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Assessment of Radionuclide Concentrations and Absorbed Dose from Consumption of Community Water Supplies in Oil and Gas Producing Areas in Delta State, Nigeria

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Abstract

A survey of radioactivity concentration in water supplies used for domestic and industrial purposes in the oil and gas producing communities of Delta State, Nigeria was carried out using a well-calibrated High-Purity Germanium (HPGe) detector system. The study area was partitioned into ten sections and a total of two samples per partition were collected for analysis. Samples of water from a non-producing area were also collected as control. In all, a total number of forty three samples were collected and analyzed. Each sample was acidified at the rate of 10 ml of 11 M HCl per liter of water to prevent the absorption of radionuclides into the wall of the container and sealed in a properly cleaned container for at least one month so as to attain a state of secular radioactive equilibrium before analysis. The photopeaks observed with reliable regularity belong to the naturally occurring series-decay radionuclide headed by ^{238}U and ^{232}Th, as well as the non-series decay type ^{40}K. The mean specific activity obtained for ^{40}K was 49 ± 15 Bq·L^{-1} with a range of 6 - 177 Bq·L^{-1} while for ^{238}U, the mean specific activity was 3 ± 1 Bq·L^{-1} with a range of 1 - 12 Bq·L^{-1} and the mean specific activity for ^{232}Th was 3 ± 2 Bq·L^{-1} with a range of 2 - 10 Bq·L^{-1} and the total annual effective dose, which vary between 0 - 2 μSv·y^{-1}, did not show any significant health impact.

1. Introduction

Water is an essential commodity without which there is no life. Radionuclides are present in the air breathed by man, in food and drinking water [1-3] consumed by man and in the ground from which human settlements are built [4]. Enhanced levels of uranium, thorium and their daughter products might be present in water in area that is rich in natural radioactivity or through human activities. The dumping of large amount of waste materials in sites without adequate soil protection measures result in soil as well as, surface and ground water pollution [5,6]. As groundwater moves through fractures in the bedrock that contain these deposits, radioactive minerals can leach out into ground-water system. Contaminants from human activities pass into air, soil and water, and, hence into fish crops and other animals [7]. The input of radionuclide such as K-40 to the environment is derived from terrestrial soil and atmospheric diffusion [8,9]. Con-

sidering the high radiotoxicity of ^{226}Ra and ^{228}Ra, their presence in water and the associated health risks require particular attention. Radionuclides when ingested or inhaled enter the human body and are distributed among body organs according to the metabolism of the element involved. The organs normally exhibit varying sensitivities to the radiation and thus, varying does and risks result from their consumption or inhalation. UNSCEAR [10,11], Mettler and Sinclair [12] estimated that, terrestrial sources are responsible for most of man's exposure to natural radiation, most of it by internal radiation, with cosmic rays contributing just under half of man's exposure to external radiation. Accurate estimation of the occurrence of radionuclide in community water will provide information from which estimates of average radiation exposures of the public from these sources in some oil and gas producing areas in Delta State can be made.

Radioactivity and radiation levels in various environmental samples have been of great concern in many

countries [13,14]. Cothern and Lappenbush [15] and Cothern *et al*., [16] reported the occurrence of uranium in drinking water in the United State of America. Other workers [17-20] published obtained data from monitoring community drinking water in various countries. Other researchers have investigated radon levels in the water [21] in some regions of Poland.

Here in Nigeria, Olomo *et al*., [22] reported their findings on the mean specific activities in soil and water around some nuclear establishment in Ile-Ife; while Tchokossa *et al*. [23] reported the results of measurements of naturally occurring radionuclide concentrations in the community water supplies in two local government areas in Ile-Ife Osun State.

2. Materials and Methods

The study area was partitioned into ten sections and a total of two samples were collected for analysis from each partition. Samples of water from a non-producing area were collected as control. In all, a total number of forty three samples were collected and analyzed. The study area covers the entire Delta State and the samples locations are as listed in **Table 1** and shown on **Figure 1**. The sampling locations were based on factors such as population density, farm settlements, educational institutions, hospitals etc., especially the commonly used water type around oil and gas producing areas. The type of water collected were well water, tap water, drinkable surface water, non-drinkable surface water, freely falling rain water, rain water falling through aluminum sheets and rain water falling through asbestos sheets.

