RADIOACTIVITY ASSESSMENT OF SHALLOW AQUIFERS AND WARRI RIVER IN UDU AREA OF THE WESTERN NIGER DELTA, NIGERIA

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Abstract: The availability of ^{238}U, ^{232}Th and ^{40}K in sequence of rocks consisting the Agbada Formation in the Niger Delta Basin has enhanced the discrimination of non-reservoir from reservoir rocks by geophysical logging. The overlying Benin Formation, a well-known freshwater source of the three lithostratigraphy of the basin. The radionuclide constituent of groundwater of the Benin Formation and surface water information remained unknown. The health and risk implications of consuming water with significant radionuclides is lethal. Consequently, it is necessary to establish the radionuclide status of aquifers, as groundwater to a large extent and river water to a lesser extent are sources of drinking water in the Niger delta. Therefore, gamma–ray spectroscopy and Halium Sodium Iodide (NaI) were used to appraise the Uranium (^{238}U), Thorium (^{232}Th) and potassium (^{40}K) constituents of groundwater and river water. The concentrations of these radioactive elements in shallow borehole water ranged from 31.06 - 66.18 Bq/L (^{40}K), 1.88-3.04 Bq/L(^{238}U), 1.62-3.37 Bq/L (^{232}Th). Groundwater from dug wells ranged from 41.82-58.10 (^{40}K), 2.09 -5.68 (^{238}U), 2.13–4.12 (^{232}Th) and the ^{40}K for river samples ranged from 31.32-49.12, (^{238}U) is from 4.08-4.41 and ^{232}Th is 2.84-3.11. The concentrations of ^{40}K, ^{238}U and ^{232}Th in the different water types are slightly above the maximum contaminant levels for drinking water. Radionuclide's concentrations are comparatively lesser in the groundwater samples than river samples. Additional examination disclosed that the dose rate for water, annual gonnadal equivalent dose and excess lifetime cancer riskis all far below the acceptable standard limits. It is worth mentioning that the radionuclides compositions of the waters are profoundly natural without any known effects of anthropogenic activities and also, may not constitutes a severe health threat to consumers.

Keywords: Radionuclides, Gamma-ray spectroscope, dose rate, groundwater, Warri Rivers

Introduction

Since the formation of the earth, radioactive materials have existed with potassium (^{40}K), uranium (^{238}U), and thorium (^{232}Th) are the most abundant radioactive elements found in nature (ATSDR, 2000). They are concentrated at the earth's surface and in higher quantities within the crust. ^{2238}U and ^{232}Th are abundant in silica-rich igneous and metamorphic rocks, particularly granitic rocks, and are also highly enriched in zircon-rich rocks. The pathway and mechanism of redistribution into the environment, notably in soils and sedimentary rocks, is weathering and erosion of radioactively enriched rocks. They are found as trace elements in rocks and soils (UNSCEAR, 2000) and invariably exist in dissolved form in groundwater and surface water.

Runoff enriches surface water, such as streams and rivers, with radioactive materials. Their concentrations in water can range from extremely low to extremely high. The emission of alpha, beta, and gamma radiations as byproducts of radionuclide decay is a prominent and important property of radionuclides. Some of these radiations have been linked to negative health effects in humans, as a result of unprotected exposures to radiation from their decays, humans have been diagnosed with lung illnesses, leucopoenia anemia, and mouth necrosis (Suresh Gandhi et al 2014).Lung, pancreas, hepatic, bone, kidney, and leukemia are all known to be caused by long-term unprotected exposure to external ^{232}Th concentrations (Taskin et al., 2009).Internal radiation exposure is frequently caused by drinking polluted water, eating contaminated foods, and breathing contaminated air. The degree of health risk is determined by the geological conditions of the soils and the extent of exposure. Given the seriousness of the health effects of radionuclide radiation on humans, it is imperative that humans exercise vigilance in their surroundings, as radionuclides can be found in rocks, plants, water, and air.

