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# Assessment of Annual Effective Dose Associated with Radon in Drinking Water from Gold and Bismuth Mining area of Edu, Kwara, North-central Nigeria

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**ABSTRACT:** The aim of this paper is to assess the radon concentration of surface and ground waters around Bismuth mining site located in Edu, Kwara State, Nigeria, in order to ascertain its radiological risk. Seventeen (17) water samples were collected and analyzed for radon concentration using a calibrated Rad7-Active Electronic Detector Durridge. The Radon concentration for surface water ranged from 16.23±3.45 Bq/l to 24.71±4.51 Bq/l with a mean of 19.14±3.98 Bq/l while that of ground water ranged from 21.59±3.29 to 27.93±5.74 Bq/l with a mean of 24.16±4.21 Bq/l. The concentration results were used to estimate the annual effective doses. The mean total annual effective dose obtained by summing the dose due to inhalation and ingestion for surface water samples were 187.97 $\mu Svy^{-1}$, 257.84 $\mu Svy^{-1}$ and 292.77 $\mu Svy^{-1}$ for adult, children and infants respectively. Also, the mean effective doses for ground water samples were of 237.25 $\mu Svy^{-1}$, 325.44 $\mu Svy^{-1}$ and 369.53 $\mu Svy^{-1}$ for adult, children and infants respectively. Both the radon concentration and the effective dose due to its inhalation and ingestion were higher than the recommended limit of 11.1 Bq/l and 100 $\mu Svy^{-1}$ respectively for all samples. Therefore, consumption of the water in this area poses serious health risk as the water is not safe for all age groups considered. Therefore, it is advised that the water from both sources be treated before consumption.

**Keywords:** Cancer, Radioactivity, Radon, Annual Effective Dose.

## INTRODUCTION

Cancer has been a major health problem in all parts of the world. Lung and Stomach cancer are the most common causes of cancer death with lung cancer causing about 1.8milion death and stomach cancer, 783,000 deaths (WHO, 2018). Cancer is the transformation of normal cells into tumour cells in a multistage process usually progressing from a pre-cancerous lesion to a malignant tumour. This process could be caused either by exposure to known chemical carcinogens (such as smoking tobacco, drinking water contaminant, aflatoxin, etc.), biological carcinogens or by the impact of aging and physical carcinogens (such as ultraviolet and ionizing radiation) (Aunan *et al.*, 2017). Chemical carcinogens are mostly ingested through drinking contaminated water. Contaminants in drinking water includes: heavy metals like arsenic and

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lead; asbestos; radionuclides like radon and uranium; agricultural chemicals; and hazardous waste (Orosun *et al*, 2016a&b, 2018, 2020a and Morris, 1995).

Water is generally known to be a universal solvent and thus it is important to man. Since water is often gotten from natural sources, which includes wells, rivers, etc., significant amount of radionuclides; $^{40}$K, $^{226}$Ra, $^{232}$Th, $^{238}$U, $^{222}$Rn have over time been found traceable in water (Orosun *et al*., 2016a; Darabi *et al*., 2020). The activities of these radionuclides can be heightened by anthropogenic activities like mining of mineral ores (Orosun *et al*., 2019, 2020a, 2020b). This work focuses on Radon, a natural radioactive gas which stems from the decay of $^{238}$U. The Uranium available in the soil gradually breaks down to other radionuclides such as Radium that over time eventually becomes Radon (Keramati *et al.*, 2018; Akinnagbe *et al*., 2018; Jobbagy *et al*., 2017; UNSCEAR, 2000; Jarzemba *et al*., 1989; Ghosh *et al*., 1976). A fraction of the Radium stays at the sub-surface and penetrates the groundwater (Usikalu *et al.*, 2017a). This radon present in either surface or ground waters may find its way into the human body through inhalation (during degassing) or ingestion (drinking of the polluted water). During either process (ingestion or inhalation) this radon disintegrates to its daughter nuclides giving out alpha particles which irradiates the cells of either the lungs or the stomach and causes it to mutate and in an end result, induces cancer.