Well water, tap water, rain water, surface water were collected as may be appropriate from their sources as for instance tap water was collected at the water processing (filtration/purification) plants just prior to discharge into the distribution system or if in a residence, the pipes were flushed sufficiently prior to sample collection while rain water was collected with the aid of a rain collector previously washed with dilute acid (0.1 M HCl) and located on the roofs of buildings to avoid contamination by airborne soil and surface dust. Surface water samples from streams were collected directly from the stream using a 1 liter plastic keg. Well water was collected directly from
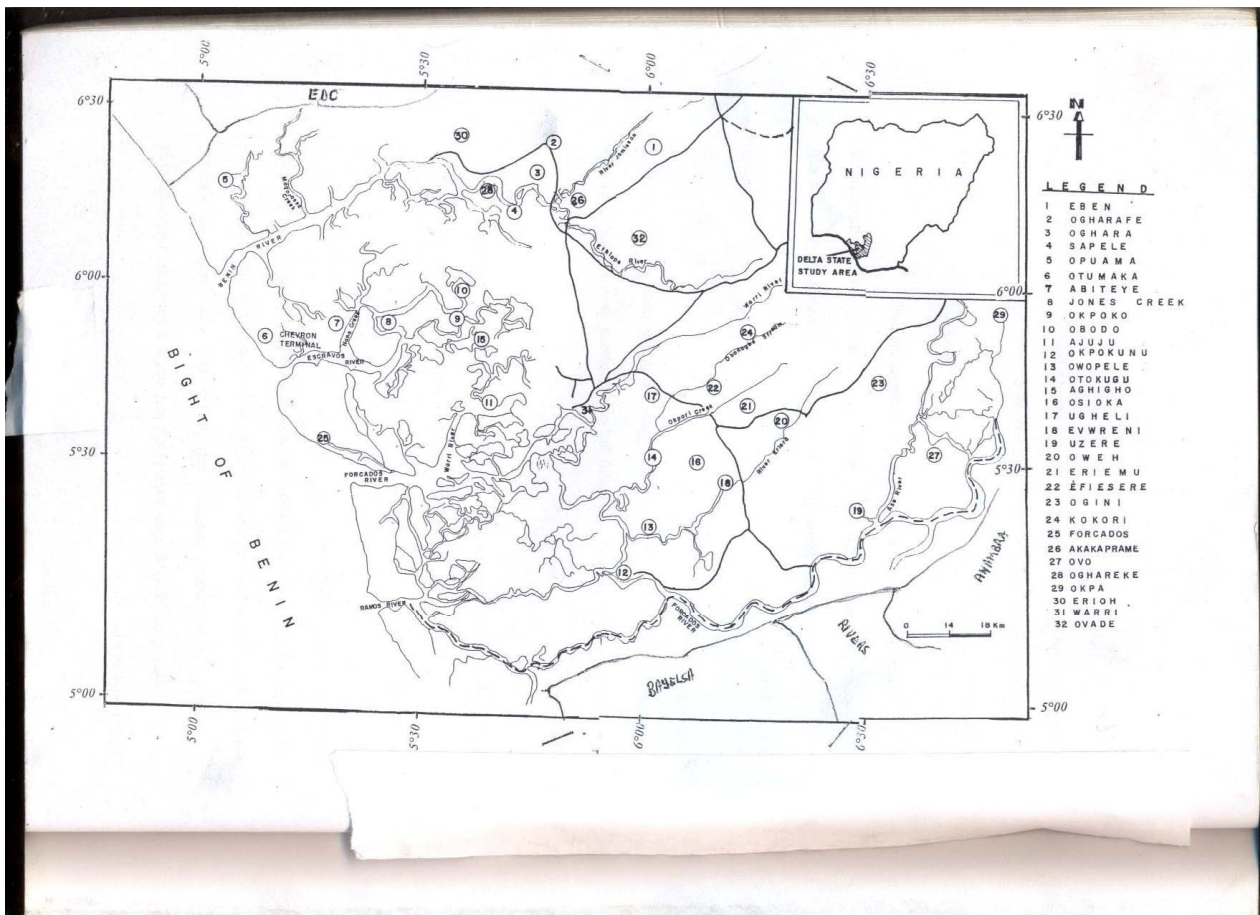

Figure 1. Map of the study area.

Table 1. Geology and locations of the sampling points.