The Agbada Formation is a Niger Delta oil and gas province with a sufficient amount of ^{238}U, ^{232}Th, and ^{40}K. Their presence in this formation has improved the mapping of reservoir from non-reservoir rocks, in this example sandstone from shale rocks, over time.Of the three formations that make up the Niger Delta stratigraphy, the Benin Formation is the only one that contains freshwater. There is a scarcity of data on the natural radioactivity of the groundwater and surface water in this Formation and the study region. In the lack of water infrastructure, the health and risk consequences of drinking water from shallow aquifers of the Benin Formation and river water have not been extensively explored. As a result, we look into the state of groundwater and river water to ascertain if they are enriched in ^{238}U, ^{232}Th, and ^{40}K, and hence safe to drink.

The area of study

The area comprises of Ovwian, Aladja, Ekete, Ujevwu, Owasie and Obudu towns located in the flood plains of the Warri River (Fig. 1). The Delta state steel complex is located in the Ovwian-Aladja town. Geomorphologically, the area is low-lying with elevation that varies from 4 to 6 m above msl, thus the topography is entirely flat without no discernible difference in elevation. The climate is solely dominated by dry and wet seasons, respectively. Temperature varies from 26ºC in the wet season to a maximum of 34ºC dry season. The wet season is often experienced from April to October with high humidity, while dry season is from November to March with low humidity. A brief season within the dry season is the Harmattan season, which often spans from December to January. This season is characterized by dry and dusty wind. The wind enters Nigeria from the Sahara desert and blows towards the Gulf of Guinea located some 40 km from the study area.

Geologically, the subsurface beneath the area under consideration consists of alluvial deposits of the Benin Formation, which mantled the Agbada and the marine Akata Formation. The basal unit of the Niger Delta stratigraphy is the highly pressurized Akata Formation. The alluvial deposit is commonly characterized by unconsolidated silts, clays, sands and gravels. These unconsolidated alluvial sands and gravels deposits constitute the aquifers of the area. The aquifers varied from fine through medium to coarse grained. The intercalation of aquifer sediments is common in the alluvial deposits.

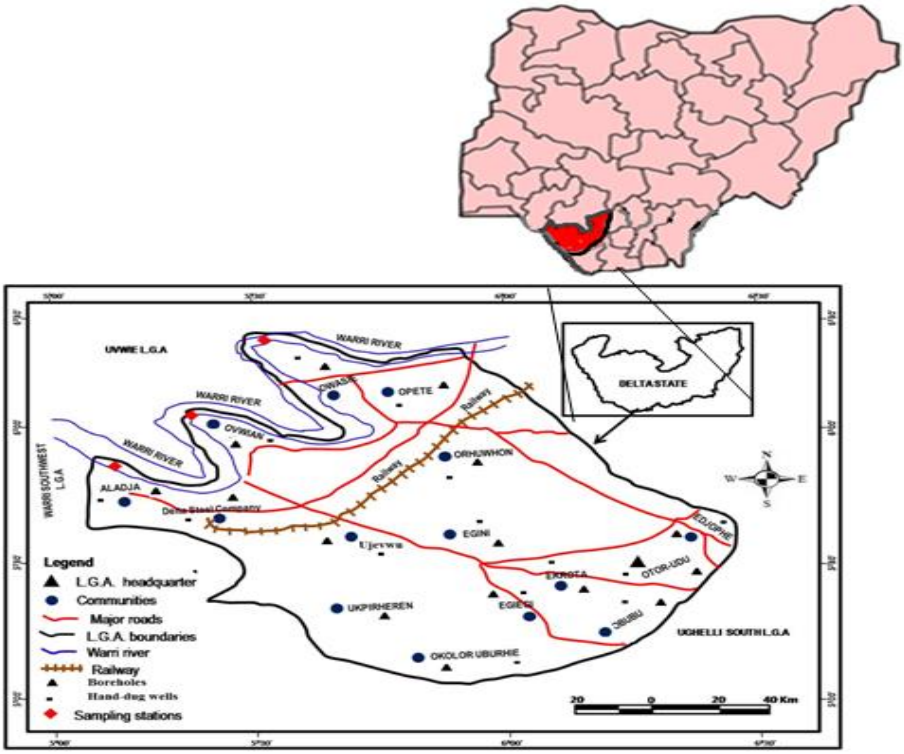

Fig. 1: Map of the study area depicting groundwater and surface water sampling points

