Scholars Journal of Physics, Mathematics and Statistics **ISSN 2393-8056 (Print)**
Sch. J. Phys. Math. Stat. 2016; 3(2):56-65 **ISSN 2393-8064 (Online)**

Determination of Radioactivity Concentration and Annual Committed Effective Dose in Drinking Water Collected from Local Borehole in Gombe, Nigeria

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Abstract: The gross alpha and beta data were generated from EURISYS MEASURE IN20 low Background multiple (eight) channels alpha and beta detector stationed at Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. Eight samples of drinking water collected from local boreholes in Gombe metropolis were evaporated to obtain the residue. The residue was later counted for gross alpha and beta activity. The mean gross alpha and beta activity obtained were 1.03 and 18.69 Bq/l respectively. The gross alpha and beta activity values were used to estimate the annual committed effective dose (ACED) due to alpha and beta emitting radionuclides. The mean ACED obtained due alpha emitting radionuclides were 0.41, 0.82 and 1.65 mSv/yr for infants (≤ year), children (1-12 years) and teenagers/adults (> 12 years) respectively while the ACED obtained due to beta emitting radionuclides were 7.51, 15.01 and 30.02 mSv/yr for infants, children and adults respectively. The results obtained were compared with the world standards and realized that most of the sample locations were above the world standards. It was concluded that the water collected from these sample locations will be threat to human health and the environment. Therefore, it was recommended that further studies need to be carried out to ensure the safety of the masses around the areas and the environment.
Keywords: Gross alpha, gross beta, borehole, drinking water, Gombe metropolis.

INTRODUCTION

Radioactivity in water is relatively easy to measure, the interpretation of the significance of the measured radioactivity to the domestic water user is beset with uncertainties and imponderables, especially when it comes to evaluating the actual risk to the consumer. Water is a necessity to man and his environment; it has existed throughout the history of the earth crust even before the existence of man. Man uses water for the following activities: irrigation, power generation and domestic activity. Water pollution arises as a result of waste and sewage disposal into the environment and rivers by industries, hospitals and use of materials such as fertilizers by farmers. In developing countries like Nigeria, lack of good drinking water is one of the serious threats to the human health as a result of that, rivers, streams, well and borehole waters are often used as supplement for the scarce pipe-borne water for drinking and domestic activities without any treatment[1]. Another form of water pollution is Naturally Occurring Radioactive Materials (NORM) that emits alpha, beta and gamma radiation.

Evidence indicated a widespread of water contamination in most of the areas in our country. It has been identifies that agriculture, urban flood/storm water and metropolitan sources as the main pollutant sources for rivers, lakes and estuaries as stated in the Environmental Protection Agency's, National Water Quality Inventory of 1994. Contaminants from these sources include pesticides, heavy metals, nitrates, solvents, and other wastes. The National Water Quality Inventory 1994 Report to Congress states that 40% of flowing river and stream miles can be used for drinking water after conventional water treatment, and 37% of lake and reservoir acres meet the designated use criteria for drinking water. Some pollutants are significance to human health in certain amount when they do not exceed the recommended level; a good example of such pollutants is heavy metals. Some have a lot of health benefit in small quantity and harmful in large quantity [2].

There is a great concern for the quality of drinking water as it is critical to overall socio-economic development of any society and involves individuals, groups, government and non-governmental organizations. Since the public utilities are simply unable to cope with the demand for qualitative water, alternative source (s) of water must be devised. Consequently, the frustrated citizen of Gombe town in north-eastern Nigeria seek realistic solutions by digging local wells and boreholes as well as other water sources that are clean, clear, odorless, apparently pure and safe to drinking.

Available statistics show that urban centers are better off than the rural areas in terms of access to safe drinking water sources. This is so perhaps where large population resides, as a result of that most of the national and international aids are directed to these centers. Moreover, the conditions are just as dreadful in the cities as in rural localities, since there is no boundary between the rural and cities centers. To justify the situation evidently, UNICEF in 2010 joint monitoring program for water supply and sanitation reported that only 58% of Nigerian population has access to improved drinking water supply and only 32% have sanitation coverage. This translates into about 64 millions of Nigerians without access to improved drinking water and over 100 million people do not have access to improved sanitation, all out a total population of about 150 million[3].

