

Activity Concentration Assessment of Natural Radionuclides in Borehole Water and its Radiological Impact from Akure, Nigeria

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Abstract: *The systematic study of activity concentration and the distribution of radionuclides in borehole water from Akure, Ondo State, Nigeria was carried out. A total of 7 samples from 7 different boreholes were collected and analyzed for activity concentrations of natural radionuclides of K-40, Ra-226 and Th-232 using a well-calibrated sodium-iodide NaI(Tl) detector. Gamma spectrometry analysis was performed and the mean concentrations obtained for ^{40}K , ^{226}Ra and ^{232}Th were $76.16 \pm 18.97 \text{ Bq l}^{-1}$, $9.51 \pm 3.62 \text{ Bq l}^{-1}$ and $8.33 \pm 3.79 \text{ Bq l}^{-1}$ respectively. The values of other radiological indices estimated also point that the health risk due to radioactivity from borehole water is higher than the recommended limits by NCRP and the health risk is very high most especially in infants of age between 0 – 1 year. The result in this work compared favorably with other result from similar studies all over the world.*

Keywords: Activity Concentration, Boreholes, Gamma Spectrometry, Effective Dose, Health Risk

1. Introduction

Water is an indispensable material in human existence. Man, animals and plants use water for growth and development. Our body contains about 65 % of water, which also is the most abundant in the universe. We take in water through different ways, like drinking and preparation of foods. Many parts of the world get their source of water from either groundwater, deep well, rainwater or boreholes. The quality of water that we take during various ingestion processes determines our state of health, the reason for adequate analysis of water radioactivity level to ascertain its safety in consumption for different age group.

Virtually, all materials and environments on our planet are both radioactive and naturally exposed to ionizing radiation. Ionizing radiation is ambient in the atmosphere because of both primordial radioactive elements and their decay products in the earth (mainly ^{238}U , ^{232}Th , ^{40}K), and extra-terrestrial cosmic radiation in the soil and rock give us an average dose of up to 60 mrad (UNSCEAR 1982).

Our living accommodations, which utilize these materials in construction, add measurable radioactive amounts to the atmosphere. The annual effective doses from natural and man-made sources for the world's population is currently about 2.8 mSv. Nearly 85% of this dose (2.4 mSv) comes from natural background radiation (UNSCEAR 2000).

In principle, environmental radioactivity involves the measurement of a sample in the laboratory or/and in-situ measurement. The purpose of an environmental measurement program is to characterize the total gamma radiation field within an overall uncertainty of 20%. (Gilmore and Hemingway, 1995)

This work was carried out in order to measure the natural radioactivity in typical borehole water. The data obtained from this work will be useful to estimate the level of exposure to radiation through ingestion of borehole water and risk to man

2. Methodology

A total of 7 samples of borehole water were collected from 7 different boreholes in Akure, Nigeria. The samples were collected manually from the taps and stored inside plastic water bottles. First, the faucet was turned on at full speed for several minutes to purge the plumbing system of any water which might have been there for some time. The faucet was then turned down to a low flow rate to reduce turbulence and, thus, reduce Radon loss during the collection directly from the faucet into seventy-five (75) centiliter (cl) plastic bottles.

The water samples were acidified with 11M of HCl at the rate of 10ml per liter of samples as soon as possible, to avoid absorption of radionuclide into the wall of container (IAEA, 1989). Marinelli beaker of 1L volume capacity previously washed, rinsed with a dilute sulphuric acid (H_2SO_4) and dried to avoid contamination was filled with sample from the container used for sampling. This was later sealed for 30 days to ensure that there is no loss of radon and to achieve equilibrium between the daughter and parent nuclides. The samples were taken to Center for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Osun State, Nigeria, for gamma spectrometry analysis. The gamma analysis was performed on a 76mm X 76mm Sodium Iodide (Thallium doped) NaI(Tl) scintillation detector. The output of the detector was connected to a Canberra series 10 plus portable multichannel analyzer (MCA) which recorded the gamma spectra of the water samples as well as background radiation. Calibration of the measuring systems had been carried out using certified reference standards for various radionuclides.

