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# Radiation Doses and Risk Assessment Due to Water Intake at Oyo Town, Southwestern Nigeria

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**ABSTRACT**
From the long standing nature of water usage, water has been has had a significant impact to all great development. Potable water has been recognized as the water intended for human consumption for the purpose of research and other human activities. Therefore, the World Health Organization (WHO) classified $^{230}$Th, $^{226}$Ra, $^{210}$Pb, $^{210}$Po, $^{232}$Th, $^{228}$Ra, $^{40}$ K and $^{228}$Th as naturally occurring radionuclide contaminants in water and a possible threat to human existence. This work evaluated the activity concentration of natural radionuclide in ground water, examine radiation doses and the threat due to water intake from Oyo town using a 5 cm × 5 cm solid NaI(Tl) gamma-ray spectrometric manufactured by ORTEC and coupled to a Digital-based multi-channel analyzer (MCA). From the results, 92.5 per percent of $^{40}$K, 87.5 per cent of $^{226}$Ra and 95 of $^{232}$Th was greater than the IAEA safe limit of 1.00 Bql$^{-1}$limit. The average value of an annual effective dose for adults was 0.17±0.06 mSvy$^{-1}$ and 0.43±0.17 mSvy$^{-1}$ for children. Cancer risk assessment was obtained to 2.98 x 10$^{-3}$ compared to ICRP recommended value of 8.4 × 10$^{-3}$. Health risk implication resulting from consumption of water from the study area poses no health concern, no artificial radionuclide was detected and the chance of cancer occurrence resulting from drinking water from the study area is stochastic. It is recommended that caution should be taken on the fertilizer application on the farm land. Further research is recommended on the radioactivity measure of the soil and food crops grown in the study area.

**Keywords:**
Water,
Cancer risk,
Radionuclide,
Oyo town,
Nigeria

## INTRODUCTION

Life on earth will be impossible and linked with challenges and difficulties without adequate supply of water. From the time immemorial, water has been a key factor to all great civilization, the absence of water is called drought and the consequence of drought is famine. Water in the context of the paper is the water intended for human consumption (drinking, cooking, food preparation or other domestic purposes) (Sveva and Serena 2015). According to Li, *et al.*, (2021) radionuclide contamination in water is a global concern due to its hazardous nature and the resulting health impact on living organism and the ecosystem. The World Health Organization (WHO, 2011) classified $^{230}$Th, $^{226}$Ra, $^{210}$Pb, $^{210}$Po, $^{232}$Th, $^{228}$Ra, $^{40}$ K and $^{228}$Th as naturally occurring radionuclide in water. Also, united Nation Scientific Committee on the Effect of Atomic Radiation (UNSCEAR, 2018) noted that human activities such exploration of crude oil, building construction, mining process, nuclear medical diagnostic, industrial discharge can also result into artificial contaminations of water. Geological formation, structure of the aquifer and the source of water (ground water and surface water) influence the concentration of natural radionuclide in water. Out of numerous sources of ionizing radiation to humans, radiation doses from naturally occurring radionuclide is the greatest because radionuclide, such as uranium, thorium, and radon, are abundant in the Earth's crust which is the main sources of water, and as a result, it is a threat to human health and of greater concern (WHO, 2011).

In 2021, UNICEF reported that only 56 per cent of Nigerians suffers from inadequate availability of safe water. Only a few wealthy Nigerians who can afford to sink deep wells and boreholes drink clean and safe water. Nigeria has abundance of water resources aside from annual rainfall; ground and surface water are available in Nigeria streams and rivers. Unfortunately, these sources of water are threatened by pollution, refuse dump, lack of proper water management system by government and industrialization. Akanbi *et al.*, 2022 studied Hydro geochemical of shallow groundwater of Oyo Town, and observed larger percentage of inhabitants relying on groundwater from hand-dug wells having depths ranging between 6.6 and 26.5 m. Israel et al., 2023 indicated that about 71.6% of households around Oyo-Ogbomosho towns sourced their water from borehole while pipe borne water could only be accessed by 1.7% of humans. Access to potable water was also reported: 68.0% of the households had potable water available within 400m distance and 18.0% could cover a distance of 1.4km before getting potable water for use. The town hosts tertiary institutions in addition to a federal government girls' college. The inhabitants consist of civil servants, farmers, artisans and students. From history, Erelu water works has been relied upon by the residents to supply water for the increasing population of the town. Literature abounds on water quality assessment in Nigeria but a very view focus on radionuclide contamination of ground water, particularly from Oyo town. The current study measured the activity concentration of natural radionuclide in ground water, assessed radiation doses and risk due to ingestion of water from Oyo, Southwestern Nigeria.

