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Natural Radionuclides And Potential Radiological Hazard Associated with Consumption of Water, *Oreochromis niloticus* and *Chrysichthys nigrodigitatus* from Ero Dam, Ekiti, Nigeria

Margaret Bose Adedokun[1*], Olusola Olurotimi Oyebola[1], Zaccheaus Ayo Ibitoye[2], Jamiu Adelakin Akinade[1]

1. Department of Physics, Faculty of Science, University of Lagos, Akoka, Lagos, Nigeria
2. Department of Radiation Biology, Radiotherapy and Radiodiagnosis, College of Medicine, University of Lagos, Idi-Araba, Lagos, Nigeria

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ABSTRACT

Introduction: This study aims to evaluate the potential radiological hazard associated with the consumption of water and fish products from Ero Dam.

Material and Methods: The activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the samples were determined using gamma ray spectrometry.

Results: Mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water were 8.49±1.38, 4.12±0.40 and 150.99±10.80 Bq/l respectively. In *Oreochromis niloticus and Chrysichthys nigrodigitatu*s mean specific activity were 23.17±7.25, 14.25±1.60, 740.86±55.00 Bq/kg and 77.92±18.79, 16.26±1.63, 842.90±62.87 Bq/kg respectively. Average annual effective dose for water (H_w) was 1.58 mSv/yr and for fish edible tissue (H_f) 0.16 mSv/yr. Mean concentrations of ^{232}Th and ^{40}K in water are 312% and 1400% higher than guidance levels and mean specific activity for ^{238}U and ^{232}Th in fish were about three orders of magnitude higher than reference values. Mean H_w is about 1500% higher than the reference level and the average H_f for fish is 540% higher than the recommended H_f for natural radionuclides in fish products. Mean ELCR from consumption of water, Oreochromis and Chrysichthys are 1900%, 62% and 131% higher than the world's average value from carcinogens respectively.

Conclusion: Continuous consumption of water and fish products from Ero Dam is associated with potential radiation risks.

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Introduction

Humans are constantly exposed to radiation from cosmic rays from the sun and from naturally occurring radioactive materials (NORM) found in the rocks, soil, air, food, and water [1,2]. Some human activities can elevate the concentrations of NORMs in different media resulting in increase in radiation exposure and in some cases above recommended safe levels, posing health risks to the public [3 – 5]. Excessive or continuous exposure to ionizing radiation may cause several health effects such as skin and tissue damage. The main health effect of exposure to low radiation level such as radiation from ingesting contaminated food or water is an increase in the chance of developing cancer [6].

Regular radiological monitoring of the levels of human exposure to ionizing radiation therefore plays an essential role in environmental and public health risks assessment. Such assessments help in determining the possible impact the level of exposure has on public health and the natural environment.

Radionuclides can contaminate surface water bodies such as dams through handling or disposal of wastes [7]. Deposit of radionuclides into water bodies contaminates water directly and causes accumulation in sediments and aquatic organisms. Aquatic organisms may take up radionuclides directly from water, sediment, and their food chain. Internal irradiation of fishes takes place as they take up radionuclides from different sources and accumulate them in their muscles [8]. Fishes are rich in protein and serve as an essential part of human diet and water is for life. However, consumption of water and fish from a NORM contaminated aquatic environment may increase internal exposure to radiation.

Ero-dam is an essential component of Ekiti State. Since commissioned in 1985, the dam has been serving as a significant source of water for many

*Corresponding Author: Tel: +23476319472; Email: magdokun@gmail.com; madedokun@unilag.edu.ng

villages and towns around the State [9]. The dam also acts as a source of water for irrigation farming, fishing, and tourist attraction [10].

Ero-dam has since gained the interest of scientists who have studied different aspects of the dam.

Studies ranged from, spatial distribution of Ero-dam water in its catchment [10], post-construction structural integrity test [9], distribution of some heavy metals in some materials from the dam [11], suitability of the surface water in Ero and Ele reservoirs for irrigation [12]. Population of *Tilapia zillii* collected from the waterworks in Ado-Ekiti, Egbe-Ekiti and Ero reservoirs condition factor and dietary composition of a fish species in Ero-dam have also been studied [13,14].

Although drinking water and eating of food rarely result in obvious radiation effect, several severe radiation risks can result from accumulation of radiation via ingestion. This research is therefore aimed at determining the levels of ^{238}U, ^{232}Th and ^{40}K in the water and two commonly consumed species of fish from Ero-dam and the evaluation of the possible radiological hazard linked with the consumption of these materials to the people of Ekiti.

