Canadian Journal of Pure and Applied Sciences
Vol. 13, No. 1, pp. 4699-4707, Feb 2019
Online ISSN: 1920-3853; Print ISSN: 1715-9997
Available online at www.cjpas.net

ASSESSMENT OF RADIONUCLIDE CONCENTRATIONS IN WATER SUPPLY FROM BOREHOLES IN SELECTED SITES OF BWARI AREA COUNCIL, FEDERAL CAPITAL TERRITORY ABUJA, NIGERIA

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ABSTRACT

An assessment of the distribution of radionuclides and their activity concentrations in Borehole water was carried out. Fifty (50) samples were collected from selected sites in Bwari town of the Federal Capital Territory, Abuja, Nigeria. A well-calibrated Sodium-Iodide Thallium doped (NaI(Tl)) Detector was used to obtain the activity concentrations of ^{40}K, ^{238}U and ^{232}Th. The results for ^{40}K ranged from 7.00 ± 0.73 to 266.43 ± 20.06 Bq.l^{-1} with an average of 95.57 ± 8.42 Bq.l^{-1}. The results for ^{238}U ranged from 0.89 ± 0.24 to 31.61 ± 5.12 Bq.l^{-1} with an average of 9.67 ± 1.86 Bq.l^{-1}. The results for ^{232}Th ranged from 0.24 ± 0.02 to 15.86 ± 1.23 Bq.l^{-1} with an average of 7.12 ± 0.64 Bq.l^{-1}. Results calculated for the committed effective doses show that the average combined contributions to a year's consumption of drinking water in the study area was less than the ICRP's recommended limit of 1 mSv.y^{-1} . However, four out of the ten locations had values that were slightly higher. Consequently, it is recommended that Government should undertake to supply safe drinking water to those locations. In addition assessment of water supply from hand-dug wells and streams should be investigated.

Keywords: Gamma spectroscopy and activity concentration, domestic water supply, boreholes, radio nuclides, health, trace elements.

INTRODUCTION

The discovery of radiation has led to dramatic advances in industry, agriculture, and research. The benefits and risks of any practice involving radiation need to be established, so that an informed judgment can be made on their use, and any risks minimized. Nevertheless, they can be harmful to human beings, and people must be protected from unnecessary or excessive exposures (IAEA, 2004).

Water is an essential element for human existence. Without water there will be no life. Humans consume water every day directly or indirectly. A considerable reliance of the population of the area under study on groundwater resources (Boreholes) for drinking water has necessitated the identification of aquifers or portions of aquifers most susceptible to such contamination. Contamination of the environment by radioactive materials has direct impact on human health. There is a strong link between the intake of water contaminated with Naturally Occurring Radioactive Materials (NORMs) and the onset of life threatening diseases such as genetic malfunction, cancer, kidney failure and reduced blood cell count. Also, there is risk of malignancy even though the radiation dose may be very low (Morgan, 1978). It becomes pertinent to obtain scientific data before claims of contamination can be made. Consequent on the findings solutions would be proffered.

This research aims at collecting Baseline Data by assessing the radioactivity concentrations of ^{238}U, ^{232}Th and ^{40}K radio nuclides present in water from Boreholes in the study area.

MATERIALS AND METHODS

The area where this research was carried out lies between latitudes 9° 15'N and 9° 18'N and longitudes 7° 19'E and 7° 25'E. It has a surface area of approximately 40 km^2. The general elevation varies from 535 to 597 m above mean sea level. The climate is characterized by a dry season (November to February) and a rainy season (April to October). Mean annual rainfall ranges from 1500 to 2099 mm. The mean annual temperature ranges from 27 to 30°C.

Fifty samples of water were collected into One-litre capacity plastic containers, from the fifty different Boreholes located as indicated on Table 1. In order to reduce turbulence and Radon loss the method used by

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Sasser and Watson (1978) was used. Each sample was acidified using the method by Avwiri *et al.* (2007). To further ensure that there was no loss of radon and to achieve secular equilibrium between the daughter and parent nuclides the containers were sealed for 30 days (Ayodele *et al.*, 2017). The Gamma Spectrometry Analyses of the samples were carried out at a facility situated at the National Institute of Radiation Protection and Research (NIRPR), University of Ibadan (Latif *et al.*, 2012). Calibration of the measuring systems had been carried out using Certified Reference Standards for various radionuclides (Ajayi, 2007).

Eqn. 1 (Faanu *et al.*, 2014) was used to calculate the total Annual Effective Dose (AED).

$$Total\ AED = \sum_i I_i \times 365 \times D_i \quad (1)$$

I_i (in Bq. l^{-1}) represents the daily intake of radionuclide and the subscript *"i"* stands for ^{40}K, ^{238}U or ^{232}Th. D_i represents the ingestion dose co-efficient (in $Sv.Bq^{-1}$) which has the following respective values for ^{40}K, ^{238}U, and ^{232}Th of 6.2×10^{-9} $Sv.Bq^{-1}$, 4.5×10^{-8} $Sv.Bq^{-1}$ and $2.3 \times 10^{-7} Sv.Bq^{-1}$ (ICRP, 1994; 2007).

