Assessment of annual effective dose in children due to intake of water samples from New Calabar River, Rivers State, Nigeria

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Abstract*- A radiological assessment of annual effective dose of ^{40}K, ^{232}Th and ^{232}U in children due to ingestion of water samples collected during wet season (July, 2022), from some randomly selected communities along the river banks of the New Calabar River, Rivers State, Nigeria, was carried out in this study. The activity concentration of ^{40}K, ^{232}Th and ^{232}U in the water samples were determined first, using Sodium Iodide (NaI) gamma ray detector. Twenty-eight, 0.5 L sterile containers were thoroughly washed with detergent and rinsed three times with distilled water. Water samples were collected into the sterile containers and acidified by injecting 16 ml, 1 M HNO_3 acid solution to reduce the pH of the water sample to less than 2, avoid adsorption of radionuclides on the walls of the container and to allow for secular equilibrium to be established before gamma ray analysis. The annual effective dose ($mSvyr^{-1}$) in children due to the intake of the water samples was estimated, using the activity concentration of the radionuclides with their ingested dose conversion factor. Results showed that the mean annual effective dose ($mSvyr^{-1}$) of the radionuclide (^{40}K) in children aged (2-7) yrs and (7-12) yrs are: 0.478±0.025 and 0.296±0.017 respectively. The mean annual effective dose ($mSvyr^{-1}$) of ^{232}Th in Children aged (2-7 and 7-12) yrs are: 0.535±0.031 and 0.443±0.025 respectively and the mean annual effective dose ($mSvyr^{-1}$) of ^{232}U in children aged (2-7 and 7-1) yrs are 1.985±0.252 and 1.936±0.248 respectively. The mean total annual effective dose ($mSvyr^{-1}$) of (^{40}K, ^{232}Th and ^{232}U) in children (2-7 and 7-12) yrs are 2.999±0.297 and 2.660±0.291 respectively. Results also indicated that all the radiological parameters considered in this present study are above the WHO and UNSCEAR recommended safe limit of 0.20. It can be conclude that the water supplies from some selected communities along the banks of the New Calabar River, are found to be radiologically contaminated, polluted and unsafe for human consumption, especially among the children population of the inhabitants. It is recommended that alternative, safe and clean source of water supplies be provided by government and nongovernmental organizations, for the inhabitants of the study area. Further research studies on determination of radiological hazards on the remaining population of the study area and other communities not captured in this present study, is highly recommended to be carried out.

***Keywords*- Rivers State, nongovernmental organization, children, gamma ray, radionuclides.**

1.0 INTRODUCTION

Water is very important to all living organisms. It is essential to survival and sustenance of life of human, animals, plants and other living organisms ([1, 2, 3, 4, 5, 6]. Without water in the environment, life cannot be sustained [7]. Access to clean and safe source of drinking water is the responsibility of any responsible government at all levels to its citizen and is of great benefits to human health [13] and forms part of basic human right [8].

Drinking water comes from two main sources: ground water and surface water. Ground water consists of water found underground in cracks and spaces in soil, sand and rock, and moves slowly through geologic formations of soil, sand and cracks known as aquifer ([9]. Examples of underground water source are the hand dug wells and boreholes. Surface water simply comprises river, lakes streams and seawater. Surface and under groundwater water supplies are the major source of water for domestic (drinking, cooking and bathing) purposes. These water sources contain some radionuclides such as Thorium, Radium, Uranium and Potassium-40 [10]. These radionuclides result from the naturally occurring radioactive materials (NORMs) which exist in the soil, minerals and rock beneath the water or with their deposits [8]. The presence of uranium and thorium in underground and surface water is as a result of uranium and thorium bearing rock. These elements dissolve through weathering processes underneath the water and are

transported and released to the surface of the water thereby radiologically contaminating the water bodies. The presence of potassium-40 (^{40}K) is due to agricultural practices such as application of fertilizers and pesticides [11]. Radionuclides can also enter the water body through surface soil erosion or water run-off from industrial wastes effluents [8] disposal of hospital wastes, dumping of large amounts of untreated wastes on unprotected soil, underground movement of water through the fractures in the bedrock containing radionuclides deposits, leaching of radioactive materials into underground system [12].

Generally, polluted drinking water has been responsible for millions of death, especially children in developing countries [22, 14].The presence of radionuclides in drinking water supplies (surface and underground) can be detrimental to human health due to direct intake of radionuclides through consumption of liquids and sea foods such as fish, shellfish and aquatic plants; leisure and sports activities (fishing and swimming) and indirect exposure due to the use of water for irrigation and watering of livestock or from the use of algae or sludge as soil sediment. However, the health risk associated with these radionuclides are relatively low when compared the risk from microorganisms and chemicals due to consumption of such drinking water [15]. In most cases, the radiation dose due to intake of radionuclides in drinking water is much lower than that received from other radiation sources. Naturally occurring radionuclides in drinking water usually give radiation doses higher than those provided by artificially produced radionuclides and are therefore, of greater concern [13, 15]. Some examples of health related cases due to intake of radionuclides in water include chronic lungs diseases, acute leucopoenia, anaemia [17, 18, 19]), cancers of the brain, lungs, pancreas, hepatic, bone, skin and kidney [1], internal organ damage, leukemia, cataracts, and other radiation induced diseases [20, 3]

1.1 Aim of the Study

The aim of the study is to assess the annual effective dose (AED) in children (2-7 and 7-12) yrs due to intake or ingestion of water samples from some selected communities along the banks of the New Calabar River.

1.2 Geographical Location of Sample Site/Location

The study area (New Calabar River), is located in Rivers Sate, Niger Delta, Nigeria (Fig.1) [21, 1]. It comprises nine communities across two local government areas and located along the banks of the New Calabar River. The New Calabar River has its source at Elele-Alimini in Emohua Local Government Area, located approximately latitude N 5° 04′ 24.30″ and longitude E 6° 44 ′ 10.33″. It flows about 150 km southward through the popular Choba bridge in Obio/Akpor Local Government, and empties at the Atlantic Ocean, at about latitudes 4˚20'N and longitudes 7˚00'E [21]. The sample locations and its co-ordinates, and the map of the study area are presented in Table 1 and Fig. 2 respectively.