From previous researches, lung cancer have been linked to Radon, as the leading cause among non-smokers and as the second leading cause among smokers, thus posing a grievous risk to human health (Bello *et al*., 2020; Ruano-Ravina *et al*., 2017). Due to the risk posed by Radon and its progeny to the human health which gets into the body via ingestion or inhalation, the International Agency for Research on Cancer (IARC) and the World Health Organization categorized it as a human lung carcinogenic (WHO, 2018; ICRP 2010). ICRP also suggests that radon survey should be carried out by all countries to discover Radon prone areas.

Since existing research works attributed increase in background radioactivity to anthropogenic activities such as mining (Ademola *et al*., 2014; Aliyu *et al*., 2015; Adagunodo *et al*., 2018; Usikalu *et al.*, 2017b) and research conducted in this part of the country (Orosun *et al*., 2019, 2020a, 2020b and 2020c), reveals significant amounts of $^{238}$U and $^{232}$Th, it is therefore necessary to assess $^{222}$Rn radioactivity level. This study will help to ascertain the radiological safety in utilizing the waters in this area and serve as baseline study since no work on $^{222}$Rn activity concentration had been carried out to the best of our knowledge.

## MATERIALS AND METHODS

The location is a Gold and Bismuth mining site which is based in Edu Local Government Area of Kwara State, Nigeria. Kwara State is situated between latitudes 4$^{\circ}$ 30'E and 5$^{\circ}$30'E and longitude 8$^{\circ}$30'N and 9$^{\circ}$15'N. It has a total land area of about 2,236km$^2$ and a population of 201,469 as of the 2006 census. To the North, Edu is bounded by River Niger. To the West, it is bounded by Ifelodun and Maro and bounded by Pategi to the East. Kwara state is known to be underlain by basement complex rocks represented by phyllites, gneisses, granodiorites, granites, schists and pegmatites (Orosun *et al*., 2016a, 2019, 2020a, 2020b & 2020d). Minerals ores are found to be linked with gneisses and schists in this part of the country (Orosun *et al*., 2020b). Sandtone beds at the contact between the Cretaceous sediments of Nupe Basin and the Basement Complex around Bishewa and Gidan Sani are known to host gold, lead and bismuth amongst other minerals. Evaluation of this resource in panned concentrate of soils and stream sediments around Bishewa, Gidan Sani, Koro and River Wara gave between 4.1g/t - 8.3g/t of gold, however assay of most of the gneisses found proximal to these areas range between 1.1g/t- 4.5g/t. New locations found are Ndanaku, Mari, Oputa , Lokomosi, Tunga Bichi, Gbajubo, Giloadi and Birnin Ruwa still in Edu LGA. Preliminary evaluation and assessment of the resource in Ndanaku and Birnin Ruwa gave gold values averaging 5g/t. This suggests that the area of mineralization is extensive and so is the mining.

