0.525, 0.501 and 0.375 mSv/y, respectively for 15 years old; and 1.889, 1.711, 1.583, 0.875, 0.837 and 0.616 mSv/y, respectively for adults.

Table 3. Dose conversion factors for ingestion of radionuclides for members of the public to 70 years of age (ICRP, 2012).

Radio Nuclides	T_{1/2} (years)	DCF (Sv/Bq) Other ages					
		Infants	1year	5years	10years	15years	Adults
⁴⁰ K	1.2x10 ⁹	5.2x10 ⁻⁸	4.2x10 ⁻⁸	2.2x10 ⁻⁸	1.3x10 ⁻⁸	7.6x10 ⁻⁹	6.2x10 ⁻⁹
²³² Th	1.405x10 ¹	1.6x10 ⁻⁶	4.5x10 ⁻⁷	3.5x10 ⁻⁷	2.9x10 ⁻⁷	2.5x10 ⁻⁷	2.3x10 ⁻⁷
²³⁸ U	4.468x10 ⁹	1.4x10 ⁻⁷	1.2x10 ⁻⁷	8.0x10 ⁻⁸	6.8x10 ⁻⁸	6.7x10 ⁻⁸	4.5x10 ⁻⁸

Table 4. Mean Annual Effective Dose for Different Ages for Selected Table Water.

Samples	Annual Effective Dose (mSv/yr)					
	Adults	15 Years	10 Years	5 Years	1 Year	Infant
VW	1.889	1.180	1.313	1.604	2.295	2.601
HW	1.711	1.022	1.178	1.470	2.090	2.612
IW	1.583	0.989	1.106	1.359	1.950	2.192
MW	0.875	0.525	0.598	0.737	1.036	1.317
DW	0.837	0.501	0.587	0.746	1.089	1.291
UW	0.616	0.375	0.452	0.593	0.905	0.950

Most of the AED values for the different age groups were higher than the acceptable limits of 1 msv/y for the public. Although it should be noted that daily intake of water per person of 2 ld⁻¹ for adults, 1 ld⁻¹ for lower ages and 0.5 ld⁻¹ for infants was used as against the 1 liter per day for adults used by Nwankwo (2013) in his determination of natural radioactivity of groundwater in Tanke - Ilorin, Kwara State. The results suggest that infants (<1year) are unsurprisingly more susceptible to radiation hazards drinking the table waters followed by children 1yr (<5years) then, Adults (> 15 years), 5years (<10years), 10years (<15years) and 15years (<adult age) respectively. It should be noted that the estimated mean AED was <1mSv/yr across all the age groups for UW. It is obvious that UW water will constitutes less radiation hazard and safest to drink.

4. CONCLUSION

Measurement of radionuclides in the commonly consumed table waters in Ilorin, Kwara State has been carried out using sodium iodide detector. The radionuclide detected belonged to the series decay of ^{238}U and ^{232}Th and a non-series decay of ^{40}K . The gamma spectrometry results show that some of table waters have high concentration of radionuclides that was believed to be due to the local geology of the area and the production process. Since the values of most of the estimated impact parameters were higher than the world average value and recommended limits for all the bottle waters except UW water, public water system should be revisited and efforts should be made to educate and enlighten the public on radiation exposure, its health effects, and remedial actions necessary to reduce radionuclides concentration in water.

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6. CONFLICT OF INTERESTS

The authors declare that they have no conflict of interest.

7. REFERENCE

- Ajibola, T. B., Orosun, M. M., Lawal, W.A., Akinyose, F. C & Salawu, N. B. 2021. Assessment of Annual Effective Dose Associated with Radon in Drinking Water from Gold and Bismuth Mining area of Edu, Kwara, North-central Nigeria. *Pollution*, **7(1)**: 231-240, <https://doi.org/10.22059/poll.2020.309470.892>.
- Ajibola, T.B., Orosun, M.M., Ehinlafa, O.E., Sharafudeen, F.A., Salawu, B.N., Ige, S.O & Akoshile, C.O. 2022. Radiological Hazards Associated with ^{238}U , ^{232}Th , and