**The study Area**

Oyo town is located in the North of Ibadan at 7º 50`-7º57`N and 03º 54`-03º 57'E as coordinates (Ufoegbune et al., 2011). Oyo town is bounded by the states of Kwara on the north, Osun on the east, and Ogun on the south and by the Republic of Benin on the west. The climate is tropical with two distinct seasons of wet and rainy season. The period of rainfall is between March and October and the dry season is from November to March. The annual rainfall ranges between 1200-1600mm while temperatures are relatively high (20 - 36ºC) with a mean value about 26ºC. In terms of geological formations, the study area lies within the Pre-Cambrian Basement Complex of Southwestern Nigeria which in turn is part of the Pan African mobile belt lying east of the West African Craton. The major rock unit in the study area include quartzite and quartz schist, migmatised undifferentiated biotite hornblende-gneiss, undifferentiated gneiss complex, hornblende-biotite granite gneiss, and biotite garnet schist/gneiss.

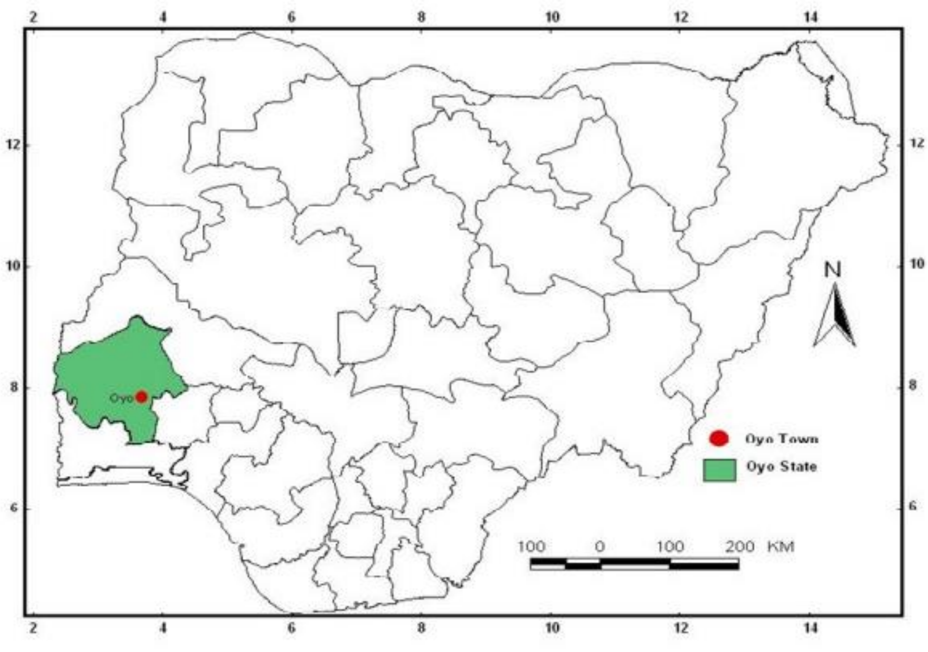


Figure 1: Map of Nigeria showing Oyo State and Oyo town

**Sample Collection and Preparation**

A total of forty (40) water samples were randomly collected at different locations within Oyo town. At each sampling point, the pH meter (model: 8803 Schwerzenbach) manufactured by Mettler Toledo Group in Switzerland and the centigrade thermometer were respectively used to measure the pH and temperature of the samples immediately after collection. The pH value of each sample was taken after dipping the pH probe in the water sample for a few minutes to obtain a steady reading. 500 ml each of the samples were poured into Marinelli plastic containers after rinsing with dilute tetraoxosulphate (VI) acid ($H_2SO_4$) and dried to avoid contamination of the water (Mahmoud *et al.*, 2014). The plastic containers were thereafter firmly sealed for four weeks to ensure a state of secular equilibrium between

$^{226}$Ra and $^{228}$Ra and their respective gaseous progenies before gamma spectroscopy.