Groundwater is sourced mostly from shallow and rarely from deep aquifers by hand-dug wells and boreholes, respectively. Groundwater level varies from less than 1 to 4 m, and it is greatly control by the operative seasons. The Warri River and its tributaries drained the areas. Fishing, sand dredging, farming, and tourism are among the economic occupation of the people.

Materials and Methods

Sample collection

Three water samples were collected from various portions of the Warri River at Udu designated as R, including 14 from boreholes designated as BH, 14 dug wells designated as DW. A thoroughly washed and well dried 2-liter plastic container was used for the collection of samples. To ensure groundwater is a representative of the aquifer, the boreholes were pumped for a reasonable time before collection of samples. Samples from dug wells and river were collected directly. Containers were rinsed with samples prior to collection. All collected samples were immediately acidified with 10 $\pm$ 1 ml of 11 MHCL per liter to avoid absorption of radioactivity on the walls of the containers (1AEA, 2003). To permit thermal expansion, samples were not filled to the brim; consequently, 1% air space was left unfilled by samples. The samples were transferred to the Obafemi Awolowo University's Centre for Energy Research and Development (CERD) in Ile-Ife, Nigeria, for laboratory analysis.

Laboratory analysis

One-liter beakers were washed and rinsed with dilute sulfuric acid and dried. This was to ensure samples were not contaminated. The beakers were subsequently filled with known volume of water samples and firmly sealed for four weeks. This was to ensure that the loss of radon is prevented and, also to ensuring secular equilibrium before gamma-ray laboratory analysis commenced.

A thallium activated 3" x 3" sodium iodide [Nal (TI)] detector was connected to a computer running SAMPO 90 window software. This program was used to match gamma energy to a database of probable isotopes. The precision of the quantitative measurements is dependent on the spectrometry system's calibration and sufficient energy. Cs137 and Co-60 standard sources from the International Atomic Energy Agency (IAEA), Vienna, were used to measure the system's background and calibrate it. To determine the concentration of 238U and 232Th, the spectrum was aggregated or background for 29000 secs at 00 volts to produce strong peaks at gamma emitting energy of 4.60 kev for 40K, 609 kev for 214 Bi, and 911 kev for 228Ac. The detector's energy resolution with Cs13 and Co standards is 39.5 percent and 22.2 percent, respectively, while the standard's activity at the time of calibration is 25.3 KBq for Cs–137 and 4.84 KBq for Co-60. The calculated sample activity concentration was corrected in line with the background spectra measurement under the same conditions for both the standard and sample measurements (Arogunjo *et al*., 2005). Each sample was sealed and counted for 36000 seconds on a sodium iodide detector. The samples were counted using a lower gamma iodide (Nai), which was combined with amplification of the input signals and integration to volts (0 = 10 VOLTS).It also includes a desktop computer with an analog to digital converter (A.D.C) and an S100 multi–Digital Analyzer card. On the computer screen, the result was shown as a spectrum, and the gamma emitting radionuclides present were identified by their characteristic pulse height.

Calculation of radiological risk indices

Absorbed dose rate (D)

The main source of D in the air is terrestrial gamma radionuclide, which is found in modest quantities in soils. The exact activity concentrations (AC) of radionuclide determined simply from 238U, 232Th, and 40K always influence D. Radionuclide concentrations and terrestrial gamma radiation are related (Avwiri, 2015). As a result, once the radionuclide activity is known, the equation below can be used to determine its exposure D in air at one meter above the surface.