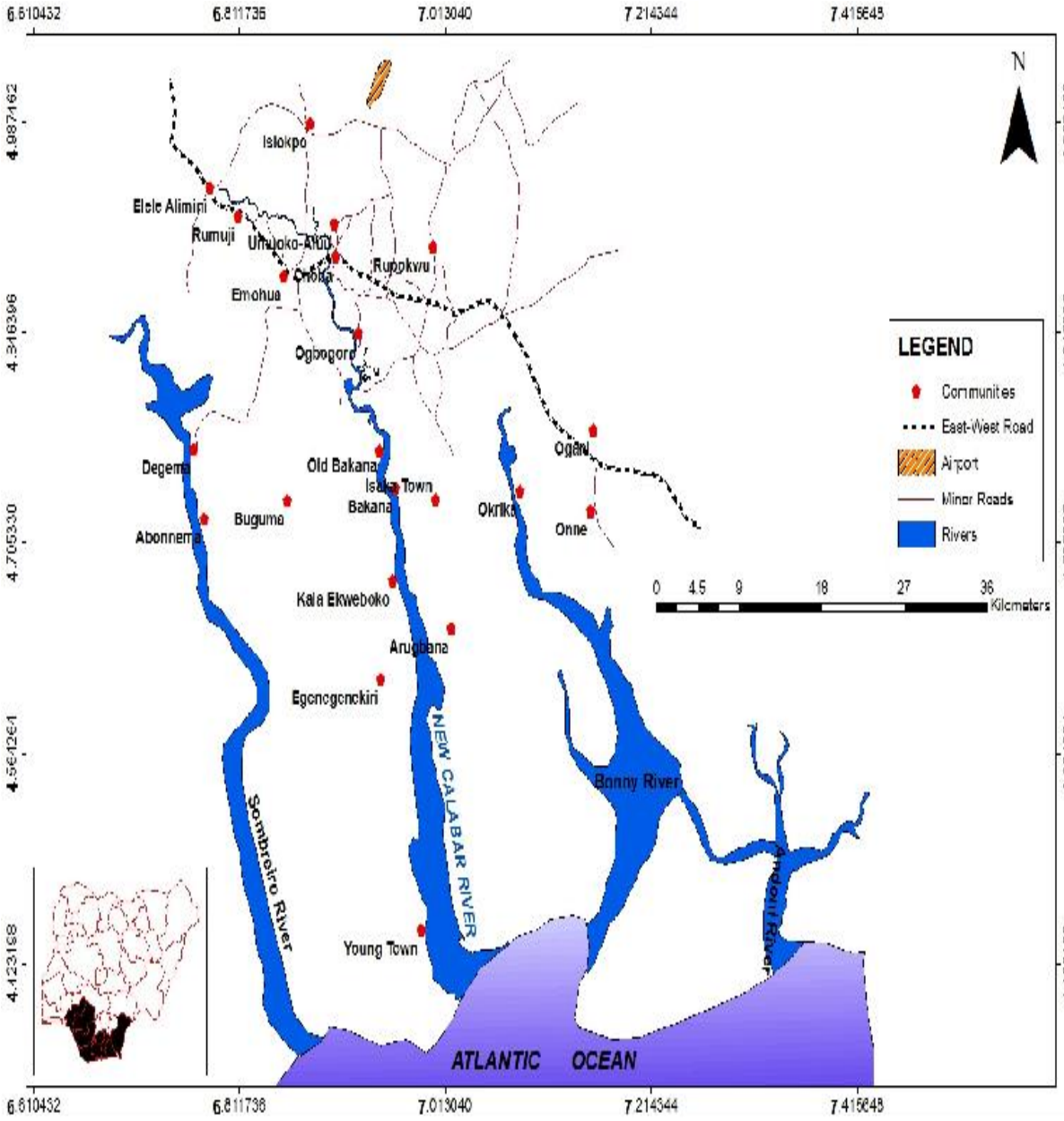

Fig. 1: Map of Lower Niger Delta showing the New Calabar River drainage system and the communities through which it traverses (Source: [21]).

Table 1: Geographical Location of randomly selected sample sites.

Location Number	Location Identity	Name of Location	Local Govt. Area	Latitude (N)	Longitude (E)
1	L1	Iwofe Jetty, Rumuolumeni Town	Obio/Akpor	4.810238889	6.92915
2	L2	Ogbogoro Water front, Ogbogoro Town	Obio/Akpor	4.848636111	6.92345
3	L3	Rumuokparali Water front, Rumuokparali Community	Obio/Akpor	4.871322222	6.904297222
4	L4	Choba Market water front, Choba Town.	Obio/Akpor	4.896733333	6.898044444
5	L5	Omuihuechi Aluu water front.	Ikwerre	4.912827778	6.89804444
6	L6	Elele-Alimini Community	Emohua	5.073416667	6.736202778
7	L7	Rumuji/Ibaa Bridge	Emohua	4.945797222	6.795111111
8	L8	Oduoha Emohua Community	Emohua	4.92479722	6.83415
9	L9	Mbuitanwo Emohua Community	Emohua	4.88195	6.893272222