The specific activities of materials containing ^{40}K, ^{238}U and ^{232}Th can be compared using the Radium equivalent (Ra_{eq}) index. It takes into account the associated radiation hazards (Ajayi and Dike, 2016). It also offers a beneficial guide in regulating the safety standard of dwellings as a weighted sum of activities of ^{40}K, ^{238}U and ^{232}Th. Ademola (2008) used Eqn.2 to calculate Ra_{eq}.

$$Ra_{eq} = C_{Ra} + 1.43C_{Th} + 0.077\,C_K \quad (2)$$

C_{Ra}, C_{Th} and C_K are the radioactivity concentrations in Bq.l^{-1} of ^{238}U, ^{232}Th, and ^{40}K.

Table 1. Borehole locations and Sample Identification tags in Study Area.

Location/ Sample ID	Coordinates		Location/ Sample ID	Coordinates	
A1	N 09° 09.143′ E 007° 22.156′		F1	N 09° 12.478′	E 007° 24.311′
A2	N 09° 08. 421′ E 001° 21.594′		F2	N 09° 12.539′	E 007° 24.332′
A3	N 09° 09.220′ E 007° 20.041′		F3	N 09° 12.693′	E 007° 24.377′
A4	N 09° 09.356′ E 007° 19.836′		F4	N 09° 12.691′	E 007° 24.450′
A5	N 09° 09.644′ E 007° 18.787′		F5	N 09° 12.867′	E 007° 24.226′
B1	N 09° 05.873′ E 007° 13.532′		G1	N 09° 14.101′	E 007° 23.355′
B2	N 09° 05.793′ E 007° 13.594′		G2	N 09° 14.071′	E 007° 23.304′
B3	N 09° 05.811′ E 007° 13.543′		G3	N 09° 15.652′	E 007° 23.489′
B4	N 09° 05.619′ E 007° 13.268′		G4	N 09° 15.713′	E 007° 23.540′
B5	N 09° 05.798′ E 007° 13.471′		G5	N 09° 15.696′	E 007° 23.505′
C1	N 09° 07.313′ E 007° 24.062′		H1	N 09° 16.857′	E 007° 23.214′
C2	N 09° 07.658′ E 007° 24.045′		H2	N 09° 17.277′	E 007° 22.784′
C3	N 09° 07.741′ E 007° 24.094′		H3	N 09° 17.173′	E 007° 22.680′
C4	N 09° 07.746′ E 007° 24.147′		H4	N 09° 17.001′	E 007° 22.682′
C5	N 09° 07.747′ E 007° 24. 216′		H5	N 09° 16.950′	E 007° 22.551′
D1	N 09° 08.703′	E 007° 22.280′	I1	N 09° 17.670′	E 007° 25.034′
D2	N 09° 09.221′	E 007° 22.535′	I2	N 09° 17.666′	E 007° 25.140′

D3	N 09° 09.605′	E 007° 22.714′	I3	N 09° 17.585′	E 007° 25.222′
D4	N 09° 10.037′	E 007° 22.837′	I4	N 09° 17.555′	E 007° 25.296′
D5	N 09° 10.734′	E 007° 23.164′	I5	N 09° 17.194′	E 007° 24.742′
E1	N 09° 11.231′	E 007° 22.528′	J1	N 09° 16.595′	E 007° 21.522′
E2	N 09° 11.314′	E 007° 22.421′	J2	N 09° 16.586′	E 007° 21.651′
E3	N 09° 11.336′	E 007° 22.294′	J3	N 09° 16.814′	E 007° 22.647′
E4	N 09° 11.228′	E 007° 22.241′	J4	N 09° 16.694′	E 007° 22.156′
E5	N 09° 11.030′	E 007° 22.538′	J5	N 09° 16.499′	E 007° 22.823′

Gamma Absorbed Dose Rate (D) measures the energy deposited in matter by ionizing radiation per unit mass, which is measured in joules per kilogram when the equivalent SI unit is gray (Gy). The absorbing medium determines the absorbed dose from a known level of incident radiation. To rate the ability of devices to survive, such as electronic components in ionizing radiation environments, the absorbed dose is used. The larger the absorbed dose the greater the hazard. El-Bahi (2004) used Eq. 3 for its calculation.

$$D = 0.462\,C_{Ra} + 0.621\,C_{Th} + 0.041\,C_K \qquad (3)$$

D represents the dose rate in nGy.h^{-1} while C_{Ra}, C_{Th}, and C_K are as represented in Eqn. (2).