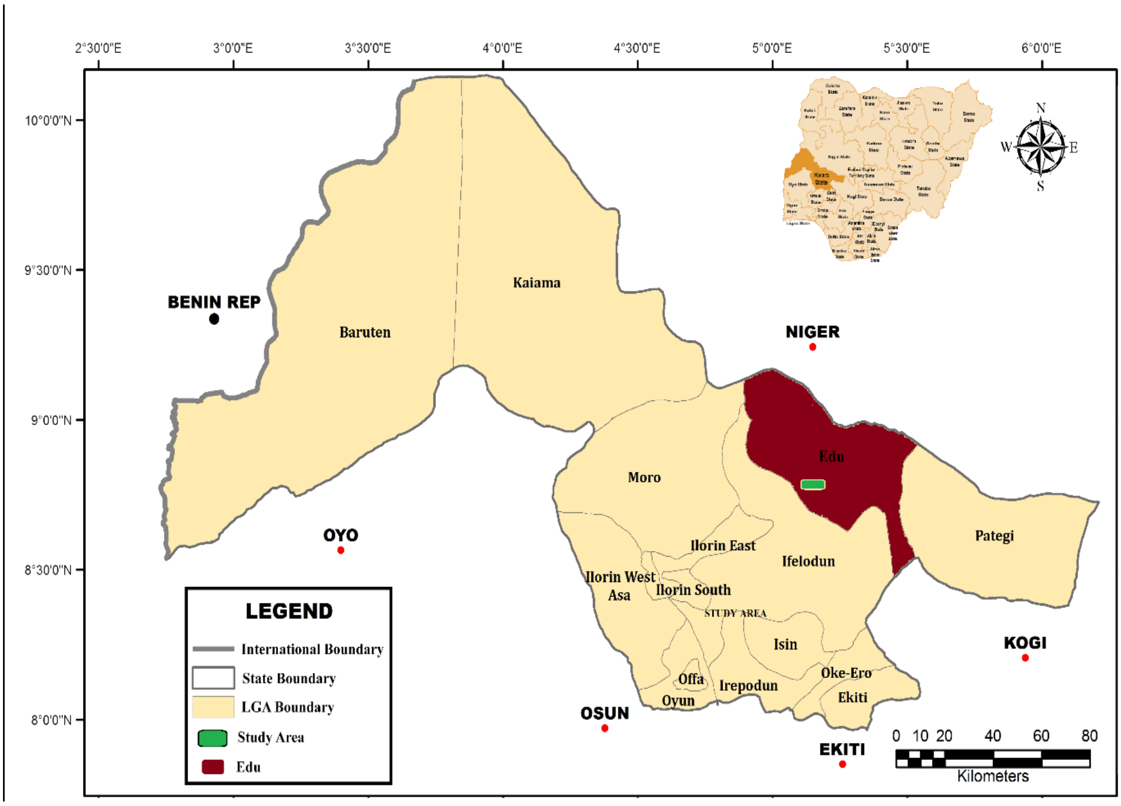


**Fig 1. Map of Kwara State, displaying the study area (Edu Local Government Area)**

Figure 1 above shows the geographical map of the study area (Edu Local Government Area).

A total number of seventeen (17) water samples were collected from Bismuth mining site in Edu, Kwara State, Nigeria and used for the radon analysis. In order to make sure that certain properties of the water to be tested had not been altered by human activities, the samples were collected very early in the morning. It was collected in a 1.51 bottle. The 1.51 bottles rinsed with distilled water are then used to collect the water samples directly from the source. In order to avoid the escape of dissolved radon in the water during water collection, the water samples were collected by dipping the bottle directly inside the fetcher and covering the bottle inside the water as it is being filled to the brim. Without allowing the samples to stay long, they were taken to the lab straightaway for the radon analysis. This was done so as to increase accuracy in the radon analysis and avoid change in the composition of water samples.