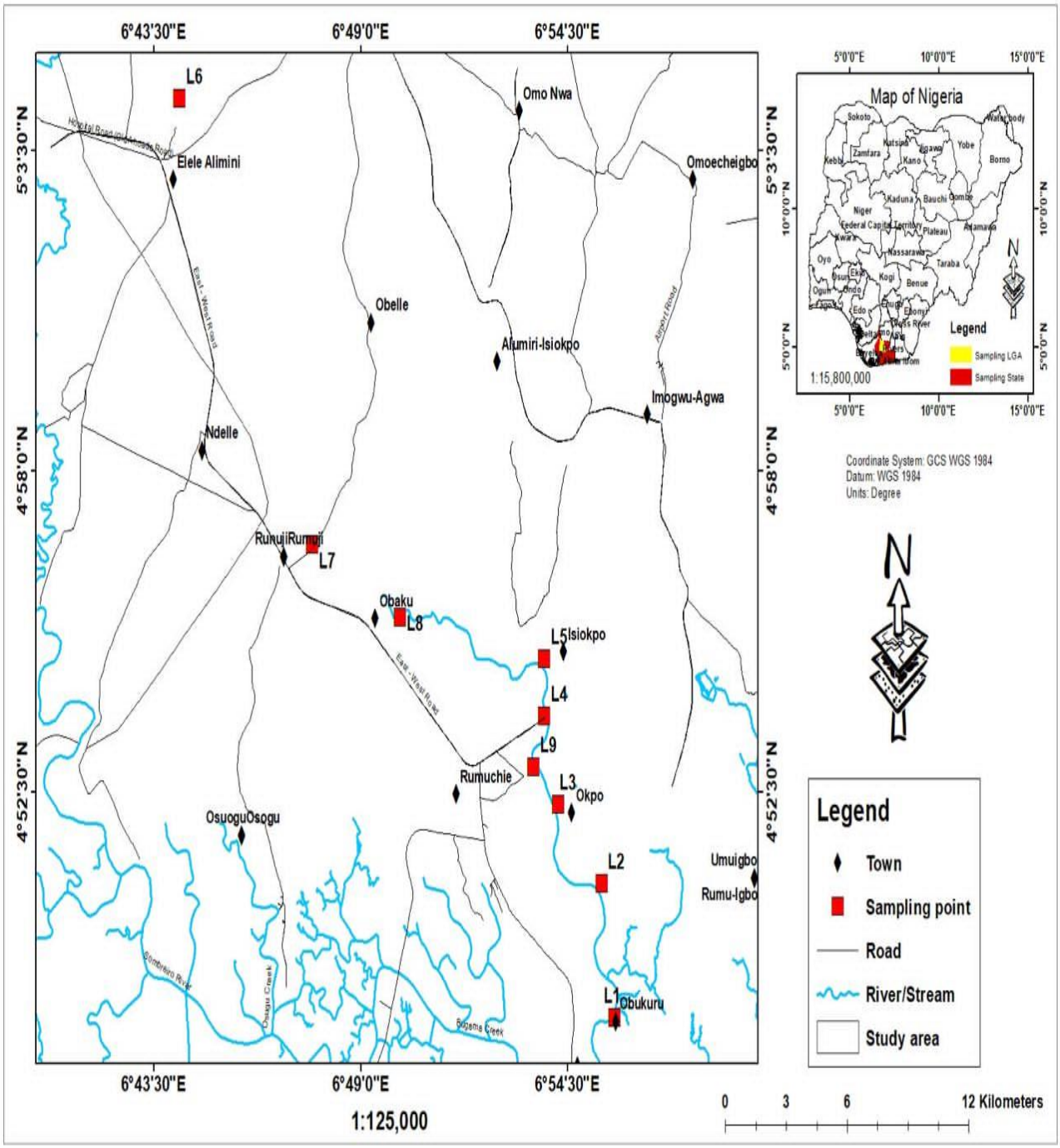

Fig. 2: Map of Nigeria showing sample state and co-ordinates of the sampling sites along the river banks of the New Calabar River, Niger Delta, Nigeria

The inhabitants of the communities along the banks of New Calabar River are engaged in fishing and farming, and play hosts to some multination and international oil company (IOC) such as the Elf Nigeria Ltd and Shell Petroleum Development Company (SPDC), Nigeria Liquefied Natural Gas (NLNG), including the University of Port Harcourt and Dufil Nigeria Ltd. The water supplies the New Calabar River is the major source of water for drinking, cooking washing and bathing [1]. A lot of economic and socio-economic activities such as hand and mechanized sand dredging, forestry operation (lumbering), maritime activities, illegal refining and transportation of Nigerian petroleum products, are carried out by inhabitants, especially the youths along the banks of the New Calabar River. These activities have resulted in general contamination and pollution of the water supplies for domestic purposes. Other forms and sources of water pollution and contamination within the study area include wastes discharge from abattoir, effluent discharge from speed boats and industries located along the banks of the New Calabar River, run off water that carries some chemical substances, disposal of hospital wastes, disposal of solid and domestic wastes into the river, and use of dynamite during fishing operations.

2.0 Literature Review

Several studies on natural radioactivity level and radiological hazards in drinking water such as surface water, ground water and packaged water in Nigeria have been carried out. Some of such studies include the assessment or determination of natural radioactivity of: surface water from coastal communities in Ndokwa East, Delta State [8]; boreholes and well water in Dutse, Jigawa State [6]; some selected packaged water in Ilorin and Ogbomoso [2]; some bottled drinking water produced in Delta State [23]; Ogun State drinking water [7]; Oniru beach, Lagos State [17]; drinking water in selected secondary schools of Epe Local Government area, Lagos State [24]; borehole drinking water in Gombe State, Nigeria [5]; community water supplies in oil and gas producing areas in Delta State [12]; some sachet drinking water samples produced in Nigeria [26]; surface and underground water and excess lifetime cancer risk due to gamma radioactivity [3]; and LAUTECH water supplies, Nigeria [11]. However, there is no baseline study on the assessment of natural radioactivity and radiological hazard indices in water samples from the New Calabar River, Rivers State, Nigeria.

3.0 Materials and Methods

3.1 Materials

The global positioning system (GPS) with model: Garmin-eTrex, is a satellite navigation system. The device was used to measure the co-ordinates (latitude and longitude) and time of the sample locations. A portable digital pH meter with model number: HI 8424 (Hanna product), was used to measure the pH of the water samples. Plastic containers (50 cl) were used to collect the water samples and Sodium Iodide (NaI) Gamma-ray detector was used in the analysis of the water sample.