Information and Geology of Location

Akure is a medium city, averagely populated and the capital city of Ondo State which is located at the South-Western part of Nigeria. Akure is a temperate region with high relative humidity of about 62 % mean (Eludoyin et al, 2014)

and high rainfall of about 1,100 mm in the northern part to over 4,000 mm in the south coastal region annually. Akure is characterized by the presence of underground rocks, with annual temperature ranging from about 18⁰ C to over 40⁰ C through the year. Nigeria is located at the equatorial region between latitude 4⁰ 05' and 13⁰ 50' N and longitude 2⁰ 44' and 14⁰ 45' E Nigeria is a coastal nation with a multi-geological condition and different climate/vegetation between the southern and northern part of the country. The climate/vegetation ranges from coastal to green forest in the south and semi-arid to arid in the north. Nigerian has varying land structure, partly hilly, partly rocky, partly riverine and partly plain. Nigeria is the most populous nation in Africa and 7th largest population in the World with population of 140,431,790 (NPC 2006) and projected population of 183,390,767 (Worldometers 2015). Nigeria is characterized by different language and culture with more than 50 % of its population living in the rural areas where there is no access to good water. The major sources of drinking water in the country both in the urban and rural area are the boreholes and deep wells.

Radiological Indices for Water Samples

Total Annual Effective Dose E_d (Sv/y)

The total annual effective dose E_d (Sv/y) estimation to an individual due to the ingestion of the natural radionuclides in borehole water samples was done using the following relation by Alam *et al.* (1999).

$$E_d = \sum A_c A_i C_f \quad 1$$

Where E_d = the total annual effective dose, A_c is the activity concentration in Bq/L, A_i is the annual consumption rate of water in l/y, and C_f is the ingested dose conversion factor in (Sv/Bq).

Committed Effective Dose

Committed effective dose to an individual (evaluated here for different age group) over an average life span of 50yrs was estimated by

$$C_d = 50 \times E_d \quad 2$$

Collective Effective Dose Equivalent

$$S_E = \sum N_i H_{Ei} \quad 3$$

Where S_E = collective effective dose equivalent (person – Sv), N_i = the numbers of individual exposed to radiation and H_{Ei} is the mean outdoor effective dose equivalent (μSv^{-1}).

Collective Health Detriment

The collective health detriment “G” (person), due to exposure to gamma radiation in an environment, can be calculated using the relation

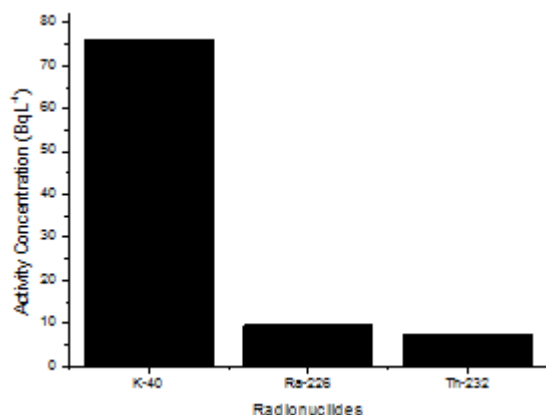
$$G = R_T S_E \quad 4$$

Where R_T = Total risk factor the body organs are exposed to and according to ICRP (1991), it has a value of $16.50 \times 10^{-3} \text{Sv}^{-1}$, S_E = Collective effective dose equivalent (person – Sv) presented in Table 5.