Sample No	Name of the Town	Brief Geology of Sampling Point	Location	
			Longitude	**Latitude**
1	Oben	Sandstones	6˚01'16" E	5˚53'5" N
2	Ogharefe	Sandstones, siltstones	6 01'17" E	5˚41'47" N
3	Oghara	Sand, siltstones	5˚56'25" E	5˚40'21" N
4	Sapele	Sand, siltstones	5˚53'55" E	5˚37'08" N
5	Opuama	Sand, gravel, clay	5˚55'42" E	5˚04'21" N
6	Otumaka	Sand, gravel, clay	5˚39'3" E	5˚09'17" N
7	Abiteye	Sand, Sandstones	5˚40'54" E	5˚17'19" N
8	Jones Creek	Sand, Sandstones	5˚41'15" E	5˚23'27" N
9	Okpoko	Sand, gravel, clay	5˚41'47" E	5˚31'4" N
10	Obodo	Sand, gravel, clay	5˚45'0" E	5˚31'25" N
11	Ajuju	Sand, gravel	5˚31'53" E	5˚35'0" N
12	Okpokunu	Sand subordinate silt	5˚11'49" E	5˚50'54" N
13	Owopele	Sand subordinate silt	5˚17'49" E	5˚53'38" N
14	Oturugu	Sand, siltstones	5˚ 25'32"E	5˚ 53'16"N
15	Aghigho	Sand, gravel, clay	5˚ 39'26"E	5˚ 33'55" N
16	Osioka	Sand, siltstones	5˚24'49" E	5˚58'53" N
17	Ugheli	Sand, gravel	5˚32'38" E	5˚53'49" N
18	Evwreni	Sand, siltstones	5˚23'2" E	6˚02'19" N
19	Uzeke	Sand, subordinate silt	5˚19'49" E	6˚16'54" N
20	Oweh	Sand, Sandstones	5˚29'49" E	6˚08'23" N
21	Eriemu	Sand, gravel	5˚31'15" E	6˚04'6" N
22	Afiesere	Sand, gravel	5˚33'23" E	6˚01'15" N
23	Ogini	Sand, Sandstones	5˚34'43" E	6˚19'17" N
24	Kokori	Sand, Sandstones	5˚39'37" E	6˚03'45" N
25	Forcados	Sand subordinate silt	5˚20'53" E	5˚27'16" N
26	Akpaprame	Sand, Sandstones	5˚54'49" E	5˚40'57" N
27	Ovo	Sand, Sandstones	5˚27'27" E	6˚25'20" N
28	Oghareke	Sand, Sandstones	5˚55'48" E	5˚35'28" N
29	Okpa	Sand, Sandstones	5˚42'08" E	6˚32'40" N
30	Enioh	Sandstones siltstones	6˚32'17" E	5˚30'45" N
31	Warri	Sand gravel	5˚30'45" E	5˚46'25" N
32	Ovade	Sand, Sandstones	5˚48'45" E	5˚48'12" N
33	Jamieson river	Coarse sand	6˚00'32" E	5˚46'5" N
34	Ethiope river	Coarse sand	5˚47'30" E	5˚48'45" N
35	Warri river	Sandstones	5˚30'33" E	5˚32'08" N
36	Eriora river	Coarse sand	5˚28'12" E	6˚08'55" N
37	Aso river	Sandstones	5˚20'43" E	6˚20'10" N

the wells using a manual procedure for collecting water from deep or shallow wells. All the storing containers were previously washed with dilute acid (0.1 M HCl), and water samples were acidified with 11 M of HCl at the rate of 10 ml per litre of sample immediately after sampling to avoid absorption of radionuclide on the walls of the container. The storage time was at least 28 days for the state of secular equilibrium to be reached among the daughter products of ^{228}U and ^{232}Th. The gamma-counting equipment was a Canberra vertical High-purity coaxial germanium (HPGe) crystal detector, model GC2018-7500, Serial No b 87063 enclosed in a 100-mm lead shied and coupled to a Canberra Multichannel Analyzing (MCA) computer system. The quantification of radionuclide present in water samples was obtained through accurate energy and efficiency calibration using a well calibrated standard water sources supplied by the International Atomic Energy Agency (IAEA), Vienna, Austria. The techniques used are well described elsewhere [24]. The MCA was calibrated so as to display gamma photopeaks in the energy range of 200-3000 keV, this being the energy range for radionuclides of interest identified with reliable regularity. The counting time was 36,000s. An empty container identical to that of the sample was also counted for the same counting time under the same geometry to determine the background distribution spectrum. The photopeaks observed with reliable regularity belong to the naturally occurring series-decay radionuclide headed by ^{238}U and ^{232}Th, as well as the non-series decay type ^{40}K. The activities of radionuclide were calculated from the difference between net peak-and net peak background areas, accumulation time, absolute peak efficiency, absolute γ-ray emission probability and the sample volume. Measurement of radionuclide concentrations in the water sample were carried out at least twice to check on the reproducibility of results and the stability of the counting system. The overall uncertainty in the measured concentrations was estimated using the procedure already described in an earlier work [23].

3. Result and Discussion

3.1. Radioactivity Content in Water

The specific activities measured in the various types of water are reported in **Table 2** and **Figure 2**.

The activity concentration of ^{40}K ranged from 46 - 98 Bq·L^{-1} with an average of 67 ± 21 Bq·L^{-1} for well water; 12 - 32 Bq·L^{-1} with an average of 22 ± 12 Bq·L^{-1} for tap water; 7 - 177 Bq·L^{-1} for non drinkable surface water; 6 - 76 Bq·L^{-1} with an average of 36 ± 13 Bq·L^{-1} for drinkable surface water; 28

- 41 Bq·L^{-1} with an average of 34 ± 12 Bq·L^{-1} for freely falling rain water; 29 - 46 Bq·L^{-1} with an average of 38 ± 10 Bq·L^{-1} for rain water falling through aluminum sheet and between 34 - 52 Bq·L^{-1} with an average of 44 ± 10 Bq·L^{-1} for rain water falling through asbestos sheet.