3.2 Methods

Twenty-eight sample sites were randomly selected from nine sampling communities (Table 1) located along the banks of the New Calabar River. The sample containers were thoroughly washed with detergent and rinsed three times with distilled water. Twenty-eight water samples were collected during wet season (July, 2022) from the across the sample sites into 0.5 L sterile containers [1]. The water samples were acidified by injecting 16 ml of 1 M of HNO_3 (Nitric) acid solution to each of the sample containers in order to reduce the pH of the water sample to less than 2, minimize precipitation and adsorption on the wall of the container [5, 10] and to allow for secular equilibrium to be established prior to the analysis of water samples, using gamma ray spectrometer. The water samples containers were tightly covered, appropriately labelled, well packed and ice-cooled for approximately 24 hours before being transported to the National Institute of Radiation Protection and Research (NIRPR) Laboratory, Nigerian Nuclear Regulatory Authority (NNRA), University of Ibadan, Ibadan, Oyo State, Nigeria, for analysis, using a Thallium activated 3″ x 3″ Sodium Iodide (NaI) (TI) gamma ray detector.

3.2.1 Gamma Ray Counting

The gamma ray counting of the water samples were carried using a 8cm active diameter co-axial Sodium Iodide (NaI) Gamma-ray detector, doped with Thallium. The detector in a 100 mm thick lead shield was connected to ORTEC 456 amplifier and connected to a computer program known as SAMPO 90 window that matched the gamma energies to a library of possible isotopes [8]. Standard of natural origin were prepared in the same manner as the samples. The samples were placed in the detector and then preset to 54,000 seconds for overnight counting or 18,000 seconds for day counting. From the counting, the activity concentration of the radionuclides ^{40}K, ^{232}Th and ^{232}U were determined using computer program connected to the detector. The spectrum acquired are analysed using gamma energy line 1460.8 keV for potassium, 1764 keV of Bismuth-214 (^{214}Bi) for Uranium-238 (or ^{238}U) and 261 keV of Thallium-208 (^{208}Ta) for ^{232}Th, where ^{214}Bi is a daughter of Uranium-238 (^{238}U) and Thallium-208 is a daughter of ^{232}Th. These spectra were considered in arriving at the activity levels of the radionuclides.

3.2.2. Determination of Natural Radioactivity and Radiological Hazard Indices

The values of the radioactivity of the water samples was obtained after analyzing the water samples with the aid of Sodium Iodide (NaI) detector or gamma-ray spectrometer connected to a computer monitor with software [27]. However, in this present study, the Sodium Iodide (NaI) spectrometer will be used to assess or determine all possible radionuclide present in the study area.

3.3. Estimation of Effective Dose

3.3.1 Activity Concentrations

The activity concentration of the radionuclides: ^{226}Ra, ^{232}Th, ^{40}K and ^{232U} for all the selected water samples were obtained after subtracting decay corrections, using Eq. (1): [28]**:**

$$C_s(Bql^{-1}\ or\ Bqk^{-1}) = \frac{C_a}{P_\gamma(M_s/V_s)\varepsilon_\gamma\ t_c} \quad (1)$$

where**:**

$C_s =$ Sample Concentration.

$C_a =$ Net peak area of a peak at energy.

$\varepsilon_\gamma =$ Efficiency of the detector for a γ-energy of interest.

$M_s/V_s =$ Sample mass/volume for soil/water samples

$t_c =$ Total counting time".

$P_\gamma =$ Abundance of the γ-line in a radionuclide

3.3.2 Annual Effective Dose (AED)

The annual effective dose (AED) (mSv y^{-1}) to an individual due to intake of natural radionuclides from the water, was obtained using Eq. (2): [29, 3, 1]:

$$E = IAC \times 365\ . \quad (2)$$

Where:

$I =$ Daily water consumption (Ld^{-1})

$A =$ Activity Concentration ($Bq\ L^{-1}$) of the radionuclide in the water samples

$C =$ Dose conversion factors ($mSvBq^{-1}$) which varies with age of individuals and the radionuclide present in the water samples.

The effective dose conversion factor varies with both the radionuclide and the age categories of human population. The values of dose conversion factor for each of the radionuclides, daily and annual water intake for the various categories of human population (infants, children and adults) were extracted from [16] and presented in Table 2 below.

Table 2: Dose conversion factor for ingested radionuclides: ^{40}K, ^{232}Th and ^{232}U for the various categories of human population (infants, children and adults).

S/N	Radionuclides	Infants		Children		Adults	
		(0-1)yr	(1-2) yr	(2-7) yr	(7-12) yr	(12-17) yr	(> 17) yr
1	^{40}K	6.2 E-8	4.2 E-8	2.1 E-8	1.3 E-8	7.6 E-9	6.2 E-9
2	^{232}Th	4.6 E-6	4.5E-7	3.5 E-7	2.9 E-7	2.5 E-7	2.3 E-7
3	^{232}U	2.5 E-6	8.2 E-7	5.8 E-7	5.7 E-7	6.4 E-7	3.3 E-7
	Daily water intake (L/day)	0.5	1.0	1.0	1.0	2.0	2.0
	Annual water intake (L/yr)	182.5	365	365	365	730	730

3.3.3 Total Annual Effective Dose (TAED)

The total annual effective dose, TAED ($mSvy^{-1}$) in children (2-7 and 7-12) yr due to ingestion of the radionuclides (^{40}K, ^{232}Th and ^{232U}) present in water samples was obtained using Eq. (3): [26, 8] AED ($mSvy^{-1}$) = $\sum A_c I_A C_F$ (3)

where:

A_c = Activity concentration (BqL^{-1}) of the radionuclide in the water sample.

I_A = Daily water consumption (Ld^{-1}).

C_F = Dose conversion factor ($mSvBq^{-1}$)

The age group was: children (2-7 and 7-12 yrs).