For assessment of any additional radiation hazard due to natural gamma radiation the External and Internal Hazard indices (H_{ext} and H_{in}) are used. They are calculated (Bello *et al.,* 2014) respectively using Eqns. (4) and (5).

$$H_{ex} = \frac{C_{Ra}}{370} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (4)$$

$$H_{ex} = \frac{C_{Ra}}{185} + \frac{C_{Th}}{259} + \frac{C_K}{4810} \qquad (5)$$

The value of the indices must be less than unity for the radiation hazard to be negligible.

RESULTS AND DISCUSSION

The details of the results obtained are displayed on Table 2. The radio nuclides identified and quantified using the gamma ray spectra were ^{40}K, ^{226}Ra (from ^{238}U decay series) and ^{228}Ra (from ^{232}Th decay series).

Results for the activity concentrations ranged from 7.00 ± 0.73 to 266.43 ± 20.06 Bq.l^{-1} for ^{40}K. The results for ^{238}U ranged from 0.89 ± 0.24 to 31.61 ± 5.12 Bq.l^{-1} . The results for ^{232}Th ranged from 0.24 ± 0.02 to 15.86 ± 1.23 Bq.l^{-1}.

The distributions of the mean Activity Concentrations values from all Locations are shown on Figure 1. It was observed that Location E had the highest mean activity concentration of 130.04 ± 10.97 Bq.l^{-1} for ^{40}K while location A had the lowest of 59.91 ± 7.25 Bq.l^{-1}.

Location A had the highest mean activity concentration for ^{238}U of 15.34 ± 2.70 Bq.l^{-1} while location J had the lowest of 6.99 ± 1.20 Bq.l^{-1}.

Location D had the highest mean activity concentration for ^{232}Th of 9.12 ± 0.94 Bq.l^{-1} while location A had the lowest of 4.55 ± 0.40 Bq.l^{-1}.

The largest contribution to the overall activity concentration was from ^{40}K with the lowest value of 7.00 ± 0.73 Bq.l^{-1} and highest value of 266.43 ± 20.06 Bq. l^{-1}. This would be attributable to the fact that its main source is food ingested. Potassium does not accumulate in the body but is maintained at a constant level no matter the amount consumed (WHO, 2011). Consequently, its consumption does not really pose danger to the body as it has little effect on the body content. The activity concentration due to ^{232}Th, which ranged from 0.24 ± 0.02 to 15.86 ± 1.23 Bq. l^{-1}, was relatively low in all the samples when compared to that due to ^{238}U . Since ^{238}U is more mobile than ^{232}Th, this was expected. The activity concentration due to^{238}U ranged of 0.89 ± 0.24 to 31.61 ± 5.12 Bq. l^{-1}.

The distribution of Mean Annual Effective Dose (AED) for ^{40}K, ^{238}U, and ^{232}Th in mSv.y^{-1} are displayed on Figure 2. Location C had the highest value for ^{40}K of 0.294 ± 0.0246 mSv. y^{-1}. Location A had the highest value for ^{238}U of 0.254 ± 0.0436 mSv. y^{-1}. Location D had the highest value for ^{232}Th of 0.764 ± 0.0794 mSv. y^{-1}.

Table 2. Activity Concentrations (I_i) of ^{40}K, ^{238}U and ^{232}Th in $Bq.l^{-1}$ in Borehole Water Samples from all Locations in Study Area.