The critical water shortage forced people of Gombe to drink untreated water obtained from surface and underground sources, thus, exposing themselves to hazardous chemicals and infectious agents. This has drawn the attention of many researchers to examine the radioactivity, physicochemical and microbial characteristics of water sources[4].

Determination and assessment of internal exposure to the general public can only be achieved by measurement of natural radioactivity in our environment. The level of radionuclides in drinking water depends on the source of the water and anthropogenic activity in the area. The activities that affect the level of radioactivity in water include the geological activity, tin mining, industrial activity and use of fertilizers in agriculture[4].

For the purpose of practical screening. The maximum recommended level of radioactivity are 0.5 Bq/l for gross alpha activity and 1.0 Bq/l for gross beta activity respectively set by the World Health Organization (WHO). The standard level does not differentiate between natural and man-made radionuclides. The essence of measurement of radioactivity is to confirm that the reference dose level (RDL) of annual committed effective dose (ACED) of 0.1 mSv/yr intake of drinking water is not exceeded in any study area. The RDL of value 0.1 mSv/yr is equivalence to 10% of the dose limit for general public recommended by the International Commission on Radiological Protection (ICRP) and the International Basic Safety Standard (IAEA) and are acceptable to most of the WHO member States, European Commission, Food and Agriculture Organization[5].

The Objectives of this study is to determine the gross alpha and beta activity in drinking water drawn from local boreholes in Gombe metropolis, Gombe State, Nigeria and to create the distribution pattern of radioactivity measured in the locations in order to identify areas of elevated if any. Further studies will be carried out to estimate annual committed effective dose and finally compare the values obtained with other studies to see if there is any correlation.

RESEARCH METHODOLOGY

Sampling Frame

The area under study is Gombe metropolis and limited to underground water sources drawn from local boreholes used by the people of Gombe metropolis for drinking, domestic's activities, irrigation and animal husbandry. A stratified random sampling was adopted.

Sampling Procedure

The sampling procedure involves the following: The sample container was rinsed three times with the water being collected, to minimize contamination from the original content of the sample container. One sample was collected per sampling point which gives the total of 8 samples; air space of about 2% of the container was left for each sample to give room for thermal expansion. The sample containers were marked indicating one liter corresponding to the air gap. A concentrated nitric acid of 10 ml volume was added to each sample at the sampling point to reduce the pH and to minimize precipitation and absorption on the container walls. The samples were tightly covered with container cover and masking tape and kept in the laboratory for analyses.

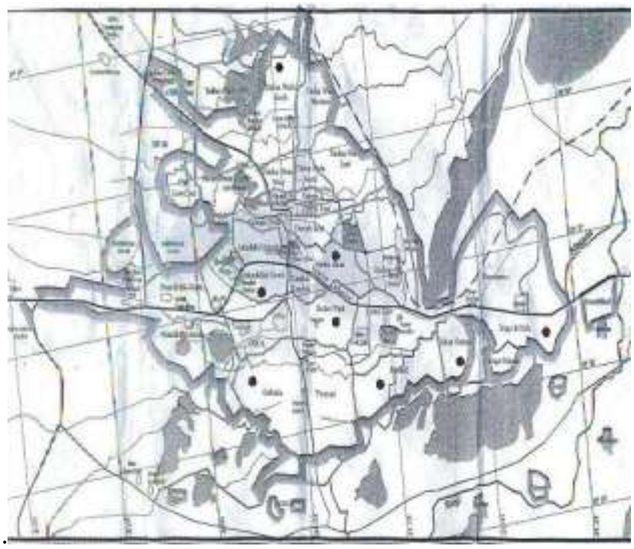

Fig. 1: Map of Gombe Metropolis and Within the Map Bold dots indicates the Sampling Points[1]

Figure 1: shows the map of Gombe metropolis and various sampling points which were marked on the figure using bold dots. The sample sites were selected based on the population and highly dependence on local water boreholes for drinking and other domestic activities. The area under study includes: Yalan-Guruza, Manawachi, Gabukka, Bolari, Jekada-Fari, Tudun-Wada, Malam-Inna and Herwagana.