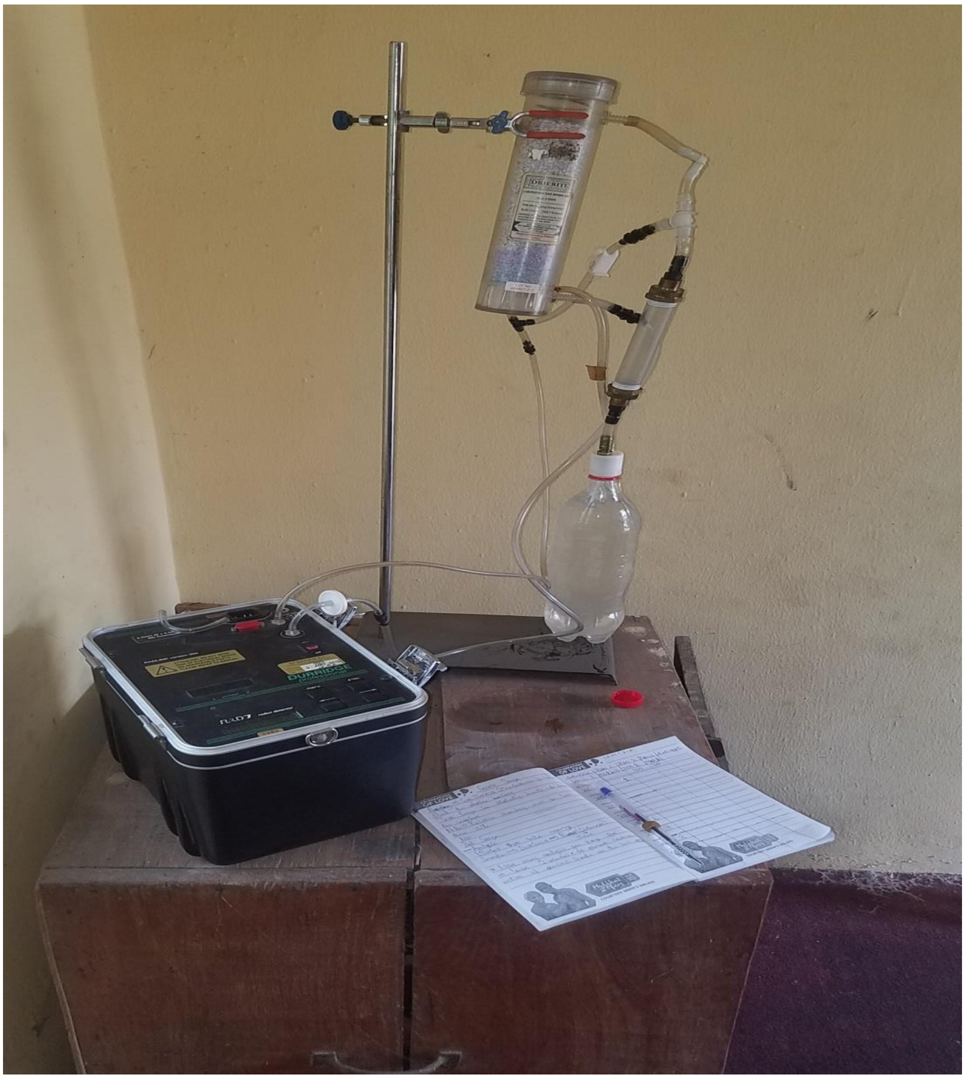

**Fig. 2. A set-up of radon in water measurement with RAD7-Active Electronic Detector**

As shown in figure 2, the water samples obtained from the mining site were analysed using a calibrated RAD7-Active Electronic detector that is linked to a RAD-$H_2O$ attachment Durridge (version 300). This detector was set up for measuring the concentration of radon in samples of water by joining it with effervescing kit that facilitates degassing of the radon from the water samples into the air in a closed loop. A desiccant that dries the air before entering the detector for the measurement of radon is located within the closed loop. The RAD7-Active Electronic detector employs the method of alpha spectrometry. This electronic detector can precisely measure the concentration of radon in a given water sample in about 20 min. This time of measurement is small in comparison to the half-life of radon that is 3.8 days. This therefore makes the Durridge RAD7-Active Electronic detector suitable for the measurement of radon in water.

The device is accompanied with in-built air pump, batteries that are rechargeable and a removable cordless printer. It has an ability of storing huge volumes of radon measurements for printing subsequently or further analysis with Durridge's capture software.

Radiation Dose from Radon in the samples can be received via ingestion or inhalation (Ezzulddin and Mansour, 2017). The inhalation and ingestion of radon in water poses a dangerous health risk by way of irradiation of radiosensitive cells in the human body once it is absorbed into the bloodstreams. Consequently, radon in drinking water could potentially cause other severe radiological health effects besides the lungs cancer that is famous for, thus provoking human attention (Hopke *et al.*, 2000). The Annual Effective Dose (μSv/year) for ingestion ($AED_{ing}$) is estimated using equation 1 (Ezzulddin and Mansour, 2017).

$$AED_{ing} = CRn_w \times C_W \times DCF_{ing} \quad (1)$$

where $AED_{ing}$ implies the Annual effective dose from ingestion (μSv/y); $CRn_w$ is the Radon concentration in drinking water (i.e. the measured concentration of $^{222}Rn$ in the selected samples), $C_w$ equals to (0.6 × 365, 0.8 × 365 and 1.3 × 365) l/y for (infants, children and adult), respectively is the annual water intake and $DCF_{ing}$ is the ingesting dose conversion factor and is equal to ($7\times10^{-8}$, $2\times10^{-8}$, $1\times10^{-8}$) Sv/Bq for infants, children and adults respectively (Ezzulddin and Mansour, 2017; UNSCEAR, 2000).