For ^{238}U, the activity concentration ranged from 2 - 7 Bq L^{-1} with an average of 4 ± 2 Bq·L^{-1} for well water; 2 - 5 Bq·L^{-1} with an average of 3 ± 1Bq·L^{-1} for tap water; 1 - 12 Bq·L^{-1} with an average of 5 ± 2 Bq·L^{-1} for non drinkable surface water; 3 - 6 Bq·L^{-1} with an average of 4 ± 2 Bq·L^{-1} for drinkable surface water; 2 - 3 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for freely falling rain water; 2 - 4 Bq·L^{-1} with an average of 3 ± 1 Bq·L^{-1} for rain water falling through aluminum sheet and between 3 - 4 Bq·L^{-1} with an average of 4 ± 2 Bq·L^{-1} for rain water falling through asbestos sheet.

For ^{232}Th, the activity concentration ranged from 2 - 3 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for well water; 2 - 4 Bq·L^{-1} with an average of 3 ± 1 Bq·L^{-1} for tap water; 2 - 10 Bq·L^{-1} with an average of 5 ± 1 Bq·L^{-1} for non drinkable surface water; 1 - 4 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for drinkable surface water, 1 - 3 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for freely falling rain water; 2 – 3 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for rain water falling through aluminum sheet and between 2 – 3 Bq·L^{-1} with an average of 2 ± 1 Bq·L^{-1} for rain water falling through asbestos sheet.

The largest contribution to the overall activity in all the various types of water sample came mainly from ^{40}K with the lowest value of 6 ± 2 Bq·L^{-1} and the highest being 177 ± 52 Bq L^{-1} compared to the activity ranges of (1 - 12) Bq·L^{-1} and (1 - 10) Bq·L^{-1} for ^{238}U and ^{232}Th respectively. In fact, this can't be a surprise because Potassium-40 is a naturally occurring radionuclide which abounds in the earth crust and in human body [25,26]. The specific activity due to ^{232}Th is relatively low in all the water sample investigated. This is because ^{238}U is more mobile than ^{232}Th [27]. The activity concentration
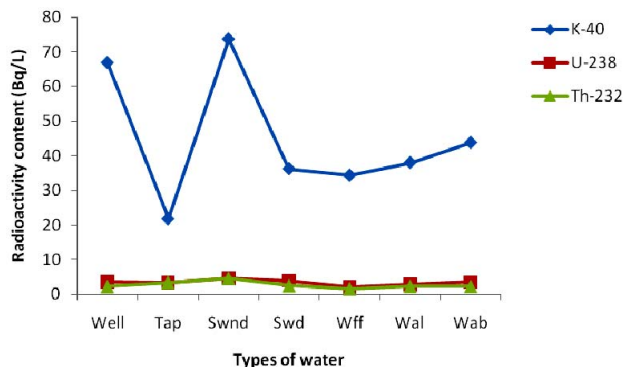

Figure 2. Radioactivity content in various types of water analyzed.

Table 2. Radioactivity in water sample in Delta State (Bq·L^{-1}).