SAMPLE ID	^{40}K			^{238}U			^{232}Th		
A1	47.28	±	4.52	18.66	±	3.01	8.25	±	0.71
A2	45.78	±	4.48	31.61	±	5.12	BDL	±	BDL
A3	151. 60	±	12.61	3.31	±	0.88	6.60	±	0.61
A4	76.80	±	7.66	16.70	±	3.04	3.30	±	0.30
A5	69.79	±	6.96	6.43	±	1.43	4.59	±	0.40
B1	121.39	±	9.68	BDL	±	BDL	15.86	±	1.23
B2	107. 82	±	9.37	BDL	±	BDL	BDL	±	BDL
B3	7.00	±	0.73	7.23	±	1.32	6.32	±	0.52
B4	74.55	±	7.47	BDL	±	BDL	5.79	±	0.55
B5	102.07	±	9.15	17.23	±	2.91	9.02	±	0.76
C1	216.65	±	17.31	12.05	±	2.05	BDL	±	BDL
C2	114.07	±	10.27	18.30	±	3.51	6.12	±	0.55
C3	73.30	±	6.55	BDL	±	BDL	7.65	±	0.67
C4	82.30	±	7.58	13.48	±	2.82	6.04	±	0.57
C5	157.85	±	12.97	0.89	±	0.24	9.22	±	0.83
D1	157.35	±	11.88	5.81	±	1.15	10.51	±	0.95
D2	35.27	±	3.23	18.84	±	3.37	13.25	±	1.99
D3	110.58	±	10.35	BDL	±	BDL	11.07	±	0.89
D4	109.32	±	9.83	BDL	±	BDL	BDL	±	BDL
D5	BDL	±	BDL	BDL	±	BDL	10.75	±	0.89
E1	119.58	±	10.30	12.23	±	2.63	BDL	±	BDL
E2	174.62	±	14.45	BDL	±	BDL	8.57	±	0.79
E3	75.55	±	6.63	6.43	±	1.15	8.73	±	0.77
E4	134.59	±	11.87	11.43	±	2.22	6.12	±	0.57
E5	145.85	±	11.59	13.04	±	2.55	8.78	±	0.74
F1	160.11	±	13.73	24.56	±	4.94	9.18	±	0.78
F2	90.56	±	8.84	22.95	±	3.83	3.75	±	0.36
F3	61.54	±	5.86	2.50	±	0.58	15.22	±	1.18
F4	93.56	±	8.09	2.86	±	0.82	4.55	±	0.42
F5	53.29	±	4.59	6.16	±	1.24	12.52	±	1.09
G1	41.28	±	3.83	7.68	±	2.23	3.02	±	0.28
G2	266.43	±	20.06	12.95	±	2.75	9.95	±	0.93
G3	19.76	±	2.06	11.07	±	2.36	10.59	±	0.92
G4	104.32	±	9.57	11.7	±	2.95	5.47	±	0.54
G5	25.01	±	2.21	15.89	±	3.01	9.86	±	0.84
H1	41.52	±	4.04	BDL	±	BDL	4.51	±	0.43
H2	BDL	±	BDL	BDL	±	BDL	11.79	±	0.99
H3	75.55	±	7.17	31.35	±	4.98	10.71	±	0.98
H4	75.05	±	6.34	9.65	±	1.91	7.37	±	0.64
H5	209.89	±	17.21	21.61	±	4.34	9.83	±	0.83
I1	9.01	±	0.93	12.41	±	3.10	2.89	±	0.28
I2	14.01	±	1.39	12.06	±	2.54	14.38	±	1.17
I3	142.85	±	10.92	8.03	±	1.77	1.01	±	0.11
I4	149.1	±	13.77	BDL	±	BDL	12.68	±	1.07
I5	74.05	±	7.53	21.61	±	4.35	BDL	±	BDL
J1	71.55	±	6.85	4.19	±	0.85	0.24	±	0.02
J2	146.85	±	12.53	4.46	±	0.97	9.30	±	0.82
J3	165.61	±	14.41	26.34	±	4.20	2.74	±	0.27
J4	68.05	±	6.23	BDL	±	BDL	2.82	±	0.27
J5	176.87	±	15.32	BDL	±	BDL	14.89	±	1.23
Range	7.00 ± 0.73 to 266.43 ± 20.06 $Bq.l^{-1}$			0.89 ± 0.24 to 31.61 ± 5.12 $Bq.l^{-1}$			0.24 ± 0.02 to 15.86 ± 1.23 $Bq.l^{-1}$		

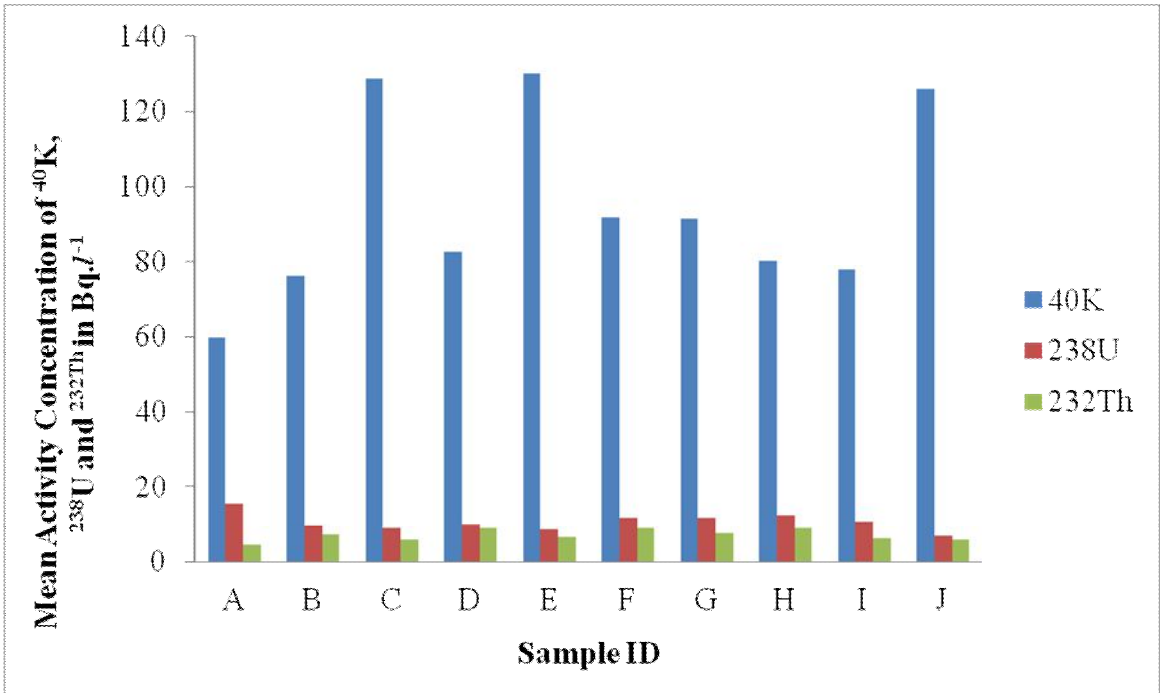

Fig. 1. The distribution of the mean activity concentrations for ^{40}K, ^{238} U and ^{232}Th in Bq.l^{-1} for Borehole water samples from the Study Area.