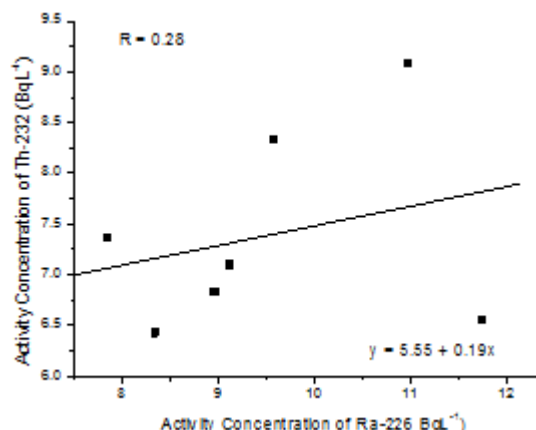
3. Result

Table 1: Activity Concentration in Collected Borehole Water Samples

Borehole Water Samples Collected	Radioactivity Content (Bq/L)		
	K-40	Ra-226	Th-232
Borehole 1	89.41 ± 23.84	9.12 ± 5.13	7.10 ± 2.53
Borehole 2	78.24 ± 18.52	11.75 ± 4.56	6.56 ± 3.15
Borehole 3	93.90 ± 16.87	9.57 ± 2.61	8.33 ± 3.79
Borehole 4	54.04 ± 14.78	8.34 ± 3.59	6.43 ± 2.94
Borehole 5	67.98 ± 21.09	10.97 ± 4.02	9.09 ± 3.43
Borehole 6	87.42 ± 19.38	7.84 ± 1.65	7.36 ± 2.45
Borehole 7	62.13 ± 18.31	8.96 ± 3.81	6.83 ± 3.48
Range	54.05 ± 14.78 – 93.90 ± 16.87	7.84 ± 1.65 – 11.75 ± 4.56	6.43 ± 2.94 – 9.09 ± 3.43
MEAN	76.16 ± 18.97	9.51 ± 3.62	7.38 ± 3.11



(a)



(b)

Figure 1: (a) Mean Activity Concentration of Natural Radionuclides. (b) Correlation of Th-232 and Ra-226 Activities.

Radioactivity Content in Water

The specific activities of natural radionuclides measured in the borehole water samples are reported in Table 1 and illustrated with figure 1a. Figure 1b shows a weak correlation of ^{232}Th and ^{226}Ra activities. The concentrations obtained for K-40 ranged from 54.05 ± 14.78 to 93.90 ± 16.87 BqL^{-1} with a mean of 76.16 ± 18.97 BqL^{-1} . Ra-226 ranged from 7.84 ± 1.65 to 11.75 ± 4.56 BqL^{-1} with a mean of 9.51 ± 3.62 BqL^{-1} . Th-232 ranged from 6.43 ± 2.94 to 9.09 ± 3.43 BqL^{-1} with a mean of 7.38 ± 3.11 BqL^{-1} .

^{40}K being with the highest activity is no surprise because it is a naturally occurring radionuclide which abounds in the earth crust. The specific activity due to ^{232}Th is also relatively low in the borehole water samples investigated compared to ^{226}Ra because ^{226}Ra is more mobile than ^{232}Th (NCRP, 1987).

High activity concentration of ^{40}K , ^{226}Ra , and ^{232}Th was observed in all the borehole water samples collected. This might be due to the fact that water from boreholes are coming directly from the earth crust and would have received its activity concentration from the rock phosphate.

The variation of the different age groups with the Ingested dose conversion factor was provided by IAEA (1996) and shown in Table 2 while the annual consumption rate of water in a year by different age group was supplied by WHO (2006) and shown in Table 3. From the result in Table 5 and illustrated in figure 2, it was discovered that the total annual effective dose ranges from 2.96 ± 1.12 mSv^{-1} (in 2-7y age group) 16.33 ± 6.50 mSv^{-1} (in 0-1y age group) with a mean values of 6.72 ± 2.61 mSv^{-1} . These values are extremely higher than the 1 mSv^{-1} recommended by the NCRP 1993.

Result of borehole water samples analyzed shows that the collective effective dose varied with the different age groups as expected because of variation in total annual effective dose for different age groups due to difference in their radiosensitivity as reflected in their conversion factor and because of the population of different age group as presented in Table 4. The collective effective dose equivalent is presented in Table 5. The infants in the age of 0 – 1 year are the most susceptible and this was reflected in their high value of total annual effective dose and committed effective dose.