Type	Location		^{40}K	^{238}U	^{232}Th
	W1	2	54 ± 13	2 ± 1	2 ± 1
	W2	3	62 ± 17	2 ± 0	2 ± 1
	W3	1	98 ± 23	3 ± 1	2 ± 1
Well water	W4	7	46 ± 11	7 ± 0	3 ± 0
	W5	8	74 ± 18	5 ± 1	2 ± 0
	Average		67 ± 21	4 ± 2	2 ± 1
Well water from non oil area Control 1			43 ± 11	2 ± 0	2 ± 1
Well water from non oil area Control 2			52 ± 14	2 ± 1	1 ± 0
	T1	17	12 ± 2	2 ± 0	4 ± 1
	T2	10	22 ± 8	3 ± 0	3 ± 0
Tap Water	T3	11	19 ± 7	3 ± 1	2 ± 1
	T4	13	32 ± 10	4 ± 1	4 ± 1
	T5	14	25 ± 8	5 ± 1	4 ± 1
	Average		22 ± 12	3 ± 1	3 ± 1
Tap water from non oil area Control 1			15 ± 4	2 ± 1	1 ± 0
Tap water from non oil area Control 2			23 ± 6	2 ± 1	1 ± 0
Non drinkable surface water	Swnd 1	20	177 ± 52	4 ± 1	5 ± 2
	Swnd 2	22	82 ± 4	12 ± 3	10 ± 3
	Swnd 3	Jamieson river	7 ± 2	2 ± 1	3 ± 0
	Swnd 4	15	53 ± 14	2 ± 1	2 ± 0
	Swnd 5	16	50 ± 12	4 ± 1	3 ± 1
	Average		74 ± 24	5 ± 2	5 ± 1
Non drinkable surface water from non oil area control 1			48 ± 5	2 ± 1	2 ± 1
Non drinkable surface water from non oil area control 2			62 ± 16	3 ± 1	2 ± 1
	Swd1	26	76 ± 15	3 ± 2	2 ± 1
	Swd2	21	11 ± 2	3 ± 2	1 ± 0
Drinkable surface water	Swd3	Ethiope River	6 ± 2	4 ± 2	4 ± 1
	Swd4		53 ± 15	3 ± 1	4 ± 1
	Swd5	29	34 ± 13	6 ± 3	2 ± 1
	Average		36 ± 13	4 ± 2	2 ± 1
Drinkable surface water from non oil area control 1			13 ± 4	3 ± 2	2 ± 1
Drinkable surface water from non oil area control 2			18 ± 7	3 ± 1	2 ± 1
	Free fall Wff1	18	41 ± 11	3 ± 1	3 ± 1
	Wff2	19	34 ± 12	2 ± 1	1 ± 0
	Wff3	23	28 ± 11	2 ± 1	1 ± 0
	Average		34 ± 12	2 ± 1	2 ± 1
	Free fall non oil area control 1		197 ± 8	2 ± 1	1 ± 0
	Free fall non oil area control 2		21 ± 7	2 ± 1	1 ± 0
	Through Aluminum sheet Wal 1	2	46 ± 13	2 ± 1	3 ± 1
	Wal 2	32	39 ± 11	4 ± 2	2 ± 1
Rain water	Wal 3	24	29 ± 10	3 ± 2	2 ± 1
	Average		38 ± 10	3 ± 1	2 ± 1
	Non oil area Control 1		23 ± 8	2 ± 1	2 ± 1
	Non oil area Control 2		28 ± 8	3 ± 1	2 ± 1
	Through Abestor sheet Wab 1	25	52 ± 14	2 ± 1	2 ± 1
	Wab 2	27	45 ± 10	4 ± 2	3 ± 1
	Wab 3	28	34 ± 11	4 ± 2	2 ± 1
	Average		44 ± 10	4 ± 3	2 ± 1
	Non oil area Control 1		33 ± 12	3 ± 1	2 ± 1
	Non oil area Control 2		29 ± 10	3 ± 1	2 ± 1

		Others Works			
Countries	**Types of water**	^{40}K	^{238}U	^{232}Th	**Reference**
China	Ground water		0.001 - 0.93		[34]
Denmark	Wells		0.55		[35]
Austria	Domestic bottle water		0.04		[36]
Tunisia	Springs		0.034-3.9		[37]
Hungary	Bottled mineral water		0.1 - 3		[38]
Northest Spain	Surface	0.132	0.0282		[39]
U.S.A.	Drinkable		2 - 10		[16]
Nigeria	Well	92 - 108.88	2.9 - 13.55	0.34 - 3.89	[23]
	Tap	71.33 - 109.39	10.50 - 13.65	2.35 - 2.58	
	Surface	48.39 - 89.98	6.38 - 7.70	3.43 - 3.68	

of ^{238}U, ^{232}Th and ^{40}K were relatively higher in non drinkable surface water compared to other types of water. In fact, many of that non drinkable water were stable if not, have a very low flowing speed, and hence accumulated almost all the elements arising from transport and erosion. This trend is also noticeable in well water for ^{40}K.

The overall lowest activity concentration for ^{238}U, ^{232}Th and ^{40}K was obtained in freely falling rain water. This can be predictable since free fall is the first pathway from which all types of water passed through the atmosphere to the earth where more radionuclide contaminants are found. The activity concentration of ^{238}U, ^{232}Th and ^{40}K are higher in rain water collected through asbestos sheet than that of rain water through aluminum sheets. The explanation for this could be found in a recent study by Olomo *et al*. [4] on the surveying of radionuclide in building materials used for Nigerian dwellings which reported higher activity concentrations of ^{238}U, ^{232}Th and ^{40}K in asbestos as a roofing materials.

Location 20 (Oweh) present the highest activity concentration for ^{40}K from a non drinkable surface water. That location is an end point of a small tributary of Eriona river where water accumulate during raining- and dry seasons.

Enhanced levels of uranium, thorium and their daughter products might be present in water in areas that have relatively high natural radioactivity. The overall mean specific activity was high in surface water compared to other types of water such as tap and all type of rain water sample. As ground water moves through fractures in the bedrock that contain these deposits of radioactive minerals, the deposits can leach out into the ground water system. Others factors are likely to influence the uranium concentration in natural surface water and ground water [28] such as uranium content of the source rocks, sediments or soils and the processes through which uranium may be leached, the proximity of the water to the uranium source, the degree of hydraulic isolation of the water by fresher surface or ground water, the oxidation state of the water and the concentration of suitable complexing agents, which can increase the solubility of uranium [28].