**Determination of activity concentrations**

After keeping the samples for 4 weeks to attain secular equilibrium, a 5 cm × 5 cm solid NaI(Tl) gamma-ray spectrometric manufactured by ORTEC and coupled to a Digital-based multi-channel analyzer (MCA) was used to count the activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th. The detector has a poor energy resolution of about 8% at energy of 0.662 MeV. This is considered adequate to distinguish the gamma energies of interest in the study. In addition, the photons emitted by the samples would sufficiently be discriminated if the emission probability and energy were high enough and the surrounding background continuum was low enough. However, the activity concentration of $^{214}$Bi determined from its 1.76 MeV gamma ray peak was chosen to provide an estimate of $^{226}$Ra in the rock samples, while that of the daughter radionuclide $^{208}$Tl determined from its 2.61 MeV gamma ray peak was chosen as an indicator of $^{232}$Th. The activity concentration of $^{40}$K was determined from 1.46 MeV Gamma rays emitted during the decay of $^{40}$K. The standard reference sample used for efficiency calibration was from Rocketdyne Laboratories California, USA, traceable to a mixed standard gamma source (Ref No 48722-356) by Analytic Inc., Atlanta, GA, USA.

Each sample was placed on top of the well-shielded and housed detector and counted for 36,000 seconds (10h). The data acquisition, display and on-line spectrum analysis were carried out using the Genie 2000 spectroscopy software from Canberra. Equation (1) shows the usual relationship between activity concentration (Bq/kg) and the count rate under the photo peak of a given gamma-ray spectrometry detector as expressed by Alausa *et al.* (2020)

$$A_c = \frac{N_c}{\varepsilon_p I_\gamma V} \quad (1)$$

where $A_c$ is the sample's activity concentration (Bq/kg), $N_c$ is the net area under the corresponding peak per second, $\varepsilon_p$ is the detector efficiency at the specific γ-ray energy, $I_\gamma$ is the absolute transition probability of the specific gamma-ray and $V$ is the volume of the water sample in cubic meter. An empty container of the same geometry as the sample container was counted for the same time to take care of the background radiation count and determination of the radionuclide detection limits. The detection limits (DLs) which describe the operating capability of the detector without the influence of any sample were determined using Kitto et al. (2006) model. The detection limits (DLs) obtained in the present study was 0.12, 0.14 and 0.40 Bqkg$^{-1}$ for $^{40}$K, $^{226}$Ra and $^{232}$Th respectively. The activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th less than the corresponding values of the DLs are referred to as below the detection limit (BDL). One half of each DL is considered for calculating the mean activity concentrations of the radionuclide and the radiological parameters (Alausa and Odusote, 2013)

**Effective Dose due to Ingestion of Water**

Effective dose is used in radiation protection to show the potential biological effects associated with exposure to ionizing radiations in human beings (Kaur and Mehra, 2022). A range value of 0.3– 1.0 mSv per annum was recommended for public members in case of prolonged exposure to natural radionuclides (ICRP, 1999). Effective doses due to ingestion of water was calculated using equation as stated by UNSCEAR, (2000)

$$E_d = A_c A_i C_f \quad (2)$$

where $E_d$ the effective dose (mSvy$^{-1}$), $A_c$ is the activity concentration (Bql$^{-1}$), Ai is the consumption rate of water (l/year). According to (W.H.O, 2003), the dose was estimated by considering a consumption rate is 730 litter/year for adults and 350 litter/year for children. The dose conversion factors Cf were ($2.8\times10^{-7}$, $2.3\times10^{-7}$, $6.2\times10^{-9}$ for adults) and ($1.5\times10^{-6}$, $2.5\times10^{-7}$, $7.6\times10^{-9}$Sv Bq$^{-1}$for children) for $^{226}$Ra, $^{232}$Th and $^{40}$K, respectively (ICRP, 1996; W.H.O, 2011).

**Lifetime Cancer Risk Assessment (R)**

Lifetime cancer risk assessment (R) was calculated using EPA, (1999):

$$R = D_a x\, D_i x\, R_f \quad (3)$$

where $D_a$ is annual effective dose equivalent measured in Svy$^{-1}$, $D_i$ is the duration of life (55.2 years for Nigerians) and $R_f$ is the risk factor (Sv$^{-1}$). According to ICRP (1996), the risk assessment probability coefficient is $7.3 \times 10^{-2}$ Sv$^{-1}$.

