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Determination of Radioactivity Concentration and Estimation of Annual Effective Dose for All Age Categories of Drinking Water Collected From Dutse Town, Nigeria

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Abstract: *The level of radioactivity in water samples collected from Dutse town, the capital city of Jigawa State, Nigeria was determined and annual effective dose for intake of radionuclides in the water were estimated. Twenty-four (24) samples of drinking water were collected and evaporated using hot plate to obtain the residue. A specified quantity of the residues was measured and analyzed using MPC-2000, a low background gross alpha and beta counter. The average activity obtained were 0.23 Bq/l and 283 Bq/l for alpha and beta activity respectively. The estimated annual effective dose (AED) ranged from infants to adults were also examined. The internal exposure due to alpha emitting radionuclides were above the maximum recommended level for almost all the age categories except for infant which was below the recommended level set by International Commission on Radiological Protection (ICRP) of value 0.1 mSv/yr while due to beta radionuclides were above the recommended level set by ICRP of 0.1 mSv/yr. It was concluded that the water locations were radiologically contaminated. Therefore, we recommend that the water sources should be treated for radioactivity before consumption and other domestic activities.*

Keywords:*Annual Effective Dose, Drinking Water, Jigawa State, Radioactivity*

I. Introduction

Water is one of the most significant resource to humans and every other life. Several studies have been carried out to assess the quality of our drinking water and yet the assessment of water contamination remains significant especially in developing countries. There are two sources of water: rain and ground waters. It is found in rivers, wells, lakes and streams. Surface water that penetrated into the ground, filling soil pores spaces, fissures, fractures of the lithological formations, among others, is known as groundwater [1]. Pollution is a world serious issue and water pollution is one of the most important problem in developing countries. This is because abundant supply of clean water is necessary for every country. The most crucial natural resources are expected to be free from pollution. The quality of the water resources of a country define the quality of food production, public health, industrial development and hence, its economy [2]. With this regard it is mandatory to study the quality of our water used for consumption and other activities.

Radioactivity of drinking water is an important measure for the quality of drinking water similar to microbiological and chemical criteria. Radioactivity of drinking water is defined as the sum of gross alpha and gross beta activity. Gross alpha activity is the total activity of all alpha emitters such as ^{210}Po, ^{226}Ra, ^{238}U, when radon has been removed while gross beta activity is the total activity of all beta emitters excluding tritium, ^{14}C and other weak beta emitters. United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) in 2000 reported that intake of drinking water and foods contributes about eight percent of the total natural exposure for humans including external and internal sources of radiation. National and international organizations provide maximum recommended level of radioactivity of drinking water. The most acceptable guidelines are that of World Health Organization (WHO) of 0.5 Bq/l for alpha activity and 1.0 Bq/l for beta activity and International Commission on Radiological Protection (ICRP) which states the guidelines for the maximum exposure level of 0.1 mSv/yr [3].

More than 70% of the people in Nigeria depends on the ground water that has not undergone any preliminary test to determine its quality for consumption and other activities. From the previous works, many locations in Nigeria are radiologically contaminated. Therefore, studying the level of radioactivity in drinking water for Dutse town, the capital city of Jigawa State, Nigeria is necessary.

Many works has been done on evaluation of radioactivity and estimated committed effective dose in drinking water within and outside Nigeria. A study was carried out on "Evaluation of the Radiation Hazard Indices and Excess Life Time Cancer Risk due to Natural Radioactivity in Ground