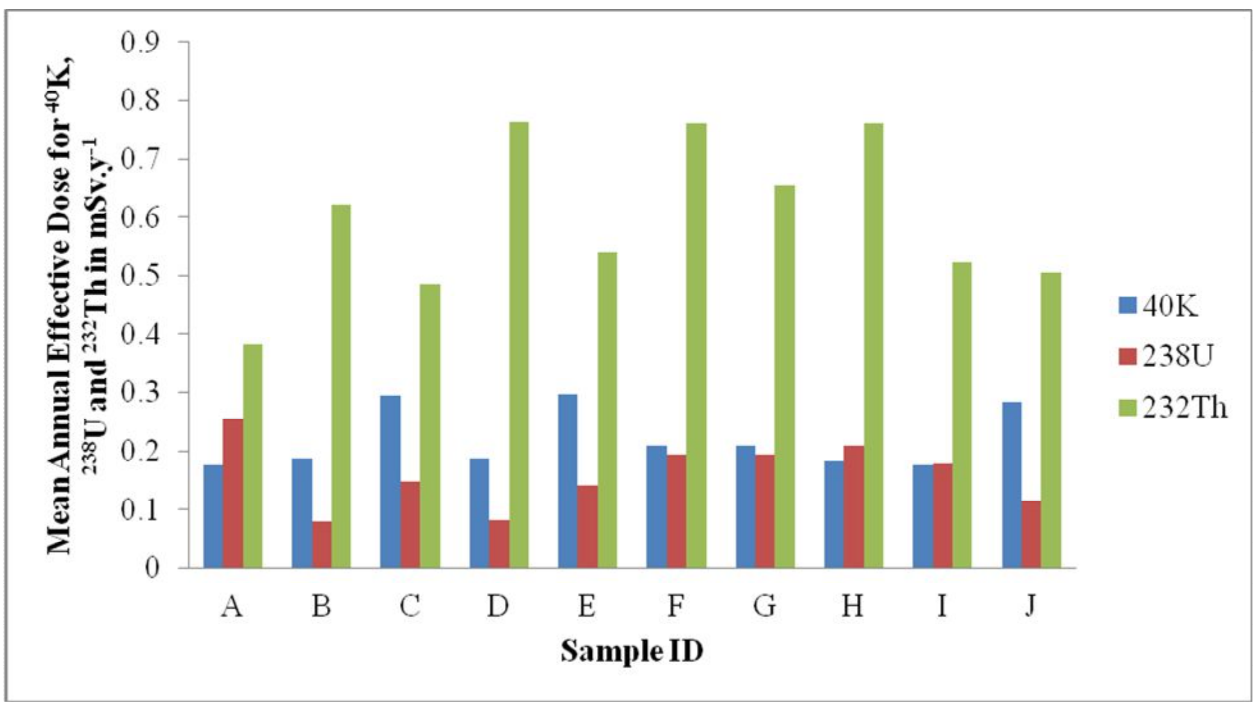

Fig. 2. The distribution of the Mean Annual Effective Dose for ^{40}K, ^{238}U and ^{232}Th in mSv.y^{-1} for Borehole water samples from the Study Area.

Using Eqn. 1, the Total Annual Effective Dose (AED) was calculated. Figure 3 shows the distribution of Mean Total Annual Effective Dose (AED). Location A had the least value of 0.812 ± 0.094 $mSv.y^{-1}$ while F had the highest value of 1.164 ± 0.1198 $mSv.y^{-1}$.

Close examination of Figure 3 shows that Locations A, B, C, E, I and J all had Total AEDs less than the recommended value of 1$mSv.y^{-1}$. However, Locations D, F, G and H had values that were slightly higher hence the need for constant monitoring in the event that the values rise much higher than they are now. As an interim measure, it is recommended that Government should undertake to supply safe drinking water to those locations.

Using Eqn. 2 above, the results for the estimated Ra_{eq} are displayed on Table 5. The values ranged from 8.30 $Bq.l^{-1}$ to 52.48 $Bq.l^{-1}$ with an average of 27.31 $Bq.l^{-1}$. These values which are lower than the suggested maximal permissible value of 370 $Bq.l^{-1}$ indicate no significant radiological hazard if water samples are ingested.