Sample Preparation

The calculated volume of each sample was measured into a beaker and evaporated on a hot plate to almost dryness and transferred to a clean dry planchet, the samples were still taken back to the hot plate to complete the evaporation until a dry residues were obtained.Hence, the residues obtained were then transferred onto to another clean, dry and previously weighed planchet. The difference between the mass of empty planchet and that of the empty planchet plus residue gives the mass of the residue. The residue was uniformly spread and stick on the planchet by dropping a few drops of vinyl acetate. The residue was allowed to dry and then covered with Mylar film ready for counting.

$$\text{Sampling efficiency} = \frac{(w_2-w_1)-(w_3-w_1)}{w_2-w_1} \times 100\% \quad (1)$$

The sampling efficiency was obtained by measuring the weight of the empty beaker, w_1, and weight of empty beaker plus the sample obtained after evaporation, w_2, the difference between w_2 and w_1 gives the total weight of the sample obtained after evaporation. The sample is then transferred to a planchet and the weight of the beaker was measured again, w_3. The difference between w_3 and w_1 gives the total weight of sample loss from the beaker.

Counting and Analysis

The gross alpha and beta counting equipment used in this study is a EURISYS MEASURE IN20 low Background multiple (eight) channelsalpha and beta detector. It is a gas flow proportional counter. The counting gas is an argon-methane mixture at the ratio of 90% and 10% respectively. The protocol involves entering preset time, counting voltage and number of counting cycles. Also the necessary parameters to be entered are the counter characteristics (efficiency and background), volume of sample used and sample efficiency. Results are displayed as raw count, (count/min) count rate, activity, and standard deviation. Acquisition was made in α-only and β (+α) mode. The selection of mode of counting was arbitrary[1]. The calculation formulae for count rate, activity and other parameters for a given sample are shown below:

$$\text{Rate } (\alpha,\beta) = \frac{Raw\ (\alpha,\beta) Count}{Count\ Time} \quad (2)$$

In all modes except mode alpha then beta:

$$\text{Activity } (\alpha,\beta) = \frac{Rate\ (\alpha,\beta) - Bgd\ (\alpha,\beta)}{Sample\ Efficiency \times Channel\ Efficiency \times Volume} \times \frac{1}{60} \quad (3)$$

Gross Alpha and Beta Activity

The alpha and beta activity are expressed as activity concentration denoted with (C_α and C_β for alpha and beta respectively) in Becquerel per liter (Bq/l) as shown in equation 4 and 5 respectively.

$$C_\alpha = \frac{(R_b - R_0)\times A_s \times m \times 1.02}{(R_s - R_0)\times V \times 1000} \quad (4)$$

$$C_\alpha = \frac{(R_b - R_0)\times A_s \times m \times 1.02 \times 14.4}{(R_s - R_0)\times V \times 1000} \quad (5)$$

Where; R_b is observed sample count rate (S^{-1}), R_s is observed standard count rate (S^{-1}), $R_0$is background count rate (S^{-1}), V is volume of sample in liters, and m is mass in milligrams of the counted residue from volume V and 14.4/1000 represent the specific activity for potassium-40 (^{40}K in KCl). It is important that the factor 1.02 be included in the final equation to correct for the 10ml of the nitric acid added to the sample for preservation[6].

The statistical precision is calculated for each channel, on each measurement and it depends only on the preset count whose value is declared indirectly. Assume N measurements are made during a time T, the average is given by x = $\frac{\sum xi}{N}$ and the standard deviation is given by

$$\sigma = \sqrt{\frac{\sum(x-\mu)^2}{N}} \text{ and } \sigma = \sqrt{\left[\frac{R_s}{t_s} + \frac{R_b}{t_b}\right]} \quad (6)$$

Where:

R_s = Sample counting rate
R_b= Background counting rate
t_s= Sample counting time
t_b = Background counting time
µ = Population mean

$$CR = 1.96\sigma \quad (7)$$

Where CR = Counting Error

Statistical Analysis

To determine the radioactivity measured, statistical analysis employed are estimation of the central tendencies and correlation analysis[7]. The correlation coefficient (r) and the geometric mean are given in equations (6) and (7) below:

$$r = \frac{n\sum xy - \sum x \sum y}{\sqrt{[n\sum x^2 - (\sum x)^2][n\sum y^2 - (\sum y)^2]}} \quad (8)$$

$$\text{Geometric Mean} = \sqrt[n]{(x_1, x_2 \ldots x_n)} \quad (9)$$

Where µ is the population mean and σ is the standard deviation. All statistical analyses were made using the Microsoft Excel.