4.0 Results

The annual effective dose, AED ($mSv\ yr^{-1}$) of ^{40}K, ^{232}Th and ^{232}U in children age groups: (2-7 yr and 7-12 yr) are presented in Table 3. The mean activity concentration (BqL^{-1}) of (^{40}K, ^{232}Th and ^{232}U) in water samples collected during wet season (July, 2022) and WAV are displayed in Fig. 3. The distribution of mean total annual effective dose for children aged:(2-7) yr due to intake of water samples collected during wet season (July, 2022) and the world average value are displayed in Fig.4. The distribution of mean total annual effective dose for children aged: (7-12) yr due to water samples collected during wet season (July, 2022) and the world average value, are presented in Fig. 5.

Table 3: Annual Effective Dose ($mSv\ y^{-1}$) of (^{40}K, ^{232}Th and ^{232}U) in Children age groups (2-7 and 7-12 rs) in water samples collected during wet season (July, 2022).

Sample Code	^{40}K Children (2-7) yr	(7-12) yr	^{232}Th Children (2-7) yr	(7-12) yr	^{232}U Children (2-7) yr	(7-12) yr
L1P1	0.307±0.016	0.190±0.010	0.580±0.034	0.481±0.029	1.207±0.178	1.186±0.175
L1P2	0.276±0.015	0.171±0.009	0.498±0.029	0.413±0.024	2.337±0.330	2.297±0.325
L2P1	0.114±0.006	0.071±0.004	0.264±0.015	0.219±0.013	0.957±0.127	0.940±0.125
L2P2	0.217±0.011	0.134±0.007	0.359±0.022	0.297±0.018	2.551±0.343	2.507±0.337
L3P1	0.762±0.040	0.472±0.025	0.689±0.041	0.570±0.034	1.437±0.205	1.413±0.202
L3P2	0.510±0.026	0.316±0.060	0.222±0.013	0.184±0.011	1.382±0.135	1.359±0.133
L4P1	0.243±0.012	0.150±0.008	0.538±0.031	0.446±0.025	1.342±0.135	1.319±0.133
L4P2	0.429±0.023	0.266±0.014	0.353±0.022	0.292±0.018	2.149±0.294	2.112±0.289
L5P1	0.309±0.016	0.192±0.010	0.405±0.024	0.336±0.020	2.278±0.318	2.239±0.312
L5P2	1.050±0.055	0.650±0.034	0.453±0.027	0.376±0.022	2.020±0.290	1.985±0.285
L6P1	0.486±0.026	0.301±0.016	0.821±0.049	0.681±0.040	1.336±0.186	1.313±0.183
L6P2	0.731±0.038	0.452±0.024	0.166±0.008	0.109±0.006	5.354±0.641	5.261±0.630
L7P1	0.188±0.010	0.117±0.006	0.606±0.034	0.502±0.029	1.736±0.174	1.706±0.171
L7P2	0.713±0.037	0.441±0.023	0.637±0.038	0.528±0.032	3.194±0.432	3.139±0.424
L8P1	0.103±0.005	0.063±0.003	0.747±0.043	0.619±0.036	2.653±0.264	2.607±0.260
L8P2	0.542±0.029	0.336±0.018	0.767±0.046	0.636±0.038	1.164±0.163	1.144±0.160
L9P1	2.040±0.107	1.263±0.066	0.622±0.037	0.512±0.031	2.902±0.432	2.852±0.424
L9P2	0.588±0.031	0.364±0.019	0.632±0.037	0.524±0.031	0.102±0.015	0.010±0.015
L10P1	0.557±0.028	0.345±0.017	0.492±0.028	0.407±0.023	2.979±0.292	2.927±0.287
L10P2	0.080±0.004	0.050±0.003	0.752±0.044	0.623±0.037	0.976±0.133	0.959±0.131
L11P1	0.309±0.016	0.192±0.010	0.581±0.034	0.482±0.029	1.952±0.254	1.918±0.250
L11P2	0.728±0.038	0.451±0.024	0.508±0.031	0.421±0.025	5.011±0.658	4.924±0.647
L12P1	0.153±0.008	0.094±0.005	0.899±0.054	0.745±0.044	0.152±0.023	0.150±0.023
L12P2	0.460±0.023	0.284±0.014	0.632±0.036	0.524±0.030	0.254±0.025	0.250±0.025
L13P1	0.169±0.009	0.105±0.005	0.321±0.019	0.266±0.016	0.385±0.038	0.379±0.037
L13P2	0.612±0.031	0.379±0.019	0.195±0.011	0.162±0.009	2.089±0.205	2.053±0.202
L14P1	0.084±0.004	0.052±0.003	0.557±0.011	0.461±0.009	2.655±0.368	2.609±0.362
L14P2	0.639±0.034	0.396±0.021	0.699±0.042	0.579±0.035	3.015±0.409	2.963±0.401
Min.	**0.080±0.004**	**0.050±0.003**	**0.166±0.008**	**0.109±0.006**	**0.102±0.015**	**0.010±0.015**
Max.	**2.040±0.107**	**1.263±0.066**	**0.767±0.046**	**0.745±0.044**	**5.354±0.641**	**5.261±0.630**
Mean	**0.478±0.025**	**0.296±0.017**	**0.535±0,031**	**0.443±0.025**	**1.985±0.252**	**1.936±0.248**
WAV	**0.12**		**0.17**		**0.17**	