Materials and Methods

Study location

Figure 1. Map of Ero-dam adapted from Omoniyi and Basorun[10]. This figure shows the study location, Ero-dam in Ikun-Ekiti, Ekiti State, Nigeria. Ero-dam is situated at a latitude of 7^0 35'N and longitude of 5^0 31'E covering a distance of about 11km [11].

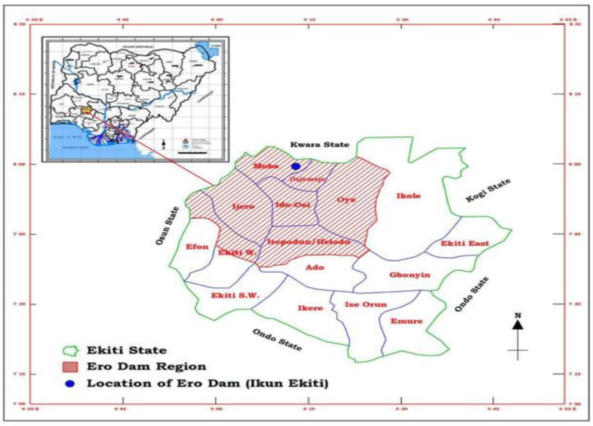

Figure 1. Map of Ero Dam adapted [10].

Sample collection and preparation

Water

Water samples were collected randomly from 15 different parts of the dam to have a good representation of the body of water. One litre polyethylene bottles were used for water sample collection. Prior to water sample collection, the sampling bottles were pre-washed with distilled water and thoroughly dried. Specific Method for collection and preparation of water samples have been discussed in detail elsewhere[15].

Fish

The two most common types of fish in Ero-dam namely *Oreochromis niloticus* and *Chrysichthys nigrodigitatus* were selected for this study. At the dam, *Oreochromis* and *Chrysichthys* (commonly called Tilapia and Silver catfish respectively) were collected at five different points where fishermen usually harvest these fishes. The fishes were collected by artisanal fishing boats with the help of fishermen. At each point, about three kilograms fresh weight of each of the two species were collected, giving a total of five groups for each species. Each fish was briefly washed with distilled water to remove any dirt on it. The fish samples were labelled according to their species and the points of collection (1-5). They were kept in an ice box and transported to the laboratory.

At the laboratory, fish samples were oven dried at an average temperature of 80 ^{0}C for about 48 hours. To estimate the internal exposure from the consumption of these fishes, only the edible portion of the fish samples were of interest (edible fish tissue) [16]. The head, skin, bone, gills, and internal organs were first separated from the fish tissue before a homogenized tissue samples were prepared for radioactivity measurement. In order to obtain sufficient amount of the edible parts of the samples for gamma spectroscopy, samples from the same sampling point were pooled together [17]. The samples were pulverized using laboratory mortar and pestle and passed through a 1 mm mesh sieve to facilitate homogenization. The sieved samples were weighed using the Ohaus-CS series portable digital scale of model number CS5000 (72212665) and an average of 136 g and 153 g of the pulverized *Oreochromis* and *Chrysichthys* respectively, were placed into in 350 ml polyethylene sampling bottle sealed and stored.

After laboratory preparations, prior to gamma spectrometry analysis, water and fish samples were hermetically sealed and stored for at least for 30 days to achieve secular equilibrium between ^{238}U, ^{232}Th and their progenies [15].

Gamma spectrometer and radioactivity analysis

The radioactivity analysis of water and the fish samples were performed at the National Institute of Radiation Protection and Research, University of Ibadan, Nigeria using gamma ray spectrometry. The detector used was a lead shielded NaI (Tl) crystal detector of model No. 802-series. The detector consisted of a NaI (Tl) of dimension 76 mm by 76 mm, which is incorporated to a Canberra Multichannel Analyzer (MCA) (model number 2007P) by a pre-amplifier base. The detector operated at a voltage of 600 V and the full-width-half-maximum (FWHM) resolution of ^{137}Cs at peak of 662keV is 7.5%. Energy and efficiency calibrations is important for gamma detectors, calibrations of the detector used were performed according to the procedure of document 385 of International Atomic Energy Agency (IAEA) [18].

Minimum Detectable Activity $(MDA) = \frac{4.653*\sigma_B+2.706}{t*\varepsilon(E)*P_{\gamma(E)}*M(kg)}$ (1)

where σ_B t, $\varepsilon(E)$, $P_{\gamma(E)}$ and m are the standard deviation of the background, the counting time, absolute efficiency at photon energy E, emission probability at peak energy E and mass of sample (for water sample, volume(l) replaces mass(kg) respectively.