Using Eqn. 3 above, the results for the estimated D are displayed on Table 3. These values ranged from 4.46 $nGy.y^{-1}$ to 24.67 $nGy.y^{-1}$ with an average of 12.81 $nGy.y^{-1}$, which are less than the World average value of 55 $nGy.y^{-1}$ (Jacob *et al.*, 1986).

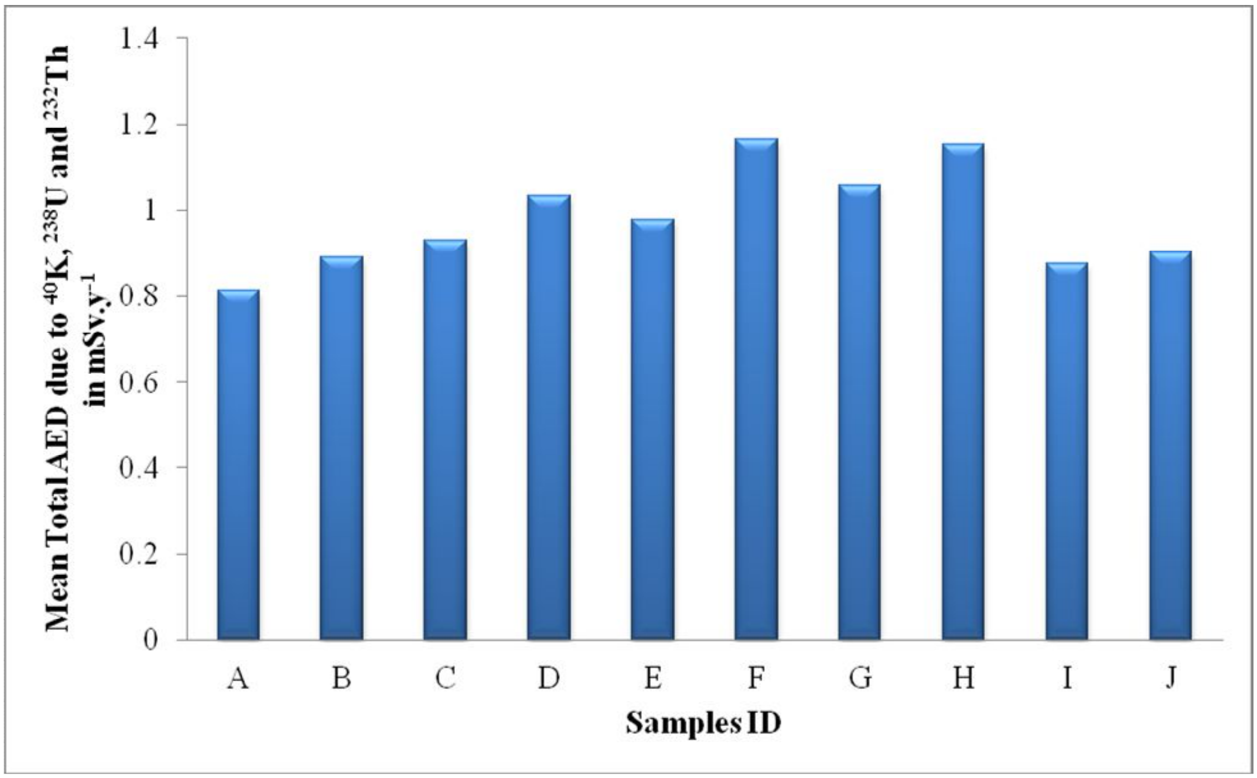

Fig. 3. Distribution of the mean Total AED due to ^{40}K, ^{238}U and ^{232}Th in $mSv.y^{-1}$ for Borehole water samples from the Study Area.

Using Eqns. 4 and 5 above, values of H_{ex} and H_{in} for all the samples in all the locations are displayed on Table 3. These values ranged from 0.02 to 0.23 with an average of 0.10, which are less than the recommended value of 1.00. the implication being that the water samples were safe and did not pose any significant radiological threat to the populace in the location.

Figure 4 shows the correlation between the Mean Activity Concentrations A_K & A_{Th} and the Mean H_{ex} & H_{in} : the correlation coefficient, R = 0.3490 with intercept = 0.0668 and slope = 0.0005. Figure 5 shows the correlation between the Mean Activity Concentrations A_K & A_U and Mean Activity Concentrations A_{Th} & A_U: the correlation coefficient, R = 0.1806 with intercept = 41.661 and slope = 1.2102. Both coefficients show a linear relationship. However, the values of one are not very much influenced by the values of the other (Edward, 1976).

Table 3. Estimated Radium equivalent (Ra_{eq}) in Bq.l^{-1}, Gamma absorbed dose rate (D) in nGy.y^{-1}, External Hazard Index (H_{ex}) and Internal Hazard Index (H_{in}) for ^{40}K, ^{238}U, and ^{232}Th in all the locations.