- 40K in some selected Packaged Drinking Water in Ilorin and Ogbomoso, Nigeria. *Pollution*, **8 (1)**: 117-131, <https://doi.org/10.22059/poll.2021.325859.1119>.
- ATSDR 2004. Agency for Toxic Substances and Disease Registry, Strontium (CAS#74440-24-6) US Department of health and human services, public health service.
- Augustine, K. A., Morounfolu, A. O & Peter. O. A. 2015. Radiological safety assessment and determination of heavy metals in soil samples from some waste dumpsites in Lagos and Ogun state, south-western, Nigeria. *Journal of Radiation Research and Applied Sciences*, **8(1)**: 148–153
- Avwiri, G.O, Ononugbo, C.P & Nwokeoji, I. E. 2014. radiation hazard indices and excess lifetime cancer risk in soil, sediment, and water around Mini-Okoro/Oginigba creek, PortHarcourt, Rivers State, Nigeria. *Comprehensive Journal of Environment and Earth Sciences*, **3(1)**: 38-50.
- Children's Health Environmental Coalition (CHEC). 2002. Safe drinking water and possible contaminants (radioactive isotopes. Articles) www.chenet.org/healthhouse/educatio/articles.
- Henry, Y. 2005. Radionuclide in public water supply. Patel Inc. New York.
- Hudson, T. Y. 2003. Radioactive isotope, Medical Association Ltd. Canada. www.radiochem.org/radioactiveisotopes/ollisotopes-line3html.
- IAEA. 1989. Measurement of Radionuclide in Food and Environment. Technical Report, International Atomic Energy Agency, Series No 295, IAEA, Vienna.
- ICRP. 1994. International Commission on Radiological Protection “Dose Coefficient for Intakes of Radionuclides by Worker”. Publication No: 68 Pergamon Press, 1994.
- ICRP. 2012. Compendium of dose coefficients based on ICRP publication 60, International Commission on Radiological Protection ICRP Publication 119, Annex of ICRP, 41.

- Isikwue, B. C., Isikwue, M. O & Danduwa, T. F. 2009. Assessment of Radionuclide concentrations in some public water in use in Markurdi metropolis of Benue state, Nigeria. *Journal of research in forestry, wildlife and environment*, **1(1)**: 93-99.
- Morakinyo, R.O., Usikalu1, M.R & Orosun, M.M. 2022. Evaluation of background radiation of Maryland School complex, Lagos, Nigeria. IOP Conf. Ser.: *Earth Environ Sci*, **993**: 012015. <https://doi.org/10.1088/1755-1315/993/1/012015>.
- Nwankwo, L.I. 2013. Determination of Natural Radioactivity in Groundwater in Tanke-Ilorin, Nigeria. *West African Journal of Applied Ecology*, **21(1)**: 1 -5.
- Olomo, J.B., Akinloye, M.K & Balogun, F.A. 1994. Distribution of gamma-emitting natural radionuclide in soil and water around nuclear research establishment, Ile-Ife Nigeria. *Nuclear Instruments and Methods in Physics Research Section A*, **353**: 553–557.
- Omeje, M., Olusegun, O.A., Joel, E. S., Ikechukwu, I.B., Timothy-Terhile, A.M., Okoro, E.E., Omeje, A.U., Adeleye, B.N., Orosun, M.M., Oha, A. I., Ogunrinola, I. E., Eze, F.A & Saeed M. A. 2021. Measurements of Seasonal Variations of Radioactivity Distributions in Riverine Soil Sediment of Ado-Odo Ota, South-West Nigeria: Probabilistic Approach Using Monte Carlo. *Radiation Protection Dosimetry*, **193(2)**: 76–89, <https://doi.org/10.1093/rpd/ncab027>.
- Omeje, M., Orosun, M. M., Adewoyin, O. O., Joel, E. S., Usikalu, M. R., Olagoke, O., Ehinlafa, O. E & Omeje, U. A. 2022. Radiotoxicity Risk Assessments of ceramic tiles used in Nigeria: The Monte Carlo Approach. *Environmental Nanotechnology, Monitoring & Management*, **17**: 100618, <https://doi.org/10.1016/j.enmm.2021.100618>.
- Orosun, M. M. 2021. Assessment of Arsenic and its Associated Health Risks due to Mining Activities in parts of North-Central Nigeria: Probabilistic Approach Using Monte Carlo. *Journal of Hazardous Materials*, **412(1)**: 125262, <https://doi.org/10.1016/j.jhazmat.2021.125262>.