To calculate the Annual Effective Dose (μSv/year) due to inhalation ($AED_{inh}$), equation 2 was applied (Ezzulddin and Mansour, 2017).

$$AED_{inh} = CRn_w \times Rn_w \times F \times O \times DCF_{inh} \quad (2)$$

where $AED_{inh}$ implies the effective dose from radon inhalation for a year (μSv/y); F = 0.4 is the equilibrium factor between radon and its progeny; $Rn_w = 10^{-4}$ is the fraction of radon in air to the radon in water; O = 7,000 h. $y^{-1}$ is the average indoor occupancy time per individual (the assumed average amount of time an individual spent indoors 7,000 h. $y^{-1}$) and $DCF_{inh}$ is the dose conversion factor for Radon exposure in air (9 $nSvh^{-1}$ ($Bqm^{-3}$)).

The total Annual Effective Dose ($AED_{total}$) derived from both ingested and inhaled dose summation as a result of utilization of the surface and ground waters in this mining area is calculated using equation 3

$$AED_{total} = AED_{ing} + AED_{inh} \quad (3)$$

$AED_{total}$ is the total yearly effective dose (μSv/y)

$AED_{ing}$ implies the yearly effective dose due to the radon ingestion (μSv/y)

$AED_{inh}$ implies the yearly effective dose due to the radon inhalation (μSv/y);

## RESULTS AND DISCUSSION

The results of the $^{222}Rn$ concentration and the effective dose absorbed due to the consumption of ground and surface waters from the Gold and Bismuth mining site located in Edu Local Government Area, Kwara State, Nigeria are shown in Tables 1 and 2, respectively.

The Radon concentration for surface water ranged from 16.23±3.45 Bq/l to 24.71±4.51 Bq/l with a mean of 19.14±3.98 Bq/l and a standard deviation of 3.09 while that of ground water ranged from 21.59±3.29 to 27.93±5.74 Bq/l with a mean of 24.16±4.21 Bq/l and a standard deviation of 2.58. The ground waters show values slightly higher than that of the surface water, which means the concentrations are reduced at the surface and this may be due to high temperature at the surface or the less oxygenated water at the ground. The concentrations in all the samples are above the recommended limit of 11.1 Bq/l (UNSCEAR, 2000; USEPA, 1991) as shown in Figures 3 and 4. This poses serious health risk as a result of consumption of the water for any purpose.

Overall, a comparative analysis of the mean activity concentration values of $^{222}Rn$ in this present study with some studies considered from across the world is given in Table 3. It was realized that these mean activity values obtained in this study compare well with the values reported by most of the authors except Pereira *et al*. (2015) and Przylibski *et al*. (2014) from Portugal and Poland respectively whose mean values are in the range of 3,000 Bq/l.

**Table 1. $^{222}$Rn concentration and annual effective dose in surface water from Gold and Bismuth mining site in Edu LGA, Kwara State, Nigeria**

| Surface Water Code | $^{222}$Rn (Bq/l) | $AED_{Ing}$ ($\mu Svy^{-1}$) | | | $AED_{Inh}$ ($\mu Svy^{-1}$) for all age groups | $AED_{Total}$ ($\mu Svy^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | | Adults | Children | Infants | | Adults | Children | Infants |
| SW1 | 16.23±3.45 | 118.48 | 177.72 | 207.34 | 40.90 | 159.38 | 218.62 | 248.24 |
| SW2 | 19.57±3.88 | 142.86 | 214.29 | 250.01 | 49.32 | 192.18 | 263.61 | 299.32 |
| SW3 | 24.71±4.51 | 180.38 | 270.57 | 315.67 | 62.27 | 242.65 | 332.84 | 377.94 |
| SW4 | 16.94±3.75 | 123.66 | 185.49 | 216.41 | 42.69 | 166.35 | 228.18 | 259.10 |
| SW5 | 16.58±6.11 | 121.03 | 181.55 | 211.81 | 41.78 | 162.82 | 223.33 | 253.59 |
| SW6 | 22.63±2.95 | 165.20 | 247.80 | 289.10 | 57.03 | 222.23 | 304.83 | 346.13 |
| SW7 | 22.34±3.29 | 163.08 | 244.62 | 285.39 | 56.30 | 219.38 | 300.92 | 341.69 |
| SW8 | 16.79±3.71 | 122.57 | 183.85 | 214.49 | 42.31 | 164.88 | 226.16 | 256.80 |
| SW9 | 16.49±4.13 | 120.38 | 180.57 | 210.66 | 41.56 | 161.93 | 222.12 | 252.21 |
| MIN | 16.23±3.45 | 118.48 | 177.72 | 207.34 | 40.90 | 159.38 | 218.62 | 248.24 |
| MAX | 24.71±4.51 | 180.38 | 270.57 | 315.67 | 62.27 | 242.65 | 332.84 | 377.94 |
| MEAN | 19.14±3.98 | 139.74 | 209.61 | 244.54 | 48.23 | 187.97 | 257.84 | 292.77 |
| SKEW | 0.75 | 0.75 | 0.75 | 0.75 | 1.88 | 2.63 | 2.63 | 2.63 |
| SD | 3.09 | 23.94 | 35.91 | 41.89 | 7.79 | 31.73 | 43.70 | 49.68 |
| CV | 6.19 | 45.19 | 67.79 | 79.09 | 15.60 | 60.80 | 83.39 | 94.69 |