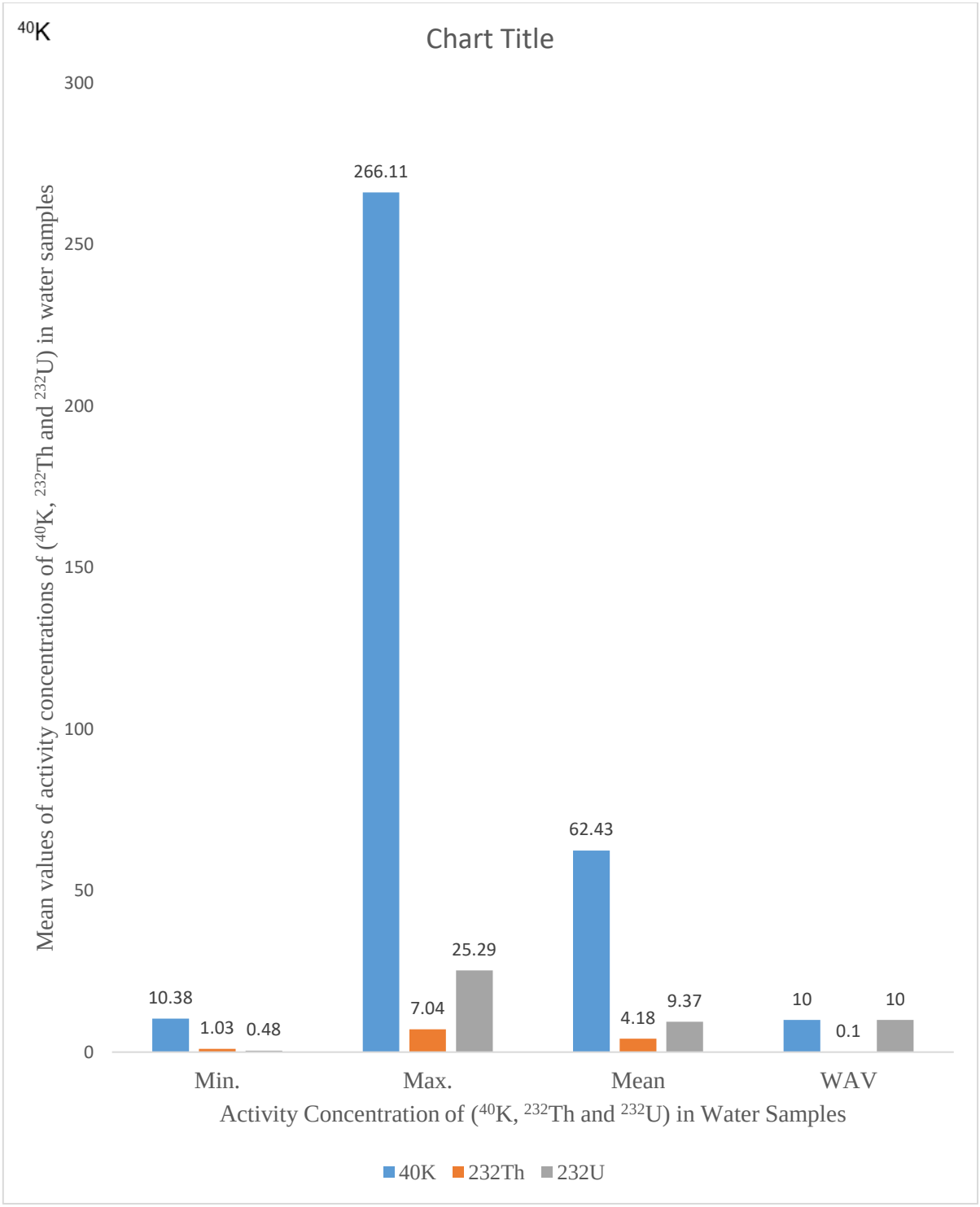

Fig. 3: Mean Activity Concentration of (^{40}K, ^{232}Th and ^{232}U) in Water Samples collected during wet season (July, 2022) and WAV