- Orosun, M. M, Lawal, T. O., Ezike, S. C., Salawu, N. B., Atolagbe, B. M., Akinyose, F. C., Ige, S. O & Martins, G. 2017. Natural radionuclide concentration and radiological impact assessment of soil and water from Dadinkowa Dam, Northeast Nigeria. *J. Nigerian Association of Mathematical Physics*, **42(1)**: 307 – 316.
- Orosun, M. M., Adisa, A. A., Akinyose, F. C., Amaechi, E. C., Ige, O. S., Ibrahim, B. M., Martins, G., Adebajo, G. D., Oduh, O. V & Ademola, O. J. 2018. Measurement of Natural Radionuclides Concentration and Radiological Impact Assessment of Fish Samples from Dadin Kowa Dam, Gombe State Nigeria. *African Journal of Medical Physics*, **1(1)**: 25-35, <https://globalmedicalphysics.org/wp-content/uploads/2019/01/AJMP>.
- Orosun, M. M., Usikalu, M.R & Kayode, K. J. 2020. Radiological hazards assessment of laterite mining field in Ilorin, North-central Nigeria. *International Journal of Radiation Research*, **18(4)**: 895-906. <http://ijrr.com/article-1-3312-en.html>
- Orosun, M.M., Ajibola, T.B., Akinyose, F.C, Osanyinlusi, O., Afolayan, O.D & Mahmud, M.O. 2021. Assessment of ambient gamma radiation dose and annual effective dose associated with radon in drinking water from gold and lead mining area of Moro, North-Central Nigeria. *Journal of Radioanalytical and Nuclear Chemistry*, **328(1)**: 129-136. <https://doi.org/10.1007/s10967-021-07644-9>
- Orosun, M.M., Ajibola, T.B., Farayade, B.R., Akinyose, F. C., Salawu, N. B., Louis, H., Ajulo, K. R & Adewuyi, A. D. 2021a. Radiological impact of mining: new insight from cancer risk assessment of radon in water from Ifelodun beryllium mining, North-Central Nigeria using Monte Carlo simulation. *Arab J Geosci*, **14**: 2380. <https://doi.org/10.1007/s12517-021-08670-3>.
- Orosun, M.M., Ajibola, T.B., Ehinlafa, O.E., Issah, A.K., Salawu, B.N., Ishaya S.D., Ochommadu K.K & Adewuyi A.D. 2022. Annual Effective Dose Assessment of Radon in Drinking Water from Abandoned Tin and Cassiterite Mining Site in

- Oyun, Kwara State, Nigeria. *Pollution*, **8(1)**: 181-192. <https://doi.org/10.22059/poll.2021.326962.1136>.
- Orosun, M.M., Usikalu, M.R., Oyewumi, K.J., Onumojor, C. A., Ajibola, T. B., Valipour, M & Tibbett, M. 2022a. Environmental Risks Assessment of Kaolin Mines and Their Brick Products Using Monte Carlo Simulations. *Earth Syst Environ*, **6**: 157–174. <https://doi.org/10.1007/s41748-021-00266-x>.
- Oyegun, R. O. 1985. The use and waste of water in a third world city. *GeoJournal*., **10(2)**: 205-210. <https://doi.org/10.1007/bf00150741>.
- Ramasamy, V., Suresh, G., Meenakshisundaram, V & Ponnusamy, V. 2011. Horizontal and Vertical Characterization of Radionuclides and Minerals in River Sediments. *Applied Radiation and Isotopes*, **69**: 184-195.
- Taskin, H., Karavus, M., Ay, P., Topuzoglu, A., Hindiroglu, S & Karahan, G. 2009. Radionuclide Concentrations in Soil and Lifetime Cancer Risk Due to the Gamma Radioactivity in Kirklareli, Turkey. *J. Environmental Radioactivity*, **100**: 49-53.
- UNSCEAR. 2000. Sources and effects of ionizing radiation in report of the United Nations Scientific Committee on the Effects of Atomic Radiation to general assembly with scientific annexes, New York, United Nations.
- UNSCEAR. 2008. Report to the general assembly with scientific annexes, Volume II, United Nations Scientific Committee on the Effects of Atomic Radiation Scientific Annexes C, D and E. United Nations, New York.
- USEPA 1982. Assessment of Risks to Human Reproduction and to Development of the Human Conceptus from Exposure to Environmental Substances (ORNL-EIS-197). <https://nepis.epa.gov/Exe/ZyPURL.cgi?Dockkey=30001PZV.txt>.
- USEPA 2000. Radiation and Health Effects. www.epa.gov/radiation/radiation-health-effects.
- WHO. 2011. World Health Organization. Guidelines for Drinking Water Quality. Fourth edition incorporating the 1st and 2nd Agenda vol.1 Recommendations; WHO Geneva.