Table 2: Radionuclides and their Ingested Dose Conversion Factor

Radionuclide	Ingested Dose Conversion Factor Per Age Group					
	(0-1)yr Sv/Bq	(1-2)yr Sv/Bq	(2-7)yr Sv/Bq	(7-12)yr Sv/Bq	(12-17)yr Sv/Bq	>17yr Sv/Bq
^{40}K	6.2E-8	4.2E-8	2.1E-8	1.3E-8	7.6E-9	6.2E-9
^{214}Bi	1.4E-9	7.4E-10	3.6E-10	2.1E-10	1.4E-10	1.0E-10
^{214}Pb	2.7E-9	1.0E-9	5.2E-10	3.1E-10	2.0E-10	1.4E-10
^{224}Ra	2.7E-6	6.6E-7	3.5E-7	2.6E-7	2.0E-7	6.5E-8
^{226}Ra	4.7E-6	9.6E-7	6.2E-7	8.0E-7	1.5E-6	2.8E-7
^{228}Ac	7.4E-9	2.8E-9	1.4E-9	8.7E-10	5.3E-10	4.3E-10
^{232}Th	4.6E-6	4.5E-7	3.5E-7	2.9E-7	2.5E-7	2.3E-7

Source: IAEA 1996

Table 3: Annual Water Consumption per Age Group

Age Group (y)	Annual Water Consumption (ly^{-1})
0-1	2.0E2
1-2	2.6E2
2-7	3.0E2
7-12	3.5E2
12-17	6.0E2
>17	7.3E2

Source: WHO, 2006

Table 4: Nigeria Population in Different Age Groups

Age Range (Years)	Population (N_i) (2006) Source: NPC (2006)	Population (N_i) (2015 Projection) (Worldometers, June 19, 2015)
0-1	3,004,421	3,923,493
1-2	4,766,927	6,225,160
2-7	23,641,824	30,874,008
7-12	18,073,170	23,601,868
12-17	18,284,692	23,878,096
>17	72,660,755	94,888,142
Total	140,431,790	183,390,767

Table 5: Total Annual Effective Dose, Committed Effective Dose and Collective Effective Dose Equivalent for Different Age Groups

Age Group (Years)	Total Annual Effective Dose (mSv^{-1})	Committed Effective Dose (mSv^{-1})	Collective Effective Dose Equivalent (Person-Sv)
0 – 1	16.33 ± 6.50	816.75 ± 324.96	64,090.20
1 – 2	3.98 ± 1.47	198.95 ± 73.73	24,769.71
2 – 7	2.96 ± 1.12	147.83 ± 55.97	91,282.34
7 – 12	3.66 ± 1.42	182.88 ± 70.78	86,326.15
12 – 17	9.69 ± 3.81	484.46 ± 190.55	231,361.80
> 17	3.45 ± 1.35	172.70 ± 67.40	327,749.50
Range	$2.96 \pm 1.12 - 16.33 \pm 6.50$	$147.83 \pm 55.97 - 816.75 \pm 324.96$	Not Applicable
Mean	6.72 ± 2.61	333.93 ± 130.57	Not Applicable

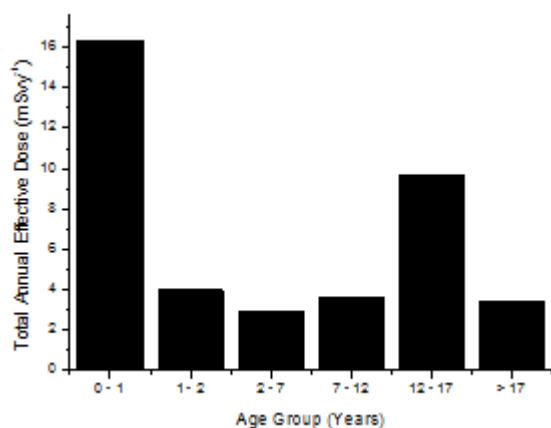


Figure 2: Total Annual Effective Dose for Different Age Groups

The result obtained in this study compared favorably with other result from similar studies all over the world. All though, the value of the activity concentration in the borehole water that was obtained is a bit higher that the value obtained by Ajayi and Achuka in deep well water samples from Ogun State, Nigeria, with a rather narrower margin. The result of ^{226}Ra concentration when compared with other result from different countries, shows an enhanced activity than many other countries except Finland which has a maximum concentration of ^{226}Ra to be 49 BqL^{-1} as shown in Table 6 and figure 3.