**Table 2. $^{222}$Rn concentration and annual effective dose in ground water from Gold and Bismuth mining site in Edu LGA, Kwara State, Nigeria**

| Ground Water | $^{222}$Rn (Bq/l) | $AED_{Ing}$ ($\mu Svy^{-1}$) | | | $AED_{Inh}$ ($\mu Svy^{-1}$) for all age groups | $AED_{Total}$ ($\mu Svy^{-1}$) | | |
|---|---|---|---|---|---|---|---|---|
| | | Adult | Children | Infants | | Adult | Children | Infants |
| GW1 | 22.08±2.95 | 161.18 | 241.78 | 282.07 | 55.64 | 216.83 | 297.42 | 337.71 |
| GW2 | 21.59±3.29 | 157.61 | 236.41 | 275.81 | 54.41 | 212.01 | 290.82 | 330.22 |
| GW3 | 27.93±6.71 | 203.89 | 305.83 | 356.81 | 70.38 | 274.27 | 376.22 | 427.19 |
| GW4 | 22.78±3.43 | 166.29 | 249.44 | 291.01 | 57.41 | 223.70 | 306.85 | 348.42 |
| GW5 | 27.67±5.74 | 201.99 | 302.99 | 353.48 | 69.73 | 271.72 | 372.71 | 423.21 |
| GW6 | 21.98±2.38 | 160.45 | 240.68 | 280.79 | 55.39 | 215.84 | 296.07 | 336.18 |
| GW7 | 25.45±4.82 | 185.79 | 278.68 | 325.12 | 64.13 | 249.92 | 342.81 | 389.26 |
| GW8 | 23.80±4.37 | 173.74 | 260.61 | 304.05 | 59.98 | 233.72 | 320.59 | 364.02 |
| MIN | 21.59±3.29 | 157.61 | 236.41 | 275.81 | 54.41 | 212.01 | 290.82 | 330.22 |
| MAX | 27.93±5.74 | 203.89 | 305.83 | 356.81 | 70.38 | 274.27 | 376.22 | 427.19 |
| MEAN | 24.16±4.21 | 176.37 | 264.55 | 308.64 | 60.88 | 237.25 | 325.44 | 369.53 |
| SKEW | 0.68 | 0.68 | 0.68 | 0.68 | 1.71 | 2.39 | 2.39 | 2.39 |
| SD | 2.58 | 18.70 | 28.04 | 32.72 | 6.49 | 25.19 | 34.53 | 39.21 |
| CV | 9.38 | 68.44 | 102.66 | 119.77 | 23.63 | 92.06 | 126.28 | 143.39 |