To determine the specific activity or activity concentration of each sample, the count rate of each sample was determined by placing each sample holder in the detector and samples counted for 25200s (7h). To obtain the net count rate of each sample at each energy peak, the background radioactivity level of the laboratory was determined as described in [15]. The background counts were subtracted from the values obtained after counting for 25200 s (7h) and Model S501 GENIE 2000 software was deployed to peruse each spectrum. For fish samples, geometry correction of the detector was included to correct for the 350 ml polyethylene sampling beaker used. The concentrations of the gamma peak considered to determine the count rate of ^{238}U, ^{232}Th and ^{40}K were ^{214}Bi through the 1764.5 keV gamma peak, ^{208}Tl through the gamma peak of 2614.7 keV and ^{40}K directly through its 1460.8 keV gamma peak of energy respectively.

Calculation

Activity concentrations of ^{238}U, ^{232}Th and ^{40}K in samples

For each water sample, the activity concentrations of ^{238}U,^{232}Th and ^{40}K in water were obtained using equation 2[15].

$$A\left(\frac{Bq}{l}\right) = \frac{C}{\varepsilon*t*v*\rho_\gamma} \quad (2)$$

$$A\left(\frac{Bq}{kg}\right) = \frac{C}{\varepsilon*t*m*\rho_\gamma} \quad (3)$$

The specific activity of ^{238}U,^{232}Th and ^{40}K in water and fish samples were obtained using equations 2 and 3 respectively where A is activity concentration in Bq/l for water and in Bq/kg for fish sample. C is the net count for the sample in the peak energy range, ε is the detector energy dependent efficiency, t is the counting lifetime measured in second, ρ_γ is the gamma-ray yield per disintegration of the radionuclides, v is the volume of water in litre and m is the mass of the fish sample in kilogram.

Annual effective ingestion dose (H)

The annual effective dose for an adult from the ingestion of ^{238}U, ^{232}Th, and ^{40}K in drinking water and water were estimated using equation 4 [19]and 5 [20] respectively.

$$H_w(Sv/yr) = \sum_i^n (A_i * DCF_i) * I_w \quad (4)$$

$$H_f(Sv/yr) = \sum_i^n (A_i * DCF_i) * I_f \quad (5)$$

where H_w, H_f are the annual effective dose from drinking water and fish respectively, A_i is activity concentration of radionuclide i, DCF_i is the dose conversion coefficient for ingestion of radionuclide i, given as 4.4 * 10^{-8}, 2.2 x 10^{-7} and 6.2 * 10^{-9} Sv/Bq for ^{238}U, ^{232}Th and ^{40}K respectively[21,22], I_w is the annual ingested volume of water (730 litres/year from the average consumption rate of two litres per day) for an adult. I_f is the fish consumption rate per capita in Kg/yr 15 kg as in UNSCEAR[23].

Excess lifetime cancer risks (ELCR)

Excess lifetime cancer risk is a parameter to estimate the potential carcinogenic effects from exposure to radionuclides through ingestion of water and sampled fish. ELCR was calculated using equation 6[24].

$$ELCR = H * FCRF * DL \quad (6)$$

where H, is annual effective ingestion dose (H_w, H_f), DL is duration of life (70 years) and FCRF is the fatal cancer risk factor which is 0.05 per Sievert for the public.

Results

Minimum detectable activity of detector

The minimum activity concentrations of the samples measured by the detector were calculated by equation 1 and presented in Table 1.

Table 1. Minimum detectable activity of detector

Radionuclide	Water (Bq/l)	Sediments (Bq/kg)	Fish (Bq/kg)
^{238}U	0.022	0.022	0.022
^{232}Th	0.020	0.020	0.020
^{40}K	0.080	0.080	0.080

Table 2. Activity concentration (Bq/l) of ^{238}U, ^{232}Th and ^{40}K in Water samples

Sample ID	^{238}U	^{232}Th	^{40}K
W1	19.01±4.16	4.79±0.47	151.56± 10.86
W2	BDL	3.89±0.38	188.00±13.00
W3	3.47±0.76	3.86±0.38	157.54±11.29
W4	BDL	5.20±0.51	113.25±8.12
W5	2.27±0.51	2.81±0.27	229.86±16.47
W6	19.38±4.24	4.94±0.48	121.38±8.72
W7	BDL	4.48±0.44	133.43±9.58
W8	4.87±1.27	3.97±0.38	220.15±15.77
W9	11.56±2.54	2.91±0.29	146.42±10.53
W10	1.15±0.26	3.84±0.37	119.89±8.59
W11	3.31±0.73	4.63±0.45	126.52±9.06
W12	0.75±0.16	3.21±0.31	131.15±9.31
W13	BDL	4.15±0.40	83.72±6.01
W14	11.05±2.42	4.70±0.46	161.84±11.65
W15	16.62±3.61	4.42±0.43	180.10±13.00
Mean	8.49±1.38	4.12±0.40	150.99±10.80
Guidance level	10.00	1.00	10 .00

*BDL- below detectable limit

Activity concentration of ^{238}U, ^{232}Th and ^{40}K in water and fish samples.