In addition, no correction was found between the concentration of ^{238}U and ^{232}Th. In our investigation, for the majority of cases the concentration of ^{238}U exceeded that of ^{232}Th. In fact, the geological and solubility properties of ^{238}U and ^{232}Th are different. Their occurrences in water are determined by several factors such as the geology and their geochemistry [29] which allows them to move easily and to contaminate much of the human's environment. Uranium, in particular, is easily mobilized in ground water and surface water. As a result, uranium and

its decay product, radium, enter the water supply through ground water, well water, surface water, streams and rivers.

The high activity concentration may also be attributed to the oil and gas activities. In fact, not only the rock formation that hold oil and gas contain natural radioactive elements, but naturally radioactive elements are dissolved into ground water, and the produced water can accumulate at different points in oils and gas production facilities [30]. Thus, extraction and separation processes stages can have accumulation of radionuclide and some will remain in the water after the processes. This produced water is brought out with oil and gas unavoidably and then leached to the surrounding environment through transport or erosion, resulting to its contamination.

Geologically, the bedrocks are mainly sedimentary made up of sandstones and gravel. They are usually made of grains that are primarily quartz but may contain some potassium containing feldspar. On the whole, they are low in both the series and non-series radionuclide. However, many deposits of uranium are found at the boundary of different layers of sandstones.

Although the results of our investigation are high when compare to that of a non oil and gas areas (control) with similar geology, but still within arrange obtained elsewhere [23].

3.2. Total Annual Effective Doses from Daily Intakes of ^{238}U, ^{232}Th and ^{40}K from Water

When analyzing the total annual effective dose to the human population from natural sources, the dose received by ingestion of long-lived natural radionuclide must be considered. Effective doses resulting from intake of ^{238}U, ^{232}Th and ^{40}K may be determined directly from all the water types since some of them are ingested indirectly by man. Assuming the volume of the daily intake of a drinking water for adult male to be 1 L·d^{-1} [31], the annual effective dose was calculated with the intake of individual radionuclide and ingestion doses coefficients (Sv·Bq^{-1}) reported by the International Commission on Radiological Protection [32]. The equation for calculating the annual effective dose per person is given by:

The Annual Effective Dose (AED) is given by:

$$AED = \sum_i I_i \times 365 \times D_i$$

where I_i is the daily intakes of radionuclide i (Bq·d^{-1}); D_i is the ingestion dose coefficient (Sv·Bq^{-1}).

The results obtained are presented in **Table 3** and **Figure 3**. The derived AED received by the population as a result of the ingestion of ^{238}U in water is estimated to have a range of 0.1 - 0.7 μSv·y^{-1} with an average of 0.4 ± 0.2 μSv·y^{-1} in well water; 0.2 - 0.5 μSv·y^{-1} with an average of

Table 3. Daily intakes ^{40}K, ^{238}U and ^{232}Th and the estimated annual effective doses from water in Delta State, Nigeria.