Annual Effective Dose (AED)

The annual effective dose to an individual due to consumption of alpha emitting radionuclides and beta emitting radionuclides from the water samples were estimated using the relation below[8]:

$$AED = MA \times IW \times CF \quad (10)$$

Where AED = Annual Effective Dose, MA = Measured Activity in Bq/l, IW = intake water in liters, CF = Conversion Factor and is given 2.2×10^{-3}mSv/Bq

- Annual water consumption for infant (≤ year) is 182.5 L
- Annual water consumption for Children (1-12 years) is 365 L
- Annual water consumption for teenagers/adults (> 12 years) is 730 L

RESULT AND DISCUSSION

The drinking water samples collected from local borehole in Gombe metropolis, Nigeria.The samples were studied and analyzed for gross alpha and beta activity using EURISYS IN20 gas flow proportional counter stationed at

Center for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. The data were analyzed using Microsoft excel and simple statistical tools.

Measured Alpha and Beta Activity

The measured alpha and beta activity were studied. The maximum and minimum activities were also recorded as shown in figures1 to 3 below. The following were also computed arithmetic mean, geometric mean and range for both alpha and beta activity.

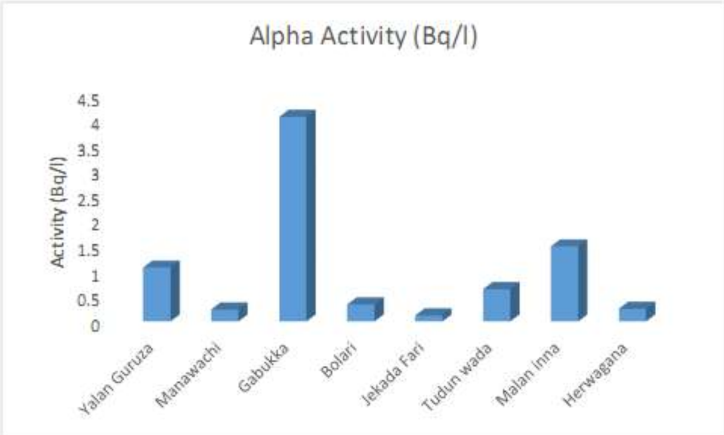

Fig. 1: Plot of Measured Alpha Activity for Gombe Metropolis

Figure 1: shows the distribution of alpha activity measured at Gombe metropolis. The plot indicated a random fluctuation. The maximum and minimum activity obtained at Gabukka and Jekadafari of 4.06 and 0.118 Bq/l. it was further observed that some locations exceeded the guidelines for safe drinking water.

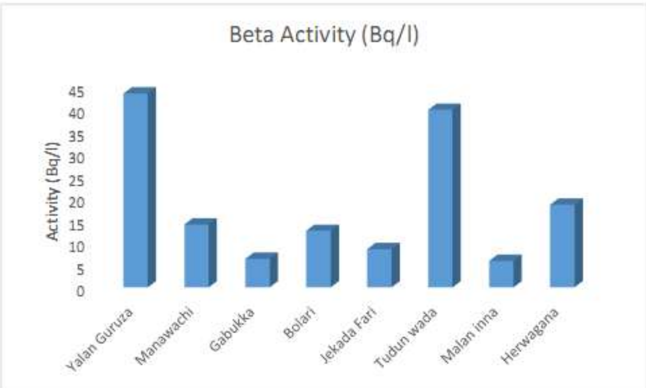

Fig. 2: Plot of Measured Beta Activity for Gombe Metropolis

Figure 2: shows the distribution of beta activity measured at Gombe metropolis. The chart reveals random fluctuation across the sample locations. The maximum and minimum beta activity obtained at Yalanguruza and Malan inna of 43.48 and 5.93 Bq/l respectively.