## RESULTS AND DISCUSSION

**Activity concentration**

Table 1 presents the activity concentrations of $^{40}$K, $^{226}$Ra and $^{232}$Th radionuclide in the water sample from Oyo town. The premise to which the interpretation of results in the present study is based on the safe limit recommendations and regulations of Uranium/Radium concentration ratios in drinking water by notable health and environmental protection agencies. However, the activity concentration of $^{40}$K ranged from 0.16±0.01 to 37.95±2.58Bql$^{-1}$ and $^{226}$Ra in the water: 0.14±0.03 to 13.74±2.60 Bql$^{-1}$; $^{232}$Th 0.91±0.08 to 39.22±0.33 Bql$^{-1}$ with an average of 11.49, 5.13 Bql$^{-1}$ and 4.08 Bql$^{-1}$ for K, Ra and Th respectively. Radionuclide distribution revealed

$^{232}$Th (39.22 Bql$^{-1}$) > $^{40}$K (37.95±2.58 Bql$^{-1}$) >$^{226}$Ra (13.74±2.60 Bql$^{-1}$) signifying the abundances of $^{232}$Th species (Figure 2). In 2014, the International Atomic

Energy Agency (IAEA, 2014) recommended 1.00 $Bql^{-1}$limit of activity concentration of $^{40}K$, $^{226}Ra$, and $^{232}Th$ in drinking water. From the results 92.5% of $^{40}K$; 87.5% of $^{226}Ra$ and 95% of $^{232}Th$ were greater than the safe limit; specifying $^{232}Th$ as the most dangerous species (Figure 3). Meanwhile, there is no any huge difference in the concentration of the three radionuclide found in the water samples, it may be evident from this that the geological formation of the study area is uniform. Furthermore, higher percentage of the concentration than the safe limit may be due to farming activities which may involve the use of fertilizers and other environmental factors, including weathering, erosion, and deposition. Similar studies in some cities with high proximity to the study area obtained 64.86, 7.21 and 7.71 $Bql^{-1}$ for $^{40}K$, $^{226}Ra$, and $^{232}Th$ in water from Asa-Dam at Ilorin, Nigeria (Orosun et *al.*, 2020); these values were lower than the values derived from the present study. Awodugba and Tchokossa (2008) also reported 3.98, 17.73 and 11.00 $Bql^{-1}$ for $^{40}K$, $^{226}Ra$, and $^{232}Th$, these values are clearly below what was obtained in the present study.