Table 2 presents the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in the water samples collected from the dam. All water sample had detectable ^{232}Th and ^{40}K while only 73.33% had detectable ^{238}U. The activity concentrations of ^{238}U ranged from below detectable limit (BLD) to 19.38 Bq/l, ^{232}Th ranged from 2.81±0.27 to 5.20±0.51 Bq/l and ^{40}K ranged from 83.72±6.01 to 229.86±16.47 Bq/l. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K (excluding BLD) were 8.49±1.38, 4.12±0.40 and 150.99±10.80 Bq/l respectively.

Table 3 presents the specific activity of ^{238}U, ^{232}Th and ^{40}K in *Oreochromis* and *Chrysichthys* collected from Ero-dam. ^{238}U, ^{232}Th and ^{40}K were detected in all the samples. For *Oreochromis*, the specific activity of ^{238}U ranged from 5.83 ±1.54 to 45.42±19.27 Bq/kg, ^{232}Th ranged from 6.16 ±0.6 to 20.95± 2.09 Bq/kg and ^{40}K ranged from 299.10± 21.44 to 1342.44 ±99.54 Bq/kg. The mean specific activity of ^{238}U, ^{232}Th and ^{40}K in *Oreochromis* were 23.17±7.25, 14.25±1.60 and 740.86±55.00 Bq/kg respectively.

For *Chrysichthys*, the specific activity of ^{238}U ranged from 4.91±1.30 to 147.62 ±34.62 Bq/kg, ^{232}Th ranged from 14.72±1.47 to 18.30±1.83 Bq/kg and ^{40}K ranged from 305.24 ±22.91 to 1161.16 ±86.14 Bq/kg. The mean specific activity of ^{238}U, ^{232}Th and ^{40}K in *Chrysichthys* were 77.92±18.79, 16.26±1.63 and 842.90±62.87 Bq/kg respectively.

Table 3. Specific Activity (Bq/kg) of ^{238}U, ^{232}Th and ^{40}K in Fish samples

Sample ID	^{238}U	^{232}Th	^{40}K	Sample ID	^{238}U	^{232}Th	^{40}K
ORN 1	32.07 ±7.84	20.95± 2.09	1342.44 ±99.54	CHN 1	4.91±1.30	18.30± 1.83	948.12 ±70.86
ORN 2	5.83 ±1.54	19.04 ±1.90	583.7± 43.73	CHN 2	73.04 ±19.52	17.65± 1.77	305.24 ±22.91
ORN 3	15.04± 3.81	14.85 ±1.48	456.62± 34.08	CHN 3	29.31 ±7.47	14.72±1.47	762.17 ±57.18
ORN 4	17.49 ±3.81	6.16 ±0.60	299.10± 21.44	CHN 4	134.73 ±31.06	14.97 ±1.50	1037.82 ±77.27
ORN 5	45.42±19.27	19.27 ±1.93	1022.87± 76.19	CHN 5	147.62 ±34.62	15.65 ±1.57	1161.16 ±86.14
Mean	23.17±7.25	14.25±1.60	740.86±55.00	Mean	77.92±18.79	16.26±1.63	842.90±62.87

ORN: Oreochromis
CHN: Chrysichthys

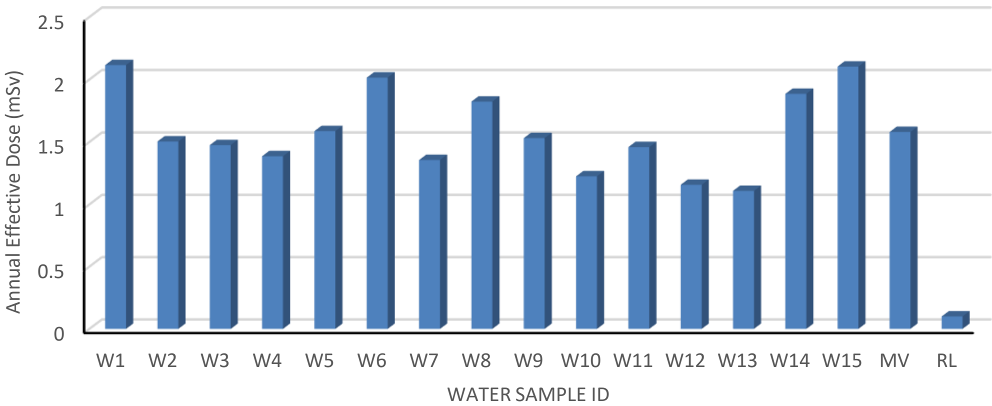

Figure 2. Annual Effective Dose from Ingestion of Water (Hw)