Samples ID	Ra_{eq}	D	H_{ex}	H_{in}
A1	34.09	15.58	0.09	0.14
A2	35.14	16.51	0.10	0.18
A3	24.42	11.84	0.07	0.08
A4	27.33	12.91	0.07	0.12
A5	18.37	8.65	0.05	0.07
B1	32.03	14.64	0.09	0.09
B2	8.30	4.49	0.02	0.02
B3	16.81	7.45	0.05	0.07
B4	14.02	6.61	0.04	0.04
B5	37.99	17.67	0.10	0.15
C1	28.73	14.60	0.08	0.11
C2	35.84	16.91	0.10	0.15
C3	16.58	7.68	0.05	0.05
C4	28.45	13.31	0.08	0.11
C5	26.23	12.56	0.07	0.07
D1	32.96	15.59	0.09	0.11
D2	40.50	18.18	0.11	0.16
D3	24.35	11.29	0.07	0.07
D4	8.42	4.56	0.02	0.02
D5	15.37	6.49	0.04	0.04
E1	21.44	10.64	0.06	0.09
E2	25.70	12.46	0.07	0.07
E3	24.73	11.39	0.07	0.08
E4	30.55	14.59	0.08	0.11
E5	36.83	17.41	0.10	0.14
F1	50.02	23.57	0.14	0.20
F2	35.29	16.64	0.10	0.16
F3	29.00	12.91	0.08	0.09
F4	16.57	7.97	0.05	0.05
F5	28.17	12.63	0.08	0.09
G1	15.18	7.09	0.04	0.06
G2	47.69	23.10	0.13	0.16
G3	27.74	12.34	0.08	0.11
G4	27.56	13.06	0.07	0.11
G5	31.92	14.34	0.09	0.13
H1	9.65	4.46	0.03	0.03
H2	16.86	7.12	0.05	0.05
H3	52.48	24.10	0.14	0.23
H4	25.97	12.04	0.07	0.10
H5	51.83	24.67	0.14	0.20
I1	17.24	7.86	0.05	0.08
I2	33.70	14.84	0.09	0.12
I3	20.47	10.28	0.06	0.08
I4	29.61	13.88	0.08	0.08
I5	27.31	13.07	0.07	0.13
J1	10.04	5.06	0.03	0.04
J2	29.07	13.80	0.08	0.09
J3	43.01	20.73	0.12	0.19
J4	9.27	4.54	0.03	0.03
J5	34.91	16.37	0.09	0.09

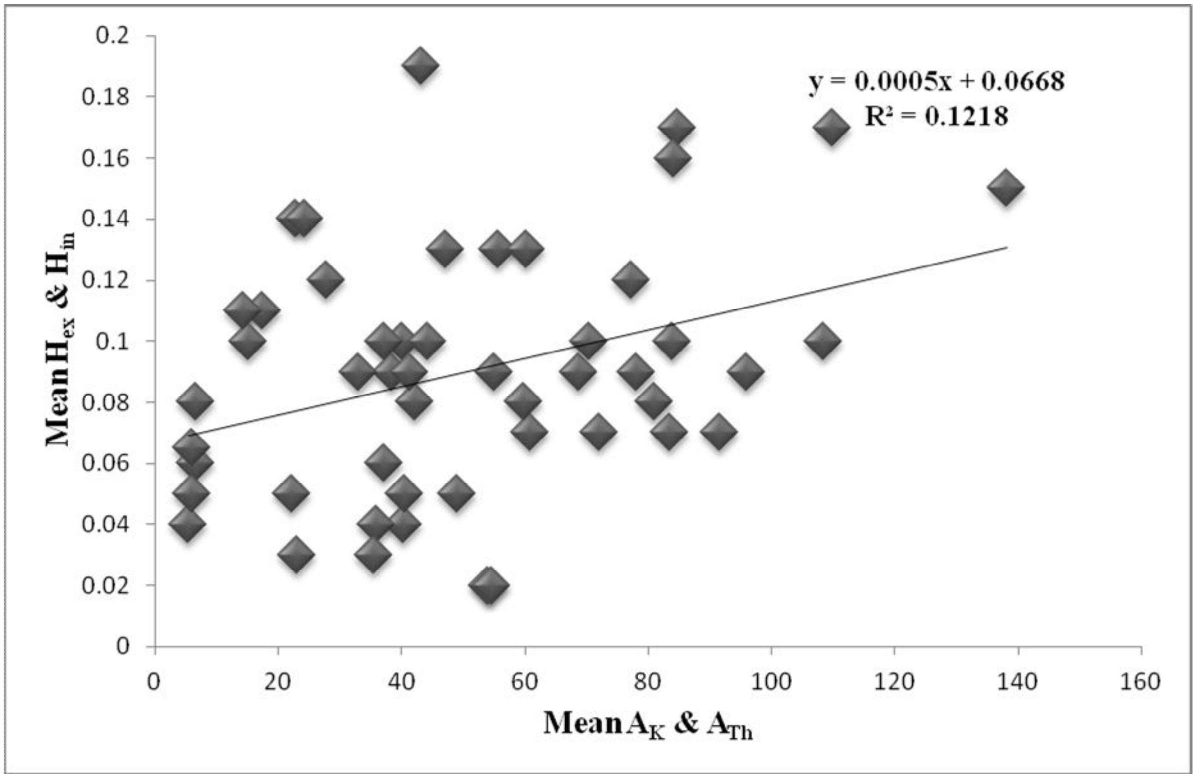

Fig. 4. Correlation between the Mean of A_K & A_{Th} and Mean H_{ex} & H_{in}.