**Table 1: Activity concentrations of $^{40}K$, $^{226}Ra$ and $^{232}Th$ in the water from Oyo Town**

| S/N | Sample code | $^{40}K(Bql^{-1})$ | $^{238}U(Bql^{-1})$ | $^{232}Th(Bql^{-1})$ |
|---|---|---|---|---|
| 1 | A | 10.32±0.79 | 0.91±0.02 | 3.51±0.31 |
| 2 | A | 2.17±0.18 | 0.14±0.03 | 3.44±0.30 |
| 3 | A | 3.07±0.23 | 4.5±0.92 | 6.23±0.53 |
| 4 | A | 15.5±1.15 | 0.85±0.18 | 3.64±0.14 |
| 5 | A | 4.11±0.31 | 2.29±0.52 | 1.62±0.12 |
| 6 | A | 7.95±0.61 | 3.45±0.71 | 2.98±0.25 |
| 7 | A | 0.16±0.01 | 5.91±1.34 | 2.37±0.21 |
| 8 | A | 12.8±0.98 | 6.87±1.62 | 2.41±0.21 |
| 9 | A | 9.85±0.73 | BDL | 2.12±0.19 |
| 10 | A | 9.32±0.71 | 8.3±1.64 | 2.01±0.17 |
| 11 | A | 6.41±0.52 | 1.52±0.32 | 6.81±0.54 |
| 12 | A | 4.31±0.36 | 4.05±0.92 | 7.79±0.65 |
| 13 | A | 18.85±1.37 | 12.64±2.47 | 2.17±0.18 |
| 14 | A | 5.48±0.48 | 2.86±0.62 | 4.04±0.35 |
| 15 | A | 17.6±1.29 | 2.34±0.64 | 3.88±0.33 |
| 16 | A | 4.78±0.41 | 0.19±0.04 | 0.91±0.08 |
| 17 | A | 3.67±0.29 | 1.91±0.44 | 1.91±0.17 |
| 18 | A | 21.12±1.64 | 2.52±0.61 | 1.9±0.17 |
| 19 | A | 34.32±2.28 | 11.12±2.22 | 3.19±0.28 |
| 20 | A | 8.32±0.62 | 2.82±0.61 | 1.22±0.11 |
| 21 | A | 15.87±1.28 | 9.11±1.98 | 3.15±0.28 |
| 22 | A | 17.87±1.28 | 9.13±1.97 | 3.17±0.22 |
| 23 | A | 13.16±1.00 | 9.39±2.17 | 4.10±0.36 |
| 24 | A | 37.95±2.58 | BDL | 1.66±0.14 |
| 25 | A | 2.20±0.17 | 0.76±0.18 | BDL |
| 26 | A | 35.31±2.24 | 10.3±2.13 | 2.39±0.21 |
| 27 | A | 4.88±0.36 | 6.01±1.31 | 5.47±0.49 |
| 28 | A | 20.24±1.49 | 7.58±1.67 | 1.73±0.15 |
| 29 | A | 4.18±0.34 | 10.11±2.02 | 4.22±0.35 |
| 30 | A | 5.88±0.48 | 3.82±0.85 | 39.22±0.33 |
| 31 | A | 24.83±1.85 | 8.02±1.68 | 3.39±0.29 |
| 32 | A | 13.59±1.05 | 13.74±2.60 | 1.912±0.16 |
| 33 | A | 18.54±1.36 | 4.53±1.11 | 3.11±0.28 |
| 34 | A | 1.77±0.15 | 8.87±1.68 | 3.30±0.29 |
| 35 | A | 6.54±0.32 | 3.34±0.67 | 2.24±0.22 |
| 36 | A | 3.58±0.31 | BDL | 4.22±0.38 |
| 37 | A | 19.78±0.07 | 6.77±1.38 | 1.71±0.16 |
| 38 | A | BDL | BDL | 3.53±0.31 |
| 39 | A | 1.1±0.94 | BDL | 5.79±0.42 |
| 40 | A | 12.56±0.35 | 10.11±2.03 | 4.26±0.38 |

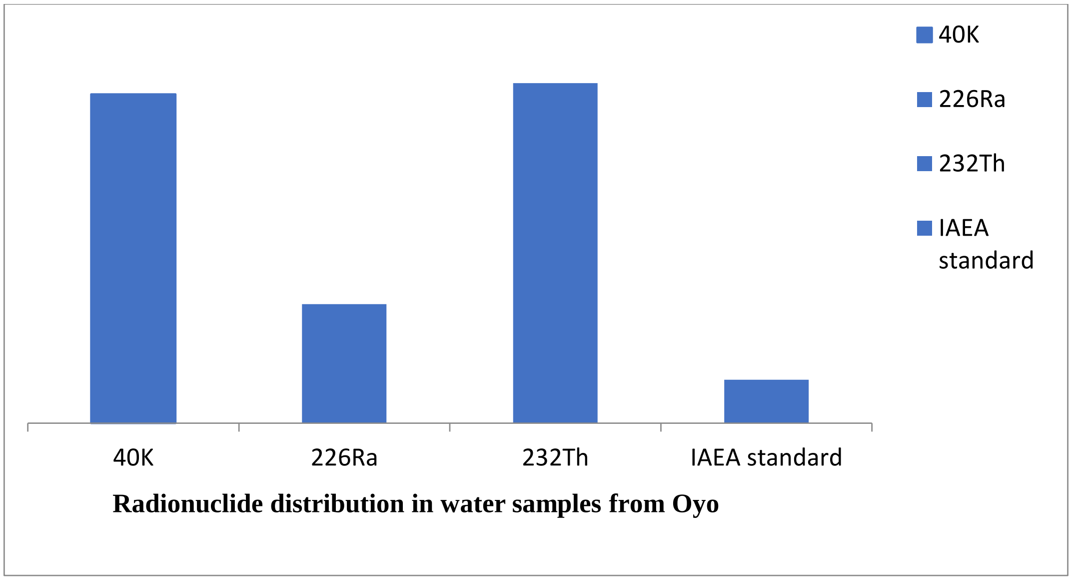


Figure 2: Radionuclide distribution revealing the abundances of $^{232}$Th species