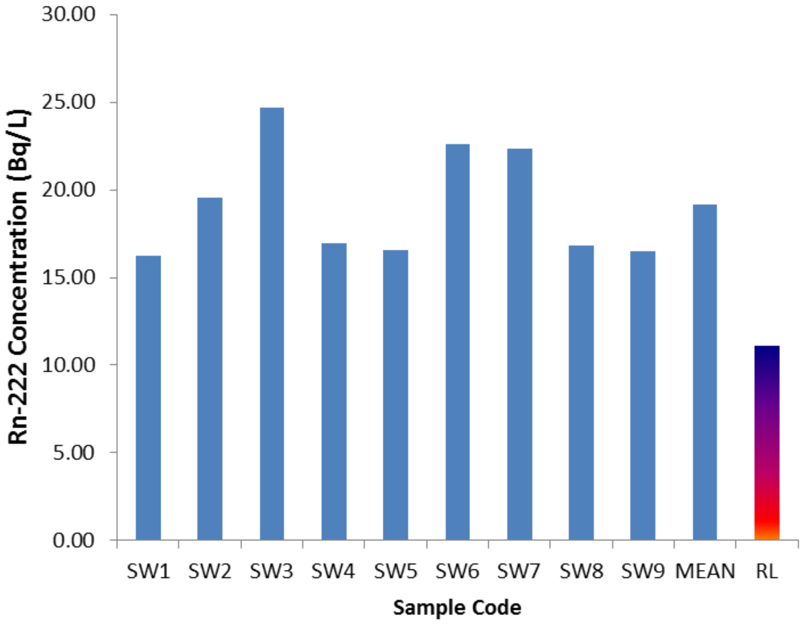


**Fig. 3. Radon Concentrations of selected water samples collected from the surface (streams). RL is the recommended limit**

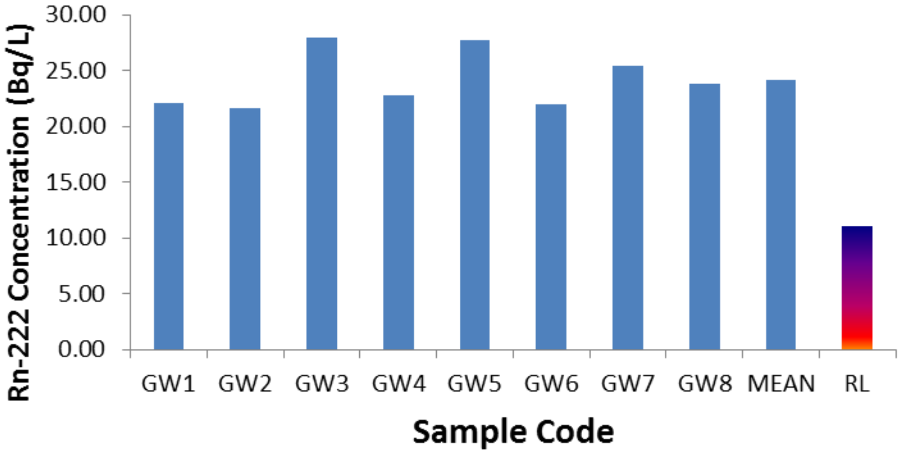


**Fig. 4. Radon Concentrations of selected water samples collected from the ground (well waters). RL is the recommended limit**

**Table 3. Comparison of Radon activity concentration with literature values.**

| Location | Water source | Radon activity concentration (Bq/l) | References |
|---|---|---|---|
| Zarand, Iran | Borehole water | 11.36 ± 3.1 | Darabi *et al*., 2020 |
| Rig Abad, Abdol Abad, Bahabad, Bab Tangal Taj abad, Motahar Abad, Iran | Well | 13.8 ± 3.5 | Darabi *et al*., 2020 |
| Kerman, Iran | Well | 15.62 | Asadi *et al.*, 2016 |
| Zaria, Nigeria | Groundwater | 7.41 ± 2.04 | Garba *et al*., 2012 |
| Ijero, Nigeria | Groundwater | 0.168 - 78.509 | Akinnagbe *et al*., 2018 |
| Minab City, Iran | Tap water | 0.46±0.04 | Fakhri *et al*., 2016b |
| Bandar Abbas City, Iran | Drinking water | 0.87–0.384 | Fakhri *et al*., 2016a |
| Norway | Well water | 10–300 | ISO, 2013 |
| Nisa, Portugal | Groundwater | 17–3856 | Pereira *et al*., 2015 |
| Slovenia | Surface water | <1 | ISO, 2013 |
| Shanono, Nigeria | Drinking water | 3.176–49.932 | Bello *et al*., 2020 |
| Sudety Mountains, Poland | Groundwater | 3043 | Przylibski *et al*., 2014 |
| La Garrotxa, Spain | Groundwater | 1–1000 | ISO, 2013 |