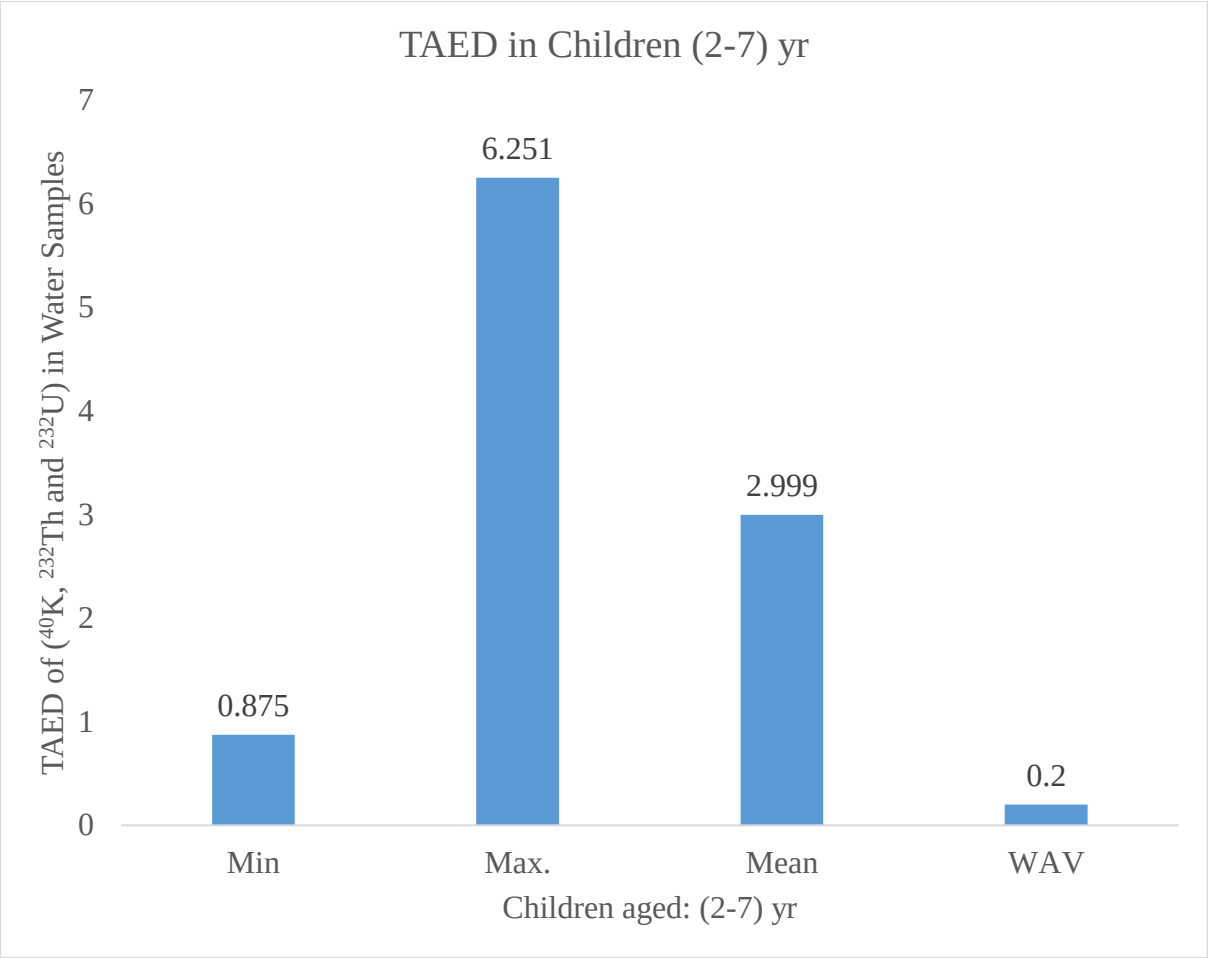

Fig. 4: Distribution of mean TAED of (^{40}K, ^{232}Th and ^{232}U) in Water Samples for children aged: (2-7) yr and the WAV.

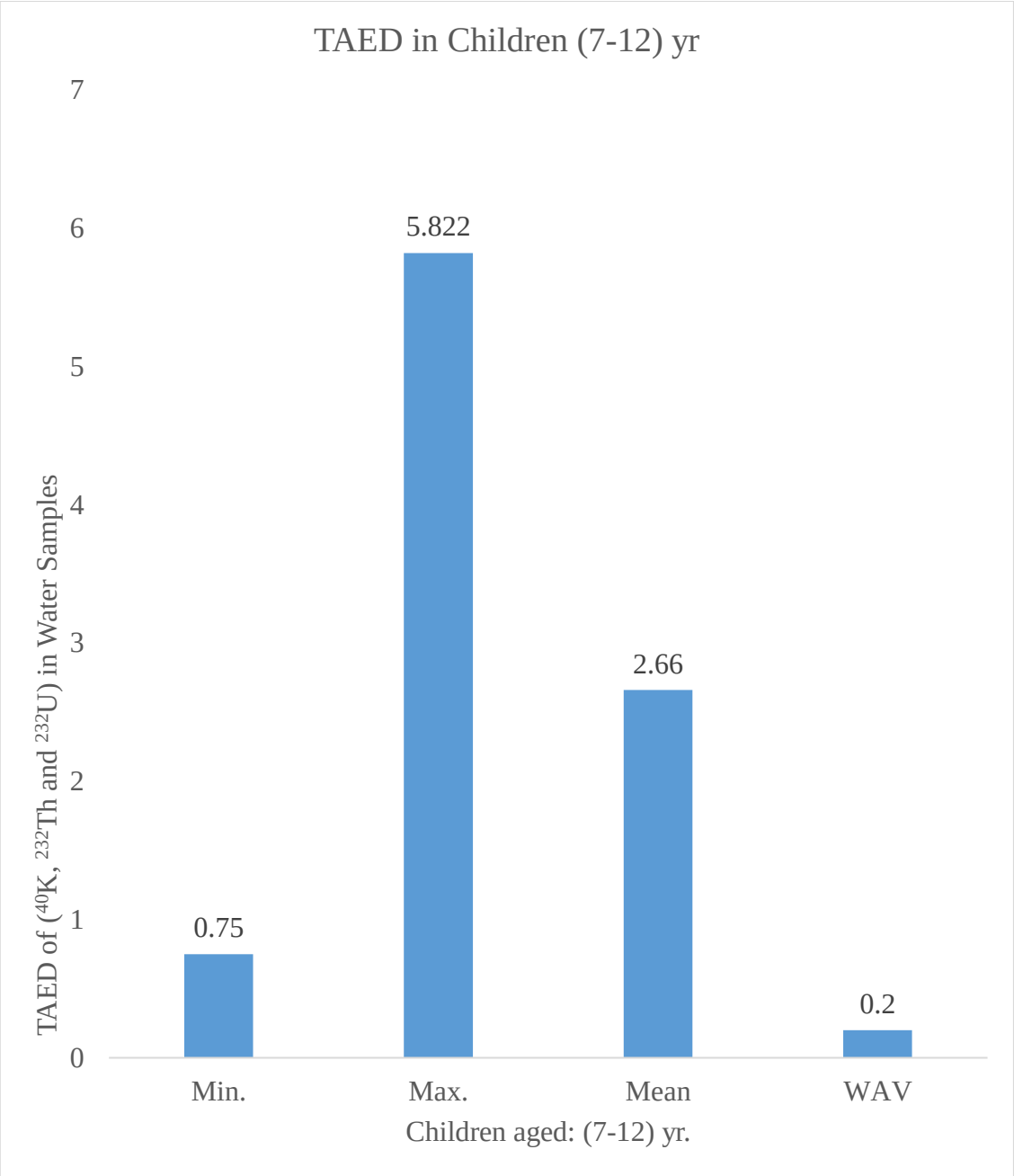

Fig. 5: Distribution of mean TAED of (^{40}K, ^{232}Th and ^{232}U) in Water Samples for children aged: (7-12) yr and the WAV.