| Water types	Code	Intake per person (Bq d^{-1})			Annual effective dose (μSv·y^{-1}) Ingestion doses coefficient (Sv·Bq^{-1}) (ICRP 68 1994)		
					6.2×10^{-9} Sv·Bq^{-1} for ^{40}K	2.8×10^{-7} Sv·Bq^{-1} for ^{238}U	6.9×10^{-7} Sv·Bq^{-1} for ^{232}Th
		^{40}K	^{238}U	^{232}Th	^{40}K	^{238}U	^{232}Th
Well	W1	54 ± 13	2 ± 1	2 ± 1	0.1 ± 0.0	0.2 ± 0.1	0.6 ± 0.2
	W2	62 ± 17	2 ± 0	2 ± 1	0.1 ± 0.0	0.2 ± 0.1	0.5 ± 0.2
	W3	98 ± 23	3 ± 1	2 ± 1	0.2 ± 0.1	0.3 ± 0.1	0.4 ± 0.2
	W4	46 ± 11	7 ± 0	3 ± 0	0.1 ± 0.0	0.7 ± 0.1	0.8 ± 0.1
	W5	74 ± 18	5 ± 1	2 ± 0	0.2 ± 0.0	0.5 ± 0.1	0.6 ± 0.1
	Average	67 ± 21	4 ± 2	2 ± 1	0.2 ± 0.1	0.4 ± 0.2	0.6 ± 0.4
Well water from non oil area Control 1		43 ± 11	2 ± 0	2 ± 1	0.1 ± 0.0	0.1 ± 0.0	0.3 ± 0.2
Well water from non oil area Control 2		52 ± 14	2 ± 1	1 ± 0	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.1
Tap Water	T1	12 ± 2	2 ± 0	4 ± 1	0.0 ± 0.0	0.2 ± 0.0	1.0 ± 0.3
	T2	22 ± 8	3 ± 0	3 ± 0	0.1 ± 0.0	0.3 ± 0.0	0.8 ± 0.1
	T3	19 ± 7	3 ± 1	2 ± 1	0.0 ± 0.0	0.3 ± 0.0	0.5 ± 0.2
	T4	32 ± 10	4 ± 1	4 ± 1	0.1 ± 0.0	0.4 ± 0.1	1.0 ± 0.2
	T5	25 ± 8	5 ± 1	4 ± 1	0.1 ± 0.0	0.5 ± 0.1	1.0 ± 0.3
	Average	22 ± 12	3 ± 1	3 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.9 ± 0.3
Tap water from non oil area Control 1		15 ± 4	2 ± 1	1 ± 0	0.0 ± 0.0	0.2 ± 0.1	0.2 ± 0.1
Tap water from non oil area Control 2		23 ± 6	2 ± 1	1 ± 0	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.1
Non drinkable surface water	Swnd 1	177 ± 52	4 ± 1	5 ± 2	0.4 ± 0.1	0.4 ± 0.1	1.3 ± 0.4
	Swnd 2	82 ± 4	12 ± 3	10 ± 3	0.2 ± 0.0	1.2 ± 0.4	2.5 ± 1.2
	Swnd 3	7 ± 2	2 ± 1	3 ± 0	0.0 ± 0.0	0.1 ± 0.0	0.8 ± 0.1
	Swnd 4	53 ± 14	2 ± 1	2 ± 0	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.1
	Swnd 5	50 ± 12	4 ± 1	3 ± 1	0.1 ± 0.0	0.4 ± 0.0	0.7 ± 0.1
	Average	74 ± 24	5 ± 2	5 ± 1	0.2 ± 0.1	0.5 ± 0.2	1.2 ± 0.4
Non drinkable surface water Control 1	from non oil area	48 ± 5	2 ± 1	2 ± 1	0.1 ± 0.0	0.2 ± 0.1	0.5 ± 0.2
Non drinkable surface water Control 2	from non oil area	62 ± 16	3 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.60 ± 0.3
Surface water drinkable	Swd 1	76 ± 15	3 ± 2	2 ± 1	0.2 ± 0.0	0.3 ± 0.0	0.3 ± 0.2
	Swd 2	11 ± 2	3 ± 2	1 ± 0	0.0 ± 0.0	0.3 ± 0.0	0.3 ± 0.1
	Swd 3	6 ± 2	4 ± 2	4 ± 1	0.0 ± 0.0	0.4 ± 0.1	1.0 ± 0.1
	Swd 4	53 ± 15	3 ± 1	4 ± 1	0.1 ± 0.0	0.4 ± 0.0	1.0 ± 0.2
	Swd 5	34 ± 13	6 ± 3	2 ± 1	0.1 ± 0.0	0.6 ± 0.3	0.6 ± 0.1
	Average	36 ± 13	4 ± 2	2 ± 1	0.1 ± 0.0	0.4 ± 0.2	0.6 ± 0.4
Drinkable surface water from non oil area Control 1		13 ± 4	3 ± 2	2 ± 1	0.0 ± 0.0	0.3 ± 0.2	0.6 ± 0.2
Drinkable surface water from non oil area Control 2		18 ± 7	3 ± 1	2 ± 1	0.0 ± 0.0	0.4 ± 0.1	0.4 ± 0.2
Free fall	Wff1	41 ± 11	3 ± 1	3 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.7 ± 0.3
	Wff2	34 ± 12	2 ± 1	1 ± 0	0.1 ± 0.0	0.2 ± 0.1	0.2 ± 0.1
	Wff3	28 ± 11	2 ± 1	1 ± 0	0.1 ± 0.0	0.2 ± 0.1	0.3 ± 0.2
	Average	34 ± 12	2 ± 1	2 ± 1	0.1 ± 0.0	0.2 ± 0.1	0.4 ± 0.3
Non oil area Control 1		197 ± 8	2 ± 1	1 ± 0	0.0 ± 0.0	0.2 ± 0.1	0.3 ± 0.2
Non oil area Control 2		21 ± 7	2 ± 1	1 ± 0	0.1 ± 0.0	0.2 ± 0.1	0.1 ± 0.0
Rain water	Wal 1	46 ± 13	2 ± 1	3 ± 1	0.1 ± 0.0	0.2 ± 0.1	0.6 ± 0.3
Through Aluminum sheet	Wal 2	39 ± 11	4 ± 2	2 ± 1	0.1 ± 0.0	0.4 ± 0.1	0.5 ± 0.3
	Wal 3	29 ± 10	3 ± 2	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.6 ± 0.2
	Average	38 ± 10	3 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.6 ± 0.3
Non oil area Control 1		23 ± 8	2 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.2
Non oil area Control 2		28 ± 8	3 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.2
Through Abestor sheet	Wab 1	52 ± 14	2 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.2	0.4 ± 0.2
	Wab 2	45 ± 10	4 ± 2	3 ± 1	0.1 ± 0.0	0.4 ± 0.2	0.7 ± 0.3
	Wab 3	34 ± 11	4 ± 2	2 ± 1	0.1 ± 0.0	0.4 ± 0.1	0.6 ± 0.3
	Average	44 ± 10	4 ± 3	2 ± 1	0.1 ± 0.0	0.4 ± 0.3	0.6 ± 0.3
Non oil area Control 1		33 ± 12	3 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.5 ± 0.2
Non oil area Control 2		29 ± 10	3 ± 1	2 ± 1	0.1 ± 0.0	0.3 ± 0.1	0.6 ± 0.3
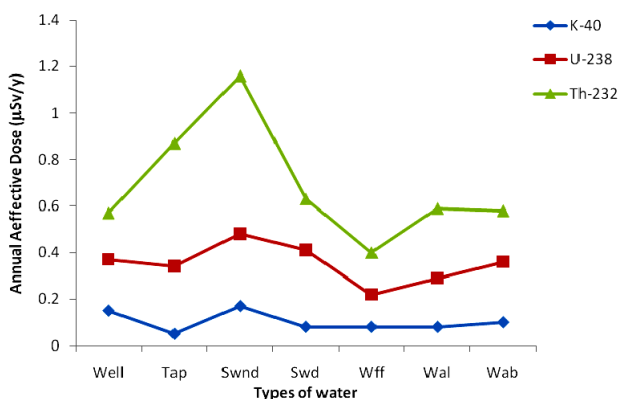
Figure 3. Annual effective dose in various types of water analyzed.