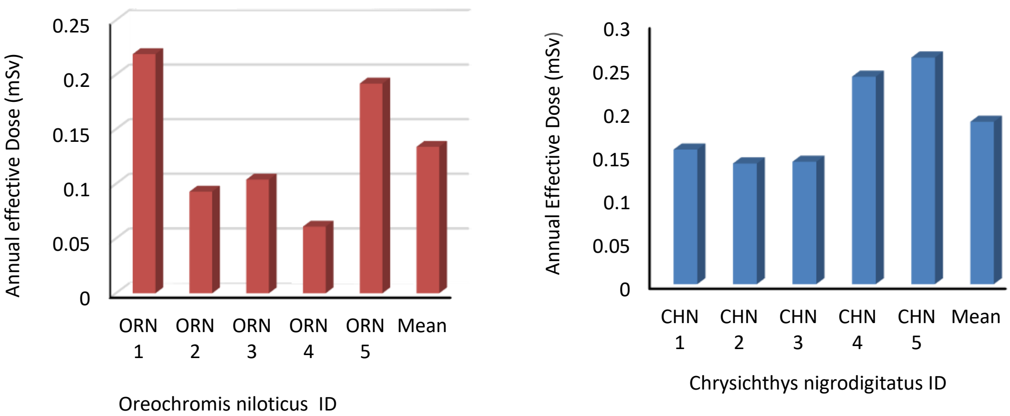

Figure 3. Annual Effective Ingestion Dose (Hf) from Oreochromis and Chrysichthys

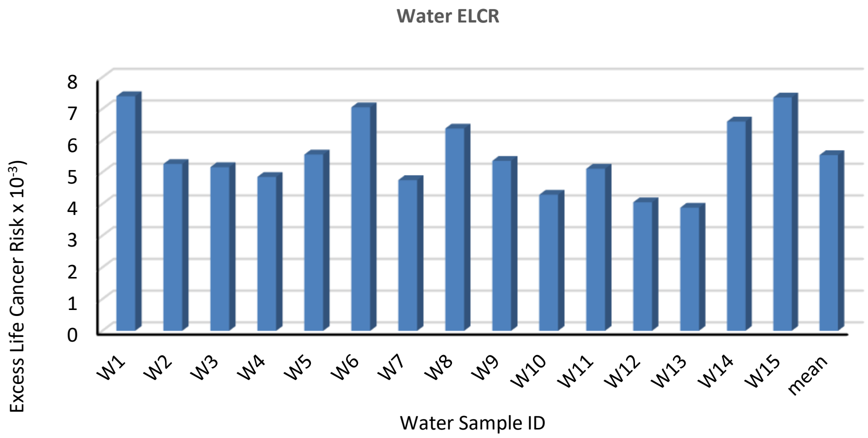

Figure 4. ELCR from ingestion of sampled Water

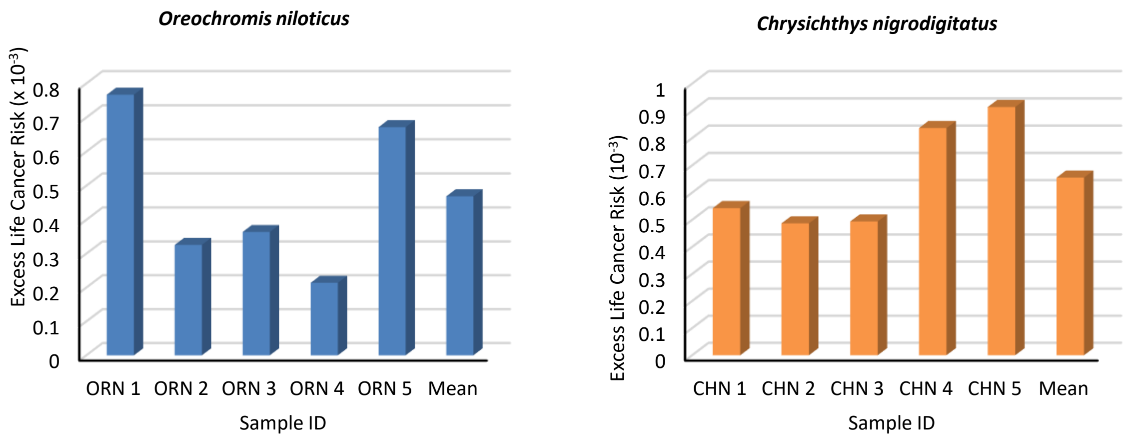

Figure 5. ELCR from ingestion of Oreochromis and Chrysichthys

Annual effective dose from ingestion of water and fish from Ero dam

The level of radiation exposure from the consumption of water from Ero-dam is presented in figure 2. H_w ranged from 1.50 to 2.12 mSv/yr with a mean value of 1.58 mSv/yr.

H_f from the ingestion of fish from the dam is presented in figure 3. H_f for *Oreochromis* ranged from 0.06 to 0.22 mSv/yr with an average of 0.13 mSv/yr. H_f from the ingestion of *Chrysichthys* ranged from 0.14 to 0.26 mSv/yr with an average value of 0.19 mSv/yr. The overall average H_f from the consumption of any of the common species of fish from Ero-dam is 0.16 mSv/yr.

Excess Life Cancer Risk (ELCR)

Figures 4 and 5 present the excess life cancer risk (ELCR) from ingestion of water and fish from Ero-dam. ELCR from ingestion of water, ranged from 3.88 x 10^{-3} to 7.40 x 10^{-3} with a mean of 5.54 x$10^{-3.}$ ELCR from ingestion of *Oreochromis* ranged from 0.21 x10^{-3} to 0.78 x10^{-3} with a mean of 0.47 x10^{-3} and ELCR from ingestion of *Chrysichthys* was from 0.49 x10^{-3} to 0.91 x10^{-3} with a mean of 0.67 x10^{-3}.

Discussion

From Table 2, the mean activity concentration of ^{238}U in water is about 15% lower than WHO guidance level but 45% of the samples with detectable ^{238}U had activity concentrations higher than the WHO guidance level of 10 Bq/l[22] in water for members of the public. The mean activity concentration of ^{238}U is about three orders of magnitude higher than UNSCEAR reference level of 1.00 mBq/l[25] for ^{238}U in drinking water.

For ^{232}Th, all sample had activity concentration higher than the WHO guidance level of 1 Bq/l[22] for members of the public. The mean activity concentration of ^{232}Th is about 312% higher than the WHO guidance level and about four orders of magnitude higher than UNSCEAR reference level of 0.05 mBq/l for ^{232}Th in drinking water[25].