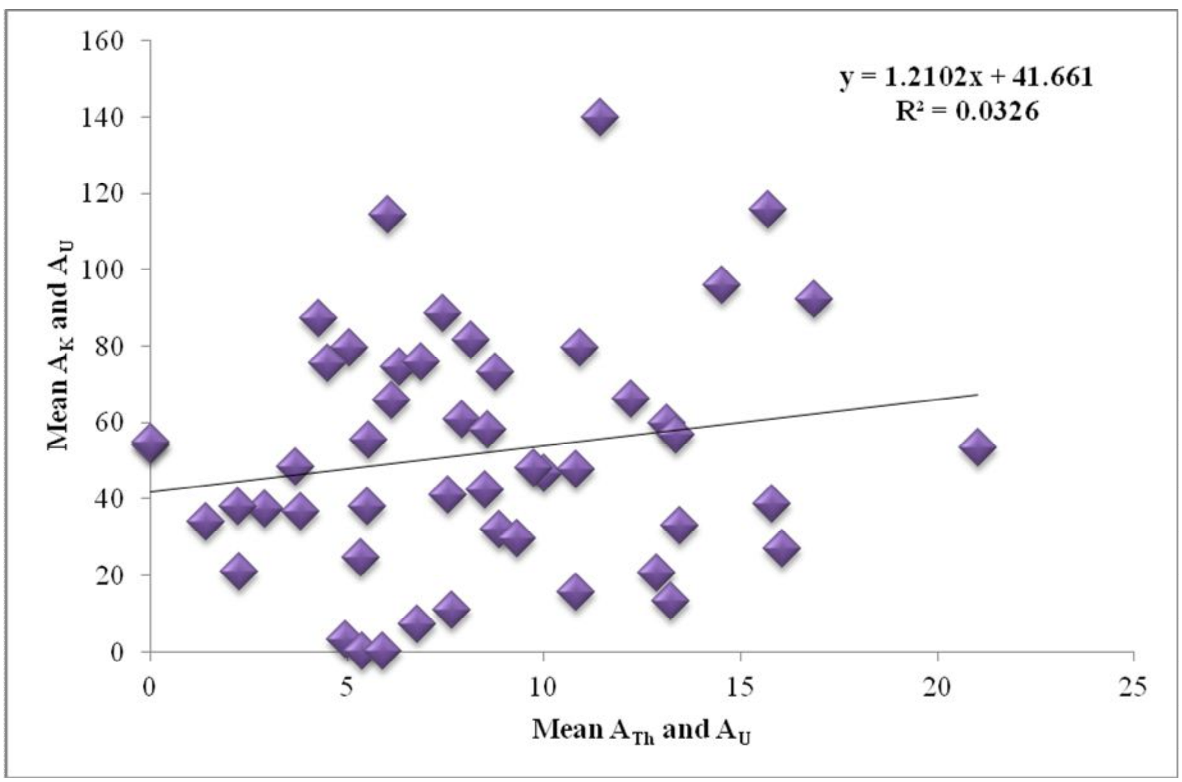

Fig. 5. Correlation between the Means of A_K & A_U and A_{Th} & A_U.

CONCLUSION

This study was conducted solely to assess levels of naturally occurring radionuclides (^{40}K, ^{238}U and ^{232}Th) in Borehole water samples collected from some selected sites of Bwari Area Council in the Federal Capital Territory, Abuja, Nigeria. Location A had the least value of 0.812 ± 0.094 $mSv.y^{-1}$ while F had the highest value of 1.164 ± 0.1198 $mSv.y^{-1}$.

It is worthy of note that Locations A, B, C, E, I and J all had values which were less than the 1$mSv.y^{-1}$ recommended by ICRP for public exposure (ICRP, 1990). However, locations D, F, G and H had values that were slightly higher. This notwithstanding, people living in these locations (D, F, G and H) who consume Borehole water directly or indirectly may not face the risk having health effects resulting from the accumulation of these radionuclides, mainly ^{238}U and ^{232}Th in their bones and other radiosensitive soft body tissues. However, there is need for constant monitoring in the event that the values do rise much higher than they are now.

In addition the calculated values of radium equivalent (R_{eq}), the absorbed dose rate (D), the external hazard index (H_{ex}) and internal hazard index (H_{in}) in all the locations, were all less than the recommended values given by the International Commission on Radiological Protection (ICRP).

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Received: Oct 29, 2018; Revised: Dec 21, 2018; Accepted: Jan 2, 2019