$D = 0.462A_u + 0.621A_{Th} + 0.041A_K$---------- (1),

D is the dose rate in Gyhy1, and A_u, A_{Th}, and A_K are the U, Th, and K concentrations, respectively. The dosage conversion factor for translating AC of 238U, 232Th, and 40K into doses [(Gyhy1 per Bq1–1)] is 0.462, 0.621, and 0.041, according to UNSCEAR (2000).

Annual gonadal equivalent dose (AGED)

Radiation sensitive organs such as bone marrow, bone surface cells, lungs, gonads, thyroid, and female breast, as well as other organs, are vital. There is a major health risk linked with their exposure to radiation doses that are higher than the recommended maximum amounts. Following that, AGED was calculated using the equation proposed by Mamont-Ciesla *et al*. (1982) as shown below:

AGED ($Svyr^{-1}$) = $3.09C_U + 4.18C_{Th} + 0.314C_K$ ---------- (2)

Where C_U, C_{Th}, and C_K are the U, Th, and K activity concentrations, respectively.

Excess lifetime cancer risk (ELCR)

ELCR refers to a person's lifetime risk of developing cancer as a result of exposure to a specific level of radiation. The equation presented by Taskin *et al*. (2009) was used to get ELCR, which is given by the expression below;

ELCR = AEDE * DL * RF ---------- (3)

Where AEDE is for annual effective equivalent; DL stands for lifetime (duration of 70 years); and RF stands for Risk Factor (0.05 Sv-1). The International Commission on Radiological Protection (ICRP, 1994) uses a value of 0.05 for the public for stochastic effects (Taskin *et al*., 2009).

Outdoor and indoor annual effective dose rate (AED)

Natural dissolved radionuclides in ground and surface waters are ingested by humans through water intake. The outdoor AED of the different radionuclides in water ingested by human was calculated from annual effective dose rate ($mSvyr^{-1}$) = D ($\eta Gyrhr^{-1}$) * 8760 $hyrh^{-1}$*0. 7 * (10^3 mSv/10^9) ηGY * 0.2 * 10^{-3}, which is summarized in equation 4 (UNSCEAR, 2000) below;

E_{ff} Dose = D1.2264 * 10^{-3} ----------4

Where, D is effective dose rate. UNSCEAR (2000) recommended 0.7 Sv/Gy as the coefficient of conservation from absorbed dose in air to effective dose, and 0.2 (5/24) as the outdoor occupancy factor.

The annual effective dosage rate for indoors was determined using the formula: Effective dose ($mSvyr^{-1}$) = D ($\eta Gyrhr^{-1}$) * 8760 $hyrh^{-1}$ * 0. 7 * 10^3 MSv/10^9) ηGY * 0.8 * 10^{-6} ---------5

UNSCEAR (2000) recommended 0.8 Sv/Gy as the conversion coefficient from absorbed dose in air to effect dose 2.8 (19/24) as the value for the occupancy factor.

Results and Discussion

Table 1 shows the AC of radionuclides 238U (226Ra), 238Th (228Ra), and 40K in groundwater and surface water samples taken from boreholes, hand-dug wells, and the Warri River. The 40K >238U >238Th sequence is the increasing order of AC of radionuclide in both groundwater (hand-dug wells and boreholes) and river water. There are small differences in the AC values measured in the study's groundwater and river samples. The AC for 238U in groundwater was found to range from 1.88±2.34 to 5.68±1.28 Bq/L, ^{238Th} from 2.62±2.43 to 4.12±2.06 Bq/L, while ^{40}K ranged from 31.06±12.09 to 58.10±17.10 Bq/L.