The activity concentrations of ^{40}K in sampled water were exceptionally high, as the value in all samples were about 10 times higher than the WHO guidance level of 10 Bq/l for ^{40}K in drinking water[26,27] and the mean activity concentration is about 14 times more than the WHO guidance level.

Table 3 suggests that *Chrysichthys* accumulates more ^{238}U and ^{40}K while *Oreochromis* accumulates more ^{232}Th. This could be because of their different physiological conditions or their feeding habits. The overall mean specific activity of ^{238}U, ^{232}Th, and ^{40}K for both surveyed species were 50.55±3.02, 15.26±1.61 and 791.88±58.93 Bq/kg respectively. The activity for ^{238}U and ^{232}Th are about three orders of magnitude higher than their UNSCEAR's respective reference values of 30 mBq/kg and 10 mBq/kg for ^{238}U and ^{232}Th series in fish products[23].

Table 4. Comparison of the activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water with similar studies

Country	^{238}U(Bq/l)	^{232}Th (Bq/l)	^{40}K (Bq/l)	Reference
Ghana	0.14±0.04	0.46±0.06	0.60±0.06	[28]
Yemen	NA	1.20	18.34	[29]
Bangladesh	1.49±0.93	0.94±0.48	NA	[30]
Egypt	1.67 ±0.69	0.08±0.22	13.69±0.77	[31]
Saudi Arabia	NA	0.43	2.84	[27]
Egypt	NA	0.08±0.00	0.688	[32]
Malaysia	NA	0.17 ± 0.09	7.67 ± 3.07	[33]
Lagos, Nigeria	NA	0.33±0.09	2.92±1.35	[15]
Iraq	3.16±0.69	3.00±0.38	65.34±2.61	[34]
Iraq	NA	68.678	447.058	[35]
Ekiti, Nigeria	8.49±1.38	4.12±0.40	150.99±10.80	current study

*NA= Not Assessed

Table 4 compares results of the activity concentrations of ^{238}U, ^{232}Th, and ^{40}K from studied water with results from similar studies in literature. Some studies evaluated the activity concentrations of ^{226}Ra, hence not applicable (NA) for ^{238}U. The mean activity concentration of ^{238}U in this study was higher than those reported in all the countries considered. The closest [34]to result of the current study was only about 37.22% of the result from this study. The mean activity concentration for ^{232}Th and ^{40}K in water of the current study were also higher than the results reported by all other study considered except the results reported by [35].