0.3 ± 0.1 μSv·y^{-1} in tap water; 0.1 - 1.2 μSv·y^{-1} with an average of 0.5 ± 0.2 μSv·y^{-1} in non drinkable surface water, 0.3 - 0.6 μSv·y^{-1} with an average of 0.4 ± 0.2 μSv·y^{-1} in drinkable surface water; 0.2 - 0.3 μSv·y^{-1} with an average of 0.2 ± 0.1 μSv·y^{-1} in free fall rain water; 0.2 - 0.4 μSv·y^{-1} with an average of 0.3 ± 0.1 μSv·y^{-1} in rain water through aluminum sheets; 0.3 - 0.4 μSv·y^{-1} with an average of 0.4 ± 0.3 μSv·y^{-1} in rain water through asbestos sheet. While the derived AED received by the population as a result of the ingestion of ^{228}Ra in water is estimated to have a range of 0.1 - 0.3 μSv·y^{-1} with an average of 0.2 ± 0.1 μSv·y^{-1} in well water; 0.2 - 0.4 μSv·y^{-1} with an average of 0.3 ± 0.1 μSv·y^{-1} in tap water; 0.2 - 0.8 μSv·y^{-1} with an average of 0.4 ± 0.1 μ Sv·y^{-1} in non drinkable surface water; 0.1 - 0.3 μSv·y^{-1} with an average of 0.2 ± 0.1 μSv·y^{-1} in drinkable surface water; 0.1 - 0.2 μSv·y^{-1} with an average of 0.2 ± 0.1 μSv·y^{-1} in free fall rain water; 0.1 - 0.2 μSv·y^{-1} with an average 0.2 ± 0.1 μSv·y^{-1} in rain water through aluminum sheets; 0.1 - 0.2 μSv·y^{-1} with an average 0.2 ± 0.1 μSv·y^{-1} in rain water through asbestos sheets (**Table 3**). Also the ^{40}K contribution for the AED was very low when compared with that of ^{238}U and ^{232}Th. According to ICRP recommendations [33] the limit for public exposure should be expressed as an effective dose of 1 mSv·y^{-1}. The doses estimated from our investigation are below that limit for all water samples. Although, the water sample with the dose close to that limit is not used for any direct purpose, but it get into soil and can find his way into foods through roots. It is therefore vital to manage it through proper disposal. The lowest AED was found in rain water falling freely and the highest in non drinkable surface water.

4. Conclusion and Recommendations

This work is aimed at measuring the concentration of naturally occurring radionuclide as well as man-made ones Cs-137 in community water in oil and gas producing areas in Delta State, Nigeria. The results of the investigation indicated that the average specific activity concentrations of ^{238}U and ^{232}Th and ^{40}K in community water have consistent values with those reported in other countries in the world. The highest Annual Effective Dose from daily intakes of these radionuclides came from non drinkable surface water. Proper disposable, seasonal and regular monitoring of this type of water, which generally is wastes from industries, should be carrying out.

5. Acknowledgements

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