The result of the annual effective doses from inhalation and ingestion of $^{222}$Rn in both surface and ground waters by adults, children and infants is presented in Tables 1 and 2, respectively. For ingestion, the annual effective dose for surface water ranged from 118.48 to 180.38 μSvy$^{-1}$ with an average value of 139.74 μSvy$^{-1}$, 177.72 to 270.57 μSvy$^{-1}$ with an average value of 209.61 μSvy$^{-1}$ and 207.34 to 315.67 μSvy$^{-1}$ with an average value of 244.54 μSvy$^{-1}$ for adults, children and infants respectively. While that of ground water ranged from 157.61 to 203.89 μSvy$^{-1}$ with an average value of 176.37 μSvy$^{-1}$, 236.41 to 305.83 μSvy$^{-1}$ with an average value of 264.55 μSvy$^{-1}$ and 275.81 to 356.81 μSvy$^{-1}$ with an average value of 308.64 μSvy$^{-1}$ for adults, children and infants respectively. In addition, the annual effective dose due to inhalation of $^{222}$Rn for both surface and ground water ranged from 40.90 to 62.27 μSvy$^{-1}$ with an average value of 48.23 μSvy$^{-1}$ and 54.41 to 70.38 μSvy$^{-1}$ with an average value of 60.88 μSvy$^{-1}$, respectively.

The total annual effective dose from the combination of $AED_{ing}$ and $AED_{inh}$ ranged from 159.38 to 242.65 μSvy$^{-1}$ with an average value of 187.97 μSvy$^{-1}$, 218.62 to 332.84 μSvy$^{-1}$ with an average value of 257.84 μSvy$^{-1}$ and 248.24 to 377.94 μSvy$^{-1}$ with an average value of 292.77 μSvy$^{-1}$ for adult, children and infants respectively for the surface water. Consequently, for ground water samples, it ranged from 212.01 to 274.27 μSvy$^{-1}$ with an average value of 237.25 μSvy$^{-1}$, 290.82 to 376.22 μSvy$^{-1}$ with an average value of 325.44 μSvy$^{-1}$ and 330.22 to 427.19 μSvy$^{-1}$ with an average value of 369.53 μSvy$^{-1}$ for adult, children and infants respectively.

The dose conversion factor (DCF) used for infants was high as result of high sensitivity their developing organs have to radiation. Though their water consumption (0.5 Litres per day) was low, their effective doses were still much higher due to the high DCF compared to that of the children and that of the adults which has the least. Irrespective of the water source, the values of the computed effective doses for all age groups were found to be higher than the acceptable limits of 100μSvy$^{-1}$ (WHO, 2004) and therefore poses serious radiological hazard.

## CONCLUSION

This study was conducted to assess the radon concentration of surface and ground water from a Gold and Bismuth mining site located in Edu LGA, Kwara State, Nigeria in order to ascertain its radiological risk. The mean values obtained for both surface and ground waters in the area were 19.14±3.98 Bq/l and 24.16±4.21 Bq/l, repectively. The mean total annual effective dose obtained by summing the dose due to ingestion and inhalation for surface water samples were 187.97 μSvy$^{-1}$, 257.84 μSvy$^{-1}$ and 292.77 μSvy$^{-1}$ for adult, children and infants respectively. Consequently, the mean for ground water samples were of 237.25 μSvy$^{-1}$, 325.44 μSvy$^{-1}$ and 369.53 μSvy$^{-1}$ for adult, children and infants respectively. Both the radon concentration and the effective dose due to its ingestion and inhalation were higher than the recommended limit of 11.1 Bq/l (UNSCEAR, 2000; USEPA, 1991) and 100 μSvy$^{-1}$ (WHO, 2004), respectively for all samples. This poses serious health risk as the water is not safe for consumption for all age groups considered. Therefore, it is advised that the water from both sources be treated before consumption.

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## CONFLICT OF INTEREST

The authors declare that there is not any conflict of interests regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/ or falsification, double publication and/or submission and redundancy has been completely observed by the authors.

## LIFE SCIENCE REPORTING

No life science threat was practiced in this research.

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