Those for the river water ranged from 4.08±1.32 to 4.41 ± 5.68 Bq/L for ^{238}U, 2.84 ±1.19 to 3.11±1.84 Bq/L, while ^{40}K ranged from 31.32 ± 18.03 to 49.12 ± 22.26 Bq/L. The values of AC obtained in the study are comparatively above the requisite permissible limit of 1.0, 0.1 and 10.0 Bq/L, respectively, specified for ^{238}U, ^{238}Th and ^{40}K (WHO, 2008) for both surface water and groundwater. Generally, the groundwater samples are characterized by low AC and are lower (Figure 2), when compared to those obtained from basement aquifers in central Nigeria (Omeje, 2016; Juliet, 2006; Onoja, 2004). Similarly, they are lower than those presented by Agbalagba *et al*. (2013) and Agbalagba and Osakwe (2013) for oil and gas producing communities in the region of the Niger Delta. Furthermore, our values are substantially lower than groundwater obtained from northern of Nigeria state of Zamfara (Saidu and Bala, 2018) and Belgium aquifers (Onoja, 2004), respectively. The low values for our groundwater samples are probably expected for unconsolidated sediments, which constitute the aquifers matrix. Unconsolidated sediments are often characterized by low AC when compared to those of igneous and metamorphic aquifers (Nguyen *et al.*, 2011).Studied areas with significant high values of AC except those from north central Nigeria are attributable to have be enimpacted by anthropogenic activities of oil and gas exploitation in the region of the Niger Delta (Agbalagba *et al*., (2013; Agbalagba and Osakwe, 2013).

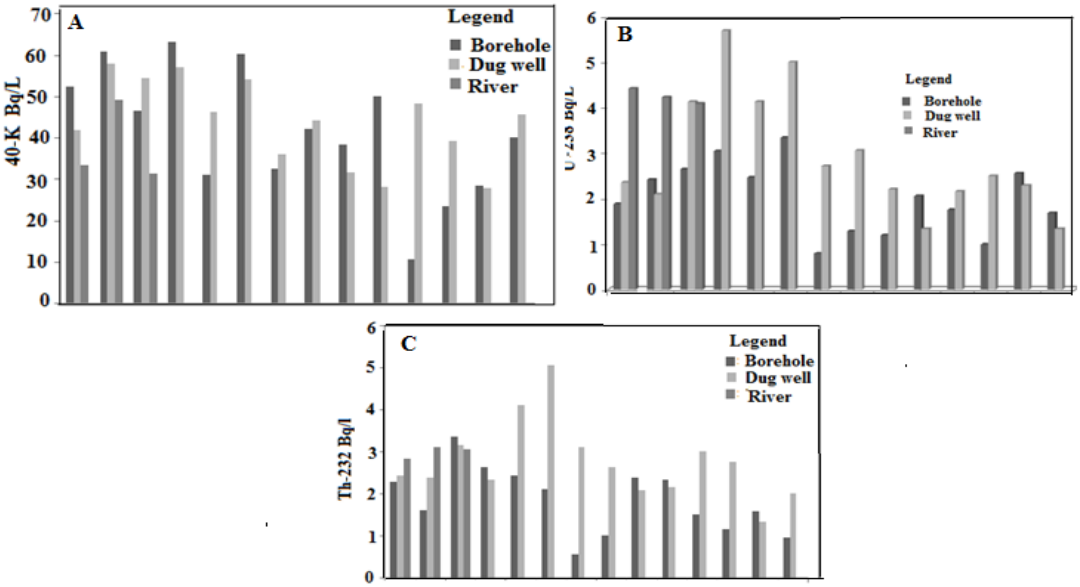

Fig. 2: Comparison of specific AC (Bq/L) of K-40 (A), U-338(B) and Th-232 (C) among boreholes, dug wells and river waters

Though our area studied is also forms part of the oil producing communities, our data were devoid of such oil exploration and exploitation activities. However, the slightly high values observed among the river samples may have resulted from impact of oil spillage, which was carried by the flowing Warri River. Therefore, radioactivity of groundwater samples may have resulted from interaction of groundwater with unconsolidated sediments of aquifer with minor quantity of ^{238}U (^{226}Ra), ^{238}Th (^{228}Ra) and ^{40}K. The unconsolidated sediments which constitute aquifers are rich in aluminosilicate and potassium feldspar (Nguyen *et al* 2011). Weathering occurring within aquifer may be responsible for the release of dissolved K into groundwater. Its concentration in groundwater is often determined by the quantity of K contained in the sediments. Confined aquifer can also release the K, U into the aquifer, since clay is often rich in organic matter rich in these elements (Nguyen *et al.,* 2011; Ohwoghere-Asuma, 2017). Organic matter rich in U and Th may enrich aquifer through infiltration from organic soils into the unsaturated zones and subsequently into groundwater through percolation. The aquifers in the Niger Delta consist of lithology matrix of admixture of clay, sand and iron.