Table 6: Activity Concentration Comparison of ^{226}Ra (Bq l-1) in Borehole Waters from Nigeria with Other Countries

Country	^{226}Ra	
	Min	Max
USA	4×10^{-4}	1.8×10^{-3}
China	2×10^{-4}	0.12
Finland	1×10^{-2}	49
France	7×10^{-3}	0.7
Germany	1×10^{-3}	1.8
Italy	2×10^{-4}	1.2
Romania	7×10^{-4}	0.021
Switzerland	0	1.5
Spain	2×10^{-2}	4
UK	0	0.18
Nigeria Deep Well (Ajayi & Achuka, 2009)	2.89	7.79
Nigeria borehole (This Study)	7.84	11.75

Data for other countries was obtained from UNSCEAR 2000 report.

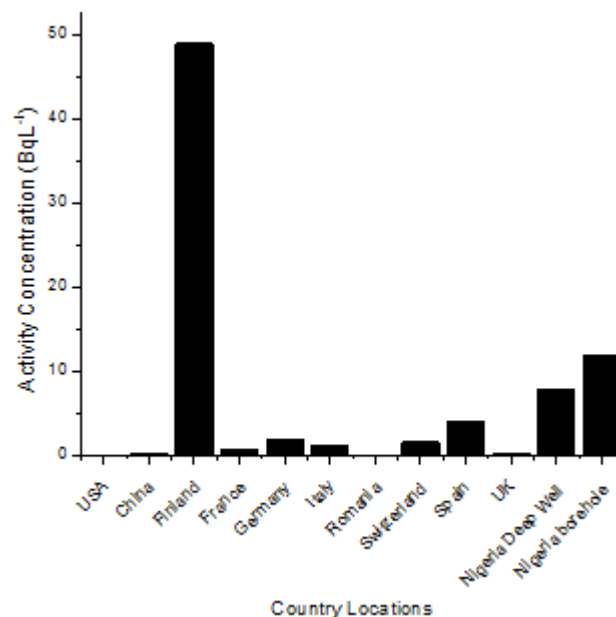


Figure 3: Illustration of Ra-226 Activity concentration in Different Countries

Collective Health Detriment

The estimated collective health detriment as a result of radionuclides present in borehole water is presented in Table 7. It could be observed that a large population of individual is susceptible to a radiation induced diseases. The value ranges from 409 persons in the age group 1 – 2 years to 5,408 persons in the age group >17 years with a total no of 13,621. The indication of this result calls for a serious attention to safe water availability in the area and all over the world.

Table 7: Collective Health Detriment in the Different Age Groups

Age Group (Years)	Collective Health Detriment in (Person)
0 – 1	1,057
1 – 2	409
2 – 7	1,506
7 – 12	1,424
12 – 17	3,817
> 17	5,408
Total	13,621

4. Conclusion

Activity concentration determination of natural radionuclides in borehole water samples has been carried out from some boreholes in Akure, South-Western Nigeria. The result shows an enhanced radioactivity in borehole waters. The mean activity concentration of ^{40}K , ^{226}Ra and ^{232}Th were found to be $76.16 \pm 18.97 \text{ Bq/L}$, $9.51 \pm 3.62 \text{ Bq/L}$, and $7.38 \pm 3.11 \text{ Bq/L}$ respectively.

The total annual effective dose for different age groups ranges from $2.96 \pm 1.12 \text{ mSv y}^{-1}$ to $16.33 \pm 6.50 \text{ mSv y}^{-1}$ with a mean of $6.72 \pm 2.61 \text{ mSv y}^{-1}$. This value is higher than the limits of 1 mSv y^{-1} and 0.1 mSv y^{-1} recommended by ICRP & WHO respectively (ICRP 1990, WHO 2006). The research work has shown that the natural radioactivity in borehole water is high. This could be as a result of the remote source of the water which is deep down inside rocks. Akure is

characterized by underground rocks which makes well water a little difficult to come by and in many cases rocks has to be blasted before water can be obtained. Considering the Phosphate composition of rocks hence a reason for an enhanced radioactivity of the borehole water in the area. The health risk through the ingestion of borehole water is very high in the area and this is likely to be the situation in any part of the world where there are underground rocks. Effort should be made therefore to provide alternative source of safe drinking water in such environment so as to reduce the level of health risk of radiation induced diseases to human.

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