4.2 Discussion

The results of this present study revealed that the activity concentration (BqL^{-1}) of the radionuclides present in Water Samples collected randomly selected sampling location (Communities) along the banks of the New Calabar River, during wet season (July, 2022) ranged between: 10.38±0.58 and 266.11±13.99 with mean value of 62.43±3.26; 1.03±0.06 and 7.04±0.42 with a mean value of 4.18±0.24; 0.48±0.07 and 25.29±3.03 with a mean value of 9.37±1.19 in ^{40}K, ^{232}Th and ^{232}U respectively (Fig. 3) [1]. The results further revealed that the radionuclide (^{40}K) was most prominent in the water samples collected across all the sample locations. This was largely due to anthropogenic activities taking place within the study area, which include application of (N-P-K) fertilizer and pesticides during agricultural practices. Furthermore, ^{40}K is a naturally occurring radioactive element found in soil, minerals and rock, and are released to the surface of the river through the process of weathering [8, 1]. Results (Fig. 3) further showed that ^{232}U is the second most abundant radioactive element in the water samples collected while ^{232}Th is the least. The presence of ^{232}U was as a result of chemical process that results in leaching of some Uranium bearing rock into the river body, and which are transported from one point to another across the river water [8]. Uranium and thorium are naturally occurring radioactive materials (NORM) that exist in the rocks beneath the river. The presence of oil and gas production activities (exploration and refining) of petroleum products located near Uranium source might also be responsible for relatively high activity concentration of ^{232}U in the water samples [12]. Though Thorium and Uranium are naturally occurring radioactive elements present in the rocks under the river, the relatively high presence of ^{232}Th in the water samples collected might be as a result of some human activities such as effluent discharges of bunkering products into the river, maritime activities, local sand mining and dredging activities [8]. A comparison of mean activity concentration(BqL^{-1}) of the radionuclides (^{40}K, ^{232}Th and ^{232}U) present in the water samples with the world average

(WAV) (Fig. 3) revealed that ^{40}K and ^{232}Th exceeded the WHO and UNSCEAR recommended safe limits of 10.0 (BqL^{-1}) and 0.1(BqL^{-1}) while that of ^{232}U was below the safe limit of 10.0 (BqL^{-1}) [13].

The annual effective dose, AED ($mSvyr^{-1}$) as a result of intake of the radionuclides (^{40}K, ^{232}Th and ^{232}U) present in the water samples in children aged: (2-7 and 7-12) yrs was calculated, using Eg. (1): with the activity concentration of the radionuclide [1] and dose conversion factor children aged: (2-7 and 7-12) yrs was extracted from [16] and presented in Table 2. Results in Table 3 showed that the annual effective dose, *AED* ($mSvyr^{-1}$) of ^{40}K, in children aged (2-7 and 7-12) yrs ranged from 0.080±0.004 to 2.040±0.107, and 0.050±0.003 to 1.263±0.066 respectively while their mean annual effective dose are 0.478±0.025 (2-7) yrs and 0.296±0.017 for children age (2-7) yr and (7-12) yrs respectively. The annual effective dose of ^{232}Th in Children aged (2-7 and 7-12) yrs ranged from 0.166±0.008 to 0.767±0.046 and 0.109±0.006 to 0.745±0.044, respectively. The mean annual effective dose ($mSvyr^{-1}$) of ^{232}Th in children are 0.535±0.031 and 0.443±0.025 for ages: (2-7) yrs and (7-12) yrs respectively. The annual effective dose of ^{232}U in children aged (2-7 and 7-12) yrs ranged from 0.102±0.015 to 5.354±0.641 and 0.010±0.015 to 5.261±0.630, respectively while their mean annual effective dose are 1.985±0.252 and 1.936±0.248 for (2-7) yrs and (7-12) yrs respectively. Results in Table 3 further showed that the mean annual effective dose of the radionuclides (^{40}K, ^{232}Th and ^{232}U) present in water samples collected are all exceeded the WHO and UNSCEAR recommended safe limits of 0.12, 0.17 and 0.17 respectively. The results indicated the water samples are radiologically contaminated and unsafe for consumption.

The total annual effective dose of the radionuclides were calculated using eq. (3). This was obtained through addition of annual effective doses of each of the three radionuclides on children aged (2-7) yrs and (7-12) yrs. Results (Fig. 4 and Fig. 5) revealed that total annual effective dose ($mSvyr^{-1}$) in children as a result of intake of water samples ranged from 0.875±0.066 to 6.251±0.687 for (2-7) yrs and 0.750±0.058 to 5.822±0.660 for (7-12) yrs respectively. The mean total annual effective dose ($mSvyr^{-1}$) in children (2-7 and 7-12) yrs are 2.999±0.297 and 2.660±0.291 (Fig. 4 and Fig. 5) respectively. Results in Figs. 4 and 5 further revealed that a comparison of the mean total annual effective dose in children aged (2-7 and 7-12) yrs due to ingestion of water samples with the world average value indicated that the mean total annual effective dose in children age groups (2-7 and 7-12) yrs exceeded the WHO and UNSCEAR recommended safe limit of 0.20 [13, 30]. The results however, showed that the water samples from this present study area are also radiologically contaminated and unsafe for consumption and other domestic purposes.

4.3 Conclusion

A radiological assessment of annual effective dose in children due to ingestion of water samples collected from some randomly selected communities along the river banks of New Calabar River, Rivers State, Nigeria, was carried out. The activity concentration of ^{40}K, ^{232}Th and ^{232}U in the water samples collected were determined using Sodium Iodide (NaI) gamma ray detector. The mean activity concentration [1], exceeded the WHO and UNSCEAR recommended limit. The mean annual effective dose ($mSvyr^{-1}$) of the radionuclide (^{40}K) in children aged: (2-7 and 7-12) yrs are: 0.478±0.025 and 0.296±0.017 respectively. The mean annual effective dose ($mSvyr^{-1}$) of ^{232}Th in Children aged (2-7 and 7-12) yrs are: 0.535±0.031 and 0.443±0.025 respectively and the mean effective dose ($mSvyr^{-1}$) of ^{232}U in children aged (2-7 and 7-1) yrs are 1.985±0.252 and 1.936±0.248 respectively. The mean total annual effective dose ($mSvyr^{-1}$) of (^{40}K, ^{232}Th and ^{232}U) due to intake of water samples in children aged (2-7 and 7-12) yrs are 2.999±0.297 and 2.660±0.291 respectively. Results indicated that all the radiological parameters considered in this present study are above the WHO and UNSCEAR recommended safe limit 0f 0.20. It can therefore, be conclude that the water supplies from some selected communities along the banks of the New Calabar River are found to be radiologically contaminated, polluted and unsafe for human consumption, especially among the children population of the inhabitants of the study area. Alternative, safe and clean source of water supplies should be provided for the inhabitants of the study area. Further research studies on determination of radiological hazards on other population of the study area and other communities not captured in this present study, is highly recommended to be carried out.

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