Although there are not much industrial activities directly around the dam, mining and quarries activities take place in Ijero and Oye [36,37]which are regions close to the dam. Radionuclides from contaminated industrial wastewater can travel far and find their way into the dam through surface run off. The source of the elevated concentrations of ^{238}U, ^{232}Th and ^{40}K in the dam could therefore be attributed to contaminated wastewater from Ijero and Oye. The use of fertilizer by irrigation farmers around the dam which can be transported into the open dam through surface run off can also be the source of elevated levels of radionuclides in the dam water.

The high activity concentrations of ^{238}U and ^{232}Th and ^{40}K in the water of Ero dam is an indicator to elevated internal radiation dose. Although the high level of the concentration ^{40}K may not be of great concern as ^{40}K is regulated naturally in the body, ^{238}U and ^{232}Th and their progenies are major contributors to internal dose.

The specific activities of ^{238}U, ^{232}Th and ^{40}K in fish samples from the dam was compared to results of fish products in literature (Table 5). Some studies reported for ^{226}Ra, ^{232}Th and ^{40}K but not ^{238}U[38,39]. For the overall specific activity of ^{238}U, ^{232}Th and ^{40}K from both studied species, activity of ^{238}U was lower than the result of [40] but higher than the result of [41], activity of ^{232}Th was lower than those reported by [38,40] but higher than the results of [39 − 41], activity of ^{40}K was higher than the results of [38,39,41] but lower than the result of [40]. The overall average specific activity of ^{238}U, ^{232}Th and ^{40}K in fish samples from Ero-dam are within the range reported in literature. The variation in the levels of radionuclides from different studies on different species of fish, further suggests that different fish species have different rate of accumulation of different radionuclides.

Comparing results of the same species as studied, mean specific activities of ^{238}U and ^{40}K in *Chrysichthys* from current study are higher than the results of [41] while [40,41] reported higher levels of ^{232}Th for *Chrysichthys*. Ademola and Ehiedu[40] reported lower specific activity of ^{40}K but higher specific activity of ^{232}Th for *Oreochromis*. Variation in activity of radionuclides in the same species of fish, shows that level of radionuclides depends on the environment they are harvested.

Table 5. Comparison of the specific activity of ^{238}U, ^{232}Th and ^{40}K in fish samples with literature.

Location	Common Name	238U	232Th	40K	Reference
Ondo	Tilapia	-	52.4±28.70	462.00± 80.00	[38]
	Silver catfish	-	32.10±5.30	723.00±39.60	
Iraq	Fish	-	3.23±0.44	101.52±19.06	[39]
Port Harcourt	Croaker	74.75± 2.55	10.43± 4.5	2305.84± 5.61	[40]
Lagos	Croaker	54.42± 2.29	299.33± 22.28	1767.19± 4.91	
Ibadan, Nigeria	Farm Catfish	3.36	4.36	619.00	[41]
	Wild Catfish	3.31	4.70	683.00	
Ekiti	Tilapia (Oreochromis)	23.17±7.25	14.25±1.60	740.86±55.00	Current study
	Silver catfish (Chrysichthys)	77.92±18.79	16.26±1.63	842.90±62.87	
Overall mean	Fish	50.55±3.02	15.26±1.61	791.88±58.93	

From figure 2, the average value of H_w from consuming water from the dam is about 15 times higher than the WHO reference level of 0.10 mSv from ingestion of water[42]. The mean H_w from current study is about 58% above 1 mSv/yr the typical annual individual doses from ingestion of radionuclides of natural origin from all sources[25] and the threshold above which there is a need to assess for remedial measures [42]. While water represents only 6% of total diet, the average yearly radiation dose from ingestion of water from the dam is about five times the total yearly radiation dose of 0.3 mSv/yr typically received by people due to radionuclides of natural origin in all diet[23].