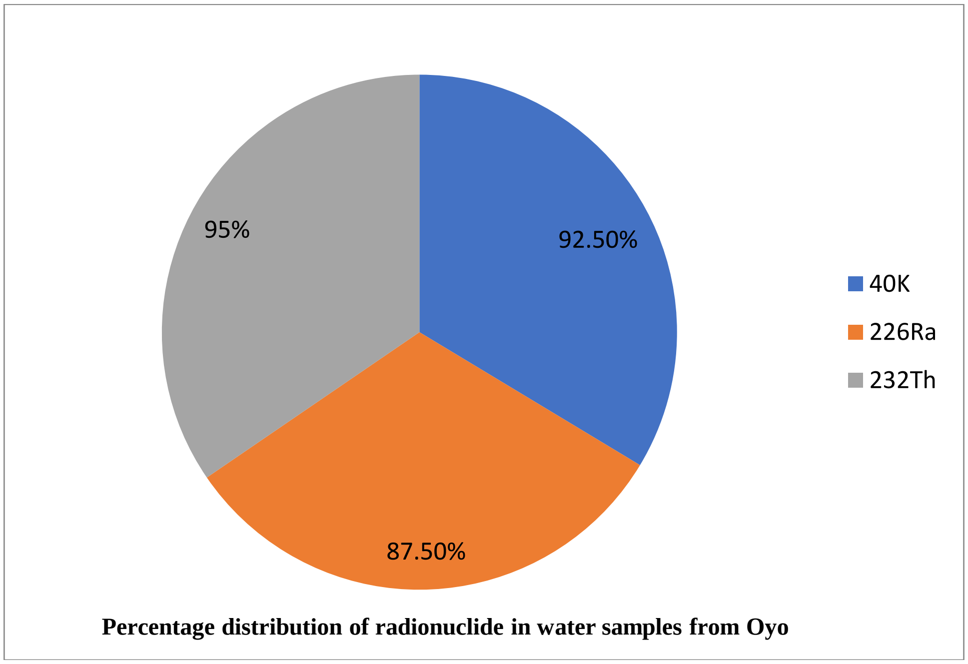


Figure 3: Percentage of distribution of Radionuclide in the study area

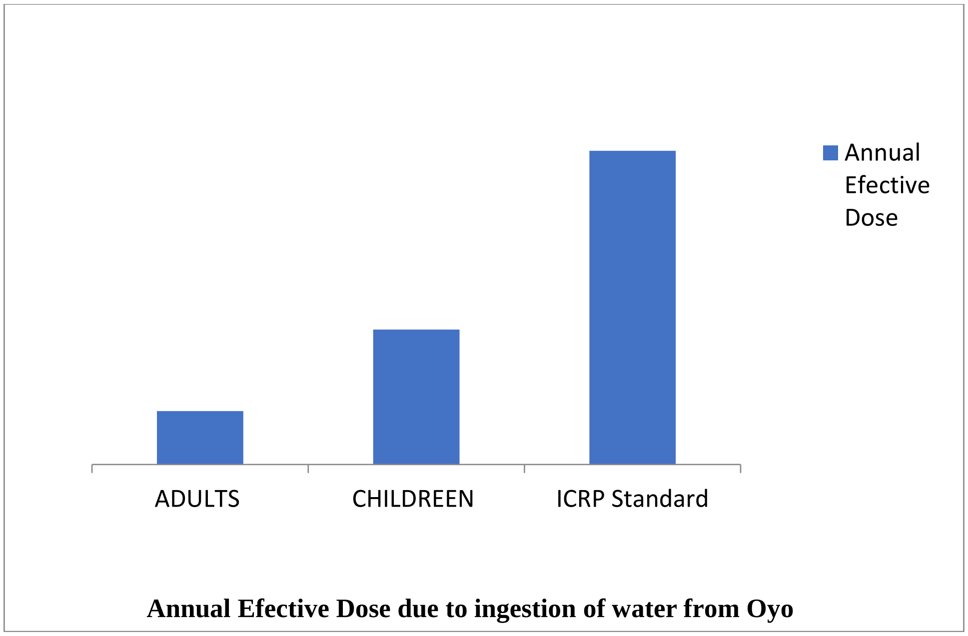


Figure 4: The annual effective dose for water in the study area

**Annual effective dose due to ingestion of water from the study area**

Table 2 shows the values of total effective doses due to primordial radionuclide ($^{40}K$, $^{226}Ra$, and $^{232}Th$). Two age groups, children and adults water consumption were considered for calculating the total effective doses. The annual effective dose ranged from 0.02 to 0.74 mSvy $^{-1}$ for adults and 0.23 to 10.80 mSvy$^{-1}$ for children. However, the mean value of an annual effective dose for adults is 0.17±0.06 mSvy$^{-1}$ and that for children is 0.43±0.17 mSvy$^{-1}$. As recommended by the ICRP, an effective dose limit of 1 millisievert (mSv) per year for the general public and 20 mSv per year (Figure 4). However, the results of the present study were compared with the recommended values of ICRP-1.0 mSvy$^{-1}$ and WHO-0.20 mSvy$^{-1}$ for both adults and children the world health organization (WHO, 2006) recommends 0.20 mSvy$^{-1}$ for children. The mean annual effective dose result for both adults and children in the present study are lower than the WHO standard value (Figure 3).