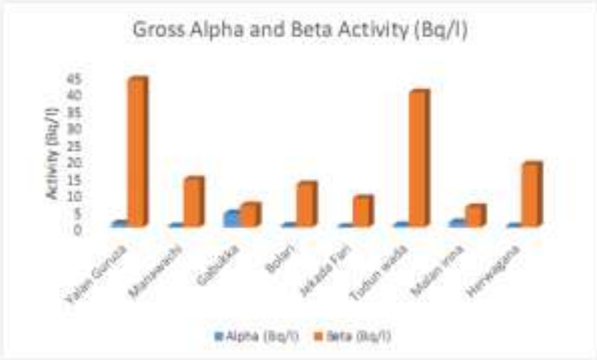

Fig. 3: Plot of Measured Gross Alpha and Beta Activity for Gombe Metropolis

Figure 3: shows the plot of alpha and beta activity measured at Gombe metropolis. The plot indicated that the measured beta activity was extremely greater than the measured alpha activity. It was further observed that the concentration of alpha activity in the location is independent of beta activity.

Comparison between the Measured Gross Alpha and Beta and WHO Standard

The measured gross alpha and beta activity were compared with WHO guidelines of drinking water as shown in figures 4 and 5 respectively.

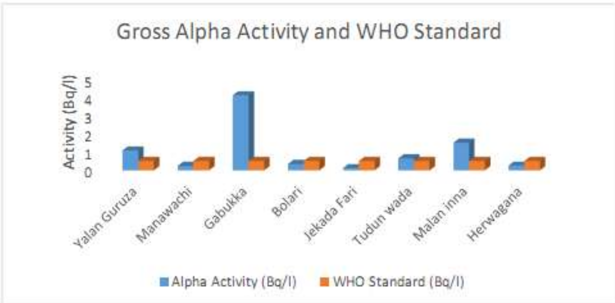

Fig. 4: Plot of Comparison between the Measured Gross Alpha and WHO Standard

Figure 4: shows the comparison between the measured alpha activity and WHO standard. The following locations: Yalanguruza, Gabukka, Tudunwada and Malan inna showed elevated above the recommended level set by WHO. The maximum activity was recorded at Gabukka and the least obtained at Jekadafari.

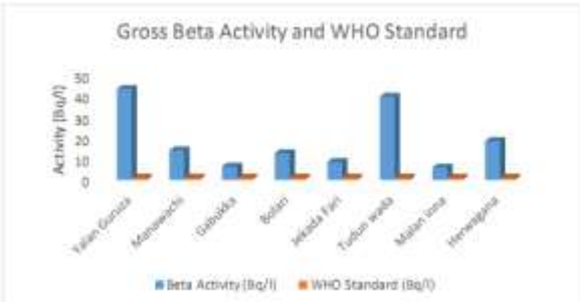

Fig. 5: Plot of Comparison between the Measured Gross Beta and WHO Standard

Figure 5: shows the comparison between the measured beta activity and WHO standard. It was observed that all the locations exceeded the guidelines recommended by WHO of 1.0 Bq/l for safe drinking water. It was further observed that Yalanguruza and Tudunwada had the highest beta activity compared to other study locations.

Annual Committed Effective Dose (ACED) for all Age Category and Compared with International Commission on Radiological Protection (ICRP) Standard

The measured gross alpha and beta activity were used to estimate the annual committed effective dose for all age category using the estimated volume of water intake per annum, measured activity and conversion factor which was constant for infants (≤ year), children (1-12 years) and adults (> 12 years). The results obtained were later compared with ICRP standard as shown in figures 6 to 9 below.

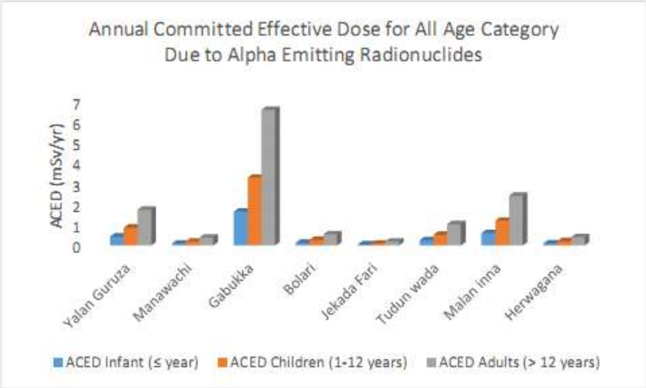

Fig. 6: Annual Committed Effective Dose for All Age Category Due to Alpha Emitting Radionuclides for Gombe Metropolis

Figure 6: shows the plot of annual committed effective dose (ACED) for all age categories due to alpha emitting radionuclides for Gombe metropolis. The chart indicated that the ACED for teenagers/adults is higher than any other age category. This is because the ACED is proportional to the amount of water intake per annum. The highest and least ACED yielded at Gabukka and Jekadafari of 6.52 and 0.19 mSv/yr respectively.