Table 6. Comparison of Annual Effective Dose from Ingestion of Water with literature

Country	Hw (µSv/yr)	Reference
Ghana Adentan	113.01	[19]
Abokobi	76.57	
Saudi Arabia	58.00	[27]
Ghana	3.58	[28]
Egypt	58.00	[32]
Malaysia	9.61	[33]
Iraq	269.00	[34]
Iraq	15.71	[35]
Nigeria	1580.00	[43]
Iran	160 - 33720	[44]
Iraq	252.00	[45]
Nigeria	1580.00	current study

Table 6 presents the comparison of from Ero-dam with results of similar studies from different countries. H_w from current study is the same as that reported by [43] and within the range reported by [44] but higher than the results of [19,27,28,32 − 35,45]. The level of has been shown to vary from one country to another. Studies from different locations in the same country: Ghana[19,28], Iraq[34,35] have also shown varying levels of H_w.

H_f from ingestion of *Chrysichthys* is about 46% higher than H_f from ingestion of *Oreochromis*, this suggests that *Chrysichthys* accumulate more natural radionuclides in their muscles than *Oreochromis.* It may therefore be relatively safer in terms of radiation protection to consume *Oreochromis* than *Chrysichthys.*

The mean H_f from ingestion of *Oreochromis* and *Chrysichthys* are about 420% and 660% respectively higher than the recommended ingestion dose of 0.025 mSv/yr[46] for natural radionuclides through the consumption of fish. The overall mean H_f from the consumption of any of the common species of fish from the dam is about 540% higher the recommended ingestion dose of 0.025 mSv/yr.

Fifteen kg has been used as the fish consumption rate per year for an adult living around Ero-dam. This is only about 0.03% of the total diet of 550 kg/yr for an adult. The overall average H_f from the consumption of any of the common species of fish from the dam is however over 50% of the typical total radiation dose of 0.3 mSv/yr received yearly from natural radionuclides in the diet[23]. Continuous consumption of *Oreochromis* and *Chrysichthys* from Ero-dam therefore poses potential radiological risks to humans.

Table 7 presents H_f from fish of different countries with that of the current study. H_f from this study was lower than the value reported by on longneck croacker [40] but higher than those reported from all others [38,39,41,47 − 51]. Longneck croacker may be a better accumulator of natural radionuclides. The H_f from consumption of *Oreochromis* from the present study is about 500%, 300% and 15% respectively higher than the three studies of [40,50,51] that reported on *Oreochromis*. Ademola and Ehiedu[38] and Isinkaye *et al*[41] reported H_f of about 2800% and 80% respectively lower than H_f from the current study from the consumption of *Chrysichthy*. The H_f from this study is relatively high.

The mean ELCR from water and fish implies that there is a potential of an average additional 5540 and 560 cancer cases in a population of 1 million over their lifetime due to the consumption natural radionuclides contained in water and fish of Ero-dam respectively. These are about 1900% and 93.10% higher than the world average value for ELCR of 0.29×10^{-3} from carcinogens in an environmental medium [20]. ECLRs from fish products suggests that in terms of cancer risk, it is safer to consume Oreochromis than Chrysichthys.

Table 7. Annual Effective Ingestion Dose H_f from fish and similar studies

Location	Type	H_f(µSv/yr)	Reference
Ondo, Nigeria	Oreochromis	23.30	[38]
	Chrysichthys	6.40	
Iraq	Fish	26.72	[39]
Port Harcourt, Nigeria	Long-neck Croakers	157.8	[40]
Lagos, Nigeria	Long-neck Croakers	388.4	
Ibadan, Nigeria	Farm Chrysichthys	104.00	[41]
	Wild Chrysichthys	104.00	
Cochin, India	Fish species	18.00	[47]
Kudankulam, India	Fish species	25.00	[48]
Singhbhum India	Fish species	1.88	[49]
Jharkhand India	Fish species	4.16	
Lebanon	Oreochromis	33.00	[50]
Bangladesh	Oreochromis	116.79	[51]
Ekiti, Nigeria	Oreochromis	133.80	Current study
	Chrysichthys	187.00	

Conclusion

This study assessed the radioactivity levels of ^{238}U, ^{232}Th and ^{40}K in water, *Oreochromis* and *Chrysichthys* from Ero-dam, Ekiti, Nigeria. The mean activity concentrations of ^{238}U, ^{232}Th and ^{40}K in water and *Chrysichthys* and *Oreochromis*, H_w, H_f and ELCR from this study suggest that consumption of these products from Ero-dam is associated with ingestion of elevated ^{238}U and ^{232}Th. Ingestion of elevated ^{238}U and ^{232}Th from food and water will lead to elevated internal radiation dose. There is therefore potential radiological hazard from the continuous consumption of water and fish products from this dam. Further radioactivity assessment of more environmental media (such as sediments) of Ero-dam is therefore recommended.

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