**Table 2: Effective doses (mSvy$^{-1)}$ and lifetime cancer risks due to ingestion of water**

| S/N | Annual Effective Dose(Adult) | Anuual effective Dose (Children) | Excess Life Cancer Risk(10x $^{-3}$) |
|---|---|---|---|
| 1 | 0.08 | 1.15 | 0.33 |
| 2 | 0.06 | 0.55 | 0.25 |
| 3 | 0.20 | 4.25 | 0.80 |
| 4 | 0.09 | 1.12 | 0.34 |
| 5 | 0.08 | 1.97 | 0.31 |
| 6 | 0.12 | 3.03 | 0.50 |
| 7 | 0.16 | 4.84 | 0.65 |
| 8 | 0.19 | 5.59 | 0.75 |
| 9 | 0.04 | 0.28 | 0.16 |
| 10 | 0.21 | 6.64 | 0.84 |
| 11 | 0.15 | 2.04 | 0.60 |
| 12 | 0.22 | 4.11 | 0.87 |
| 13 | 0.30 | 9.99 | 1.22 |
| 14 | 0.13 | 2.72 | 0.52 |
| 15 | 0.12 | 2.30 | 0.49 |
| 16 | 0.02 | 0.26 | 0.09 |
| 17 | 0.07 | 1.71 | 0.29 |
| 18 | 0.09 | 2.19 | 0.37 |
| 19 | 0.30 | 8.96 | 1.19 |

| | | | |
|---|---|---|---|
| 20 | 0.08 | 2.33 | 0.33 |
| 21 | 0.25 | 7.41 | 0.99 |
| 22 | 0.25 | 7.42 | 1.00 |
| 23 | 0.27 | 7.74 | 1.07 |
| 24 | 0.05 | 0.23 | 0.18 |
| 25 | 0.02 | 0.59 | 0.07 |
| 26 | 0.27 | 8.23 | 1.07 |
| 27 | 0.22 | 5.32 | 0.87 |
| 28 | 0.19 | 6.05 | 0.78 |
| 29 | 0.28 | 8.31 | 1.13 |
| 30 | 0.74 | 7.96 | 2.98 |
| 31 | 0.23 | 6.60 | 0.94 |
| 32 | 0.32 | 10.80 | 1.29 |
| 33 | 0.15 | 3.88 | 0.62 |
| 34 | 0.24 | 7.24 | 0.96 |
| 35 | 0.11 | 2.85 | 0.44 |
| 36 | 0.07 | 0.55 | 0.29 |
| 37 | 0.18 | 5.43 | 0.71 |
| 38 | 0.06 | 0.46 | 0.24 |
| 39 | 0.10 | 0.75 | 0.39 |
| 40 | 0.28 | 8.31 | 1.14 |