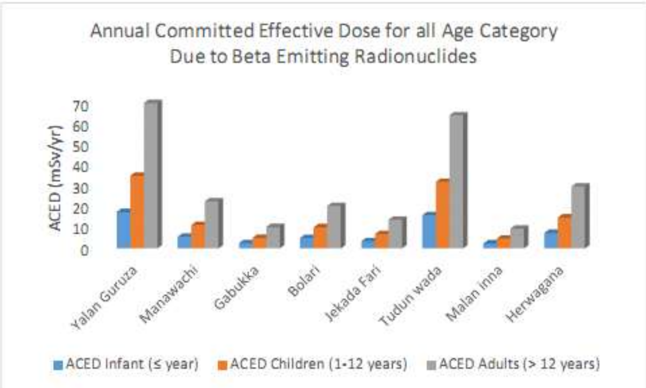

Fig. 7: Annual Committed Effective Dose for All Age Category Due to Beta Emitting Radionuclides for Gombe Metropolis

Figure 7: shows the annual committed effective dose for all age categories due to beta emitting radionuclides for Gombe metropolis. The plot indicated an increasing behavior from infant to adults. The maximum and minimum ACED obtained at Yalanguruza and Malan innaof 69.83 and 9.52 mSv/yr respectively.

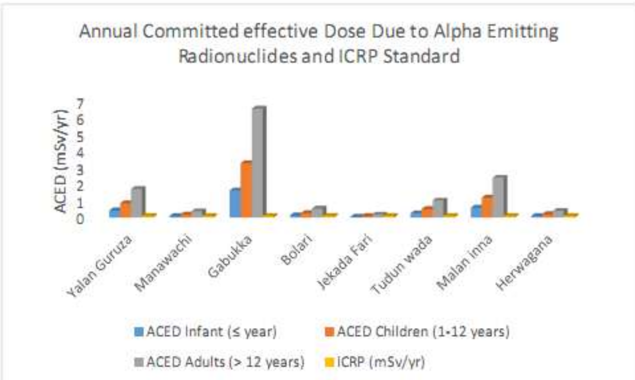

Fig. 8: Comparison between Annual Committed Effective Dose Due to Alpha Emitting Radionuclides and ICRP Standard

Figure 8: shows the comparison between the annual committed effective dose due to alpha emitting radionuclides and ICRP standard. The chart indicated that almost all the locations exceeded the ICRP standard except for Jekadafari which was below the ICRP standard and ACED obtained at some locations for infants due to low volume of water intake per annum.

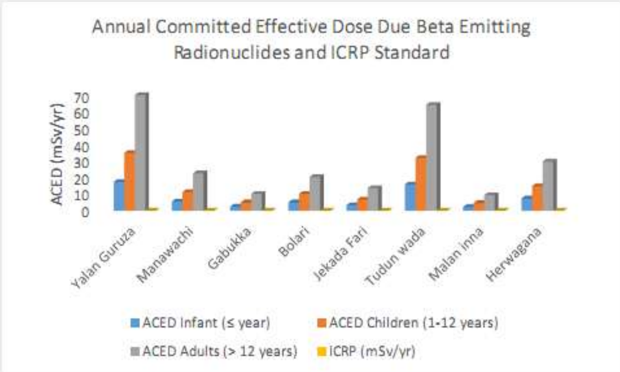

Fig. 9: Comparison between Annual Committed Effective Dose Due to Beta Emitting Radionuclides and ICRP Standard

Figure 9: comparison between annual committed effective dose due to beta emitting radionuclides and ICRP standard. The ACED observed were above the recommended level set by ICRP for locations. The maximum and minimum ACED obtained at Yalanguruza and Malan inna respectively.

Correlation between Gross Alpha and Beta Activity

A study was carried out to examine the correlation between the gross alpha and beta activity as shown in the figure 10 below.