This may also contribute to the low values of AC delineated as their mobility may be impaired by the aquifer matrixes. This known to be of slow mobility due to sorption by sediments with some amount of iron hydroxide and humic substance in the aquifer (Nguyen *et al.,* 2011; Murphy *et al*., 1999). It can also enrich groundwater through leaching of soil with weak sorption characteristics.

Among the groundwater AC values, water from hand-dug wells is generally of larger magnitude than boreholes (Fig. 2), with an exception of Dw1 and Dw2, with values of 2.35±1.76 and 2.09±1.27 Bq/L, respectively (Table 1). These values are consistent with those detected by Agbalagba *et al.* (2013) for certain areas of the Delta but higher than our values. The high magnitude of AC in hand-dug wells is probably raised by aggregates of granitic rock used for the construction of rig wells. The AC values obtained for ^{238}U, ^{238Th} and ^{40}K are greater for groundwater than river water. The AC for the three sections (R1, R2 and R3) along the Warri River course at Udu is more or less constant but not unmindful of the highest AC uncertainty values of ±5.65 Bq/L displayed by R1 (Table 1).Comparatively these values are lower than those from rivers in some other oil producing communities of Uzere, Evwreni, Otorogun and Oweh reported by Agbalagba *et al.* (2013) and Oyan river in Ogun (Ibikunle *et al.,* 2016), but higher than what Zaini *et al*. (2014) described for the Langat River Estuary, Selangor in Malaysia. The AC values observed for the Warri River at Udu is probably attributable to oil spillage from oil facilities, vessels and boats that usually navigate through the river. Another probable source of AC is influx of terrigenous materials eroded and carried by run-off into the Warri River.

Table 1: Specific AC ofU-238, Th-232 and K-40 concentrations in water from boreholes, dug wells and river

S/No	U – 238 (^{226}Ra)(Bq/L	Th – 232 (^{228}Ra)(Bq/L	40K(Bq/L
BH1	1.88±2.34	2.30± 1.38	52.33±20.09
BH2	2.41±1.43	1.62 ±2.43	60.75±12.43
BH3	2.64±2.74	3.37±0.26	46.67±10.17
BH4	3.04±2.77	2.64 ± 1.33	63.30±19.21
BH5	2.46±1.51	2.43±3.44	31.06±2.09
BH6	3.33±1.05	2.11±1.93	60.17±18.25
BH7	0.79±1.03	0.56±2.88	32.54±0,98
BH8	1.28±2.31	1.01±1.44	42.10±3.22
BH9	1.19±0.92	2.38±0.25	38.41±14.33
BH10	2.05±1.47	2.33±1.67	50.07±9.01
BH11	1.75±1.61	1.51±1.22	10.68±18.22
BH12	0.99±3.10	1.16±0.88	23.44±10.14
BH13	2.55±1.72	1.58±1.03	28.51±9.11
BH14	1.68±2.22	0.96±2.10	40.09±6.44
DW1	2.35±1.76	2.45±1.09	41.82±10.3
DW2	2.09±1.27	2.38±3.12	58.10±17.10
DW3	4.12±2.46	3.17±1.71	54.45±14.94
DW4	5.68±1.28	2.33±2.96	56.98±11.83
DW5	4.12±2.26	4.12±2.06	46.19±16.14
DW6	4.99±3.21	5.07±3.11	54.12±09.63
DW7	2.71±0.32	3.11±0.09	36.03±12.00
DW8	3.05±2.33	2.64±1.11	44.11±06.15
DW9	2.20±3.07	2.09±2.07	31.61±14.21
DW10	1.33±1.48	2.17±1.45	28.07±34.02
DW11	2.15±0.42	3.02±1.06	48.33±01.19
DW12	2.49±3.07	2.77±0.28	39.16±10.05
DW13	2.28±2.41	1.33±2.12	27.93±08.22
DW14	1.33±5.01	2.01±1.33	45.76±12.09
R1	4.41 ±5.68	2.84 ±1.19	33.42 ±15.09
R2	4.22 ±3.88	3.11 ±1.84	49.12 ±22.26
R3	4.08 ±1.32	3.07 ±1.92	31.32 ±18.03
WHO 2008	1.0	0.1	10

Table 2: Radiological indices estimated for borehole, dug well and river waters

S/No	D (nyh^{-1})	AGED ($mSvyr^{-1}$)	AEDE (outdoor) ($\mu Svyr^{-1}$)	AEDE (indoor) ($\mu Svyr^{-1}$)	ELCR x 10^{-3} ($Svyr^{-1}$)
BH1	4.44	31.85	5.45	21.78	0.0019
BH2	4.53	34.87	5.56	22.22	0.0019
BH3	5.25	36.89	6.44	25.75	0.0023
BH4	5.68	40.31	6.97	27.86	0.0024
BH5	3.94	27.51	4.83	19.33	0.0017
BH6	5.56	39.89	6.82	27.28	0.0024
BH7	2.05	15.00	2.51	10.06	0.0009
BH8	2.95	21.40	3.62	14.47	0.0013
BH9	3.60	25.67	4.42	17.66	0.0015
BH10	4.45	31.99	5.46	21.83	0.0019
BH11	2.18	15.07	2.67	10.69	0.0009
BH12	2.14	15.27	2.62	10.50	0.0009
BH13	3.33	23.44	4.08	16.34	0.0014
BH14	3.02	21.91	3.70	14.81	0.0013
Dw1	4.37	30.63	5.36	21.44	0.019
Dw2	4.86	34.31	5.96	23.84	0.021
Dw3	5.49	38.73	6.73	26.93	0.024
Dw4	6.45	45.18	7.91	31.64	0.028
Dw5	4.50	32.46	5.52	22.08	0.019
Dw6	7.67	53.60	9.41	37.63	0.033
Dw7	4.66	32.71	5.72	22.86	0.020
Dw8	4.86	34.31	5.96	23.84	0.021
Dw9	3.61	25.47	4.43	17.71	0.015
Dw10	3.11	21.99	3.81	15.26	0.013
Dw11	4.85	34.44	5.95	23.79	0.021
Dw12	4.78	31.57	5.86	23.45	0.021
Dw13	3.02	21.38	3.70	14.82	0.013
Dw14	3.74	26.88	4.59	18.35	0.016
R1	5.19	35.99	6.36	25.46	0.022
R2	5.06	41.15	6.21	24.82	0.021
R3	5.09	35.27	6.24	24.96	0.021

Some important parts of the interior of human body consists the of bone marrow, bone surface cells, lungs, gonads and thyroid, and female breast, which are regarded by (UNSCEAR, 2010) as of significant interest. The outstanding reason is that these organs are sensitive to radiation and there is attendant danger associated with their exposure to certain doses of radiations that are above desirable maximum doses. Consequently, the calculated annual gonadal equivalent dose (AGED) emanating from ^{238}U (^{226}Ra), ^{238}Th (^{228}Ra) and ^{40}K were ascertained for the different water types investigated.

The AGED of groundwater samples varied from 15.15 – 45.18 $mSvyr^{-1}$ and 35.27 – 41.15 $mSvyr^{-1}$ for river, respectively (Table 2). Again, these values are higher for water from the hand-dug wells than those from both boreholes and river, as it ranged from 30.63–45.18 $mSvyr^{-1}$. The average values for the different water types are far lesser than the 300 $mSvyr^{-1}$ required standard allowed for AGED (UNSCEAR, 2010).