**Lifetime Cancer Risk Assessment (R)**

The results of the lifetime cancer risk are presented Table 2. From the table, the results of lifetime cancer risk obtained in the present study. The least value is 0.07 x $10^{-3}$ and the highest is 2.98 x $10^{-3}$. This values are low when compared with the world recommendation of 8.4 × $10^{-3}$ (UNSCEAR 2016) corresponding to 2.4 mSvy$^{-1}$ (Figure 5). Akba and Vali, (2020) reported an average excess lifetime cancer risk (ELCR) of 1.37 × $10^{-3}$ in food around Tehran Province of Iran, the present study has a value slight higher the what was obtained in Iran (Akba and Vali, 2020)There is no potential risk to human health due to ingestion of water from the study area. This is because drinking water for ground or surface sources is considered safe due to low concentration levels of radionuclide in the samples analyzed.

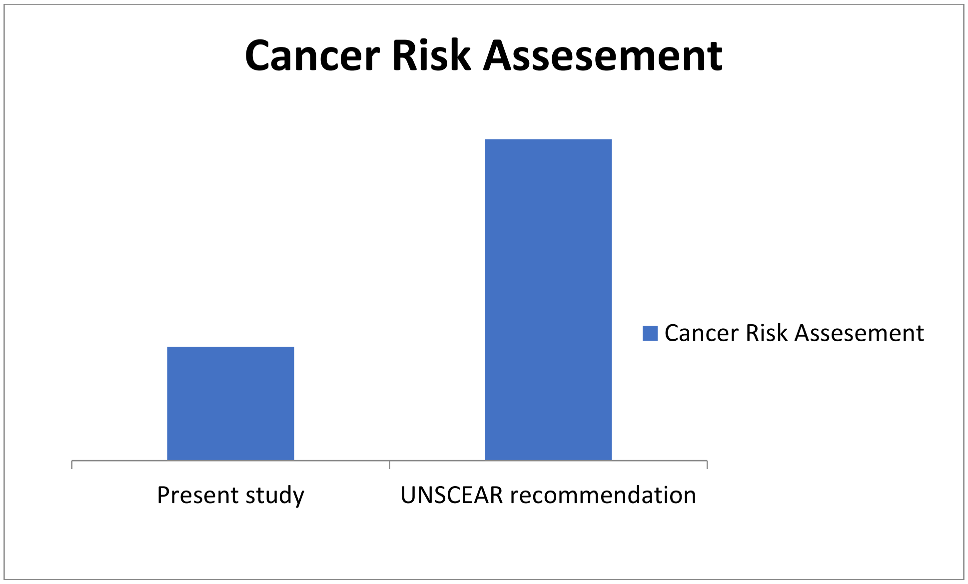


Figure 5: Lifetime cancer risk Assessment for water in the study area

## CONCLUSION

The result of the activity concentrations of $^{40}K$, $^{226}Ra$, and $^{232}Th$ have been presented vis-a vis the effective doses and cancer risks that may results from inhalation of water from Oyo town in Nigeria. Two age groups, children and adults water consumption were considered for analysis in the present study. Our analysis showed that more than 80 percent of the water samples contain activity concentration of $^{40}K$, $^{226}Ra$, and $^{232}Th$ higher than the IAEA recommended safe limit, furthermore, the results of annual effective dose in the present study were compared with the recommended values of 1.0 mSvy$^{-1}$ for adults and 0.20 mSvy$^{-1}$ for children as recommended by the world health organization (W.H.O, 2006). The mean annual effective dose for adults in the present study lower than the WHO recommended value, while in contrary, the values for children are higher than the WHO recommended value. Cancer risk assessment from consumption of water from the study area indicated no risk as the values were significantly lower than the world recommendation of $8.4 \times 10^{-3}$ corresponding to 2.4 mSvy$^{-1}$. Despite having concentration of $^{40}K$, $^{226}Ra$, and $^{232}Th$ slightly higher than the recommended value, health risk implication resulting from consumption of water is no serious concern, since no artificial radionuclide was detected, cancer occurrence is stochastic and no serious human activity (industrialization) except farming is prevalent in the study area. It is therefore recommended that caution should be taken on the fertilizer application to the farm land. Further research is recommended on the radioactivity measure of the soil and food crops grown in the study area.

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