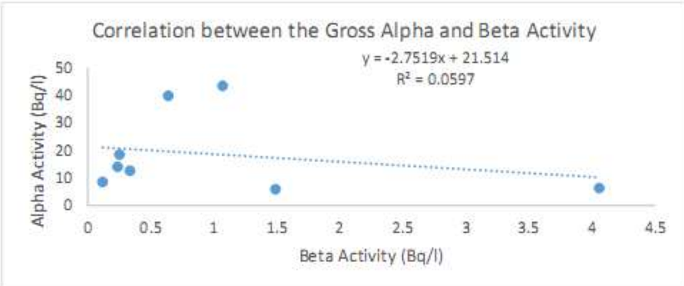

Fig. 10: Correlation between the Measured Gross Alpha and Beta Activity

Figure 10: shows the correlation between measured alpha and beta activity of local borehole water samples collected from Gombe metropolis. The following were computed: coefficient of determination (R), Pearson regression coefficient (r), gradient and intercept of values 0.06, 0.24, -2.75 and 21.51 respectively. The result indicatedthat there is no significance statistical correlation between the alpha and beta activity measured in the water.

Comparison of Results with other Works

The ACED and gross alpha and beta activity obtained in this work were compared with other works in the country. The comparison was made between ACED obtained in this work with other works; the aim was to see if there is any correlations between the ACED obtained with other areas as shown in table 1 below.

Table 1: Comparison of the Results Obtained with Other Locations

Annual Committed Effective Dose (mSv/y)							
	Alpha			Beta			
Locations	Adults	Children	Infants	Adults	Children	Infants	Sources
Sokoto	0.068	-	-	1.046	-	-	[9, 10]
Plateau	1.938	0.963	0.485	2.375	1.187	0.594	[8]
Niger Delta	0.076	-	0.209	-	-	-	[5]
Ado Ekiti	0.03	-	0.15	-	-	-	[11]
Gombe	1.65	0.82	0.41	30.02	15.01	7.51	This work

Table 1: shows the comparison between the ACED obtained at Gombe with other locations. The ACED due to alpha emitting radionuclides; the estimated ACED of adults at Gombe was less than the one estimated at Plateau and greater than all the other locations, the ACED of Children at Gombe was less than the one estimated at Plateau, the ACED of infants estimated at Gombe was also less than the one estimated Plateau and greater than all the other areas. The ACED due to beta emitting radionuclides; the ACED estimated at Gombe was greater than all the other locations in the table for adults, children and infants respectively.

The estimated ACED at Gombe was closely related to the one estimated at the mining area of Plateau especially the ACED due to alpha emitting radionuclides while the estimated ACED due to beta emitting radionuclides did not indicates any relation with the other locations in the table.

CONCLUSION

Eight samples of drinking water collected from local boreholes in Gombe metropolis were evaporated and obtained the residues. The residue was later counted for gross alpha and beta activity. The results obtained showed that the gross alpha and beta activity ranged from 0.118 to 4.06 Bq/l and 5.93 to 43.48 Bq/l respectively. A study was carried out to estimate the annual committed effective dose (ACED) for infants (≤ year), children (1-12 years) and adults (> 12 years) due to alpha and beta emitting radionuclides respectively. The results of ACED due to alpha emitting radionuclides varied from 0.047-1.630 mSv/yr, 0.095-1.196 mSv/yr and 0.190-6.520 mSv/yr for infants, children and adults respectively while the results of ACED due to beta emitting radionuclides varied from 2.381-17.457 mSv/yr, 5.131-34.914 mSv/yr and 9.524-69.829 mSv/yr for infants, children and adults respectively. Further study was carried out to examine the correlation between the gross alpha and beta activity measured in the water and poor correlation was obtained which implies no significance relationship between the alpha and beta activity measured. The values obtained were compared with the various world standards and other previous works. The results obtained in the study were above the world standards values in most locations. It was concluded that the water collected from these sample locations will be threat to human health and the environment. Therefore, it was recommended that further studies need to be carried to ensure the safety of the masses around the areas and the environment.

ACKNOWLEDGEMENT

The authors wish to acknowledge the staff and management of Centre for Energy Research and Training (CERT), Ahmadu Bello University Zaria for analyzing the water samples.

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