This underpinned that the different water types radioactivity does not constitute health problem from prolong consumption of these waters by the inhabitants of the area, especially groundwater.

The calculated absorbed does rate (D) values for the different water types generally ranged from 3.94 to 6.45 ηyh^{-1} with groundwater having the highest values of all. Its values ranged from 3.94 to 6.45 ηyh^{-1}, while river water value is from 5.06 to 5.19 ηyh^{-1} ((Table 2). Again, among groundwater and river water D values, hand-dug wells D are comparatively higher than boreholes and river water with values that ranged from 4.35 – 6.45 ηyh^{-1} (Table 2). All D values for the different water types are suggestively far lower than the 60 ηyh^{-1} value (UNSCEAR, 2000) recommended for minimum standard D value for water.

The calculated values for outdoor annual effective dose equivalent (AEDE) for people drinking borehole water varied from 4.83 – 6.97 $\mu Svyh^{-1}$, these values are marginally lower than hand-dug wells, with values that varied from 5.33 – 7.91 $\mu Svyh^{-1}$. The river water has values that ranged from 6.21 – 6.36 $\mu Svyh^{-1}$ and are lower than both waters from boreholes and hand-dug wells respectively. Overall, these values are comparatively lower when compared to the 70 $\mu Svyr^{-1}$ minimum limit (UNSCEAR, 2000). The AEDE indoor values for the different water types showed that water from boreholes ranged from 19.32 – 27.86 $\mu Svyr^{-1}$. The AEDE indoor values for water from hand-dug wells varied from 21.33 – 31.64 $\mu Svyr^{-1}$, which is slightly higher than the corresponding borehole water, while the river water has AEDE indoor values which varied 24.82–25.46 $\mu Svyr^{-1}$. These values are inconsequential compared to the minimum standard of 450 $\mu Svyr^{-1}$ (UNSCEAR, 2000).

The calculated excess lifetime cancer risk (ELCR) for the different water types investigated showed that water from borehole has values which varied from 0.016×10^{-3} – 0.024×10^{-3} $Svyr^{-1}$, water from hand-dug wells varied from 0.0188×10^{-3} – $0.027 \times 10^{-3} Svyr^{-1}$, while river water varied from 0.021×10^{-3} – 0.022×10^{-3} $Svyr^{-1}$. These values are strikingly lower than 2.7 to 4.82×10^{-3} $Svyr^{-1}$ for water around iron and steel smelting plant in Fashina village, Ile-Ife, Osun State (Oluyide *et al.*, .2019). The ELCR calculated for the different waters in this study is comparatively lower than 0.2×10^{-3} $Svyr^{-}$ minimum limit for water (UNSCEAR, 2000). This invariably means that drinking any of the water types will not result in concomitant development of cancer for lifetime of the people using the waters.

Conclusion

The natural radioactivity of groundwater and surface water from the Warri River at Udu, Delta State has been determined with NaI(TI) gamma- ray spectrometer. The activity concentration of radionuclide in both groundwater (hand-dug wells and boreholes) and river water is sequentially in the order of $^{40}K > ^{238}U > ^{238}Th$. The radionuclide concentration of the waters is probably controlled by the geology of the source of sediments constituting aquifer matrixes and river sediments. The elevated level of radioactivity of water from hand-dug wells is due to the construction materials used in the construction of rig wells in the areas. The radiological hazard indices of annual gonadal equivalent dose, annual effective dose equivalent, and excess lifetime cancer risk and absorbed does rate derived from known equations, for groundwater and river water are considerably lower than the international minimum standard. This is suggestive of the safety of all water types for drinking and can be used for different purposes, since they are not carcinogenic from their radioactivity and, also constitute no health problem. It is worth mentioning that the radionuclides compositions of the waters are profoundly natural without any known effects of anthropogenic activities except the river whose concentrations may have emanated from activities of oil and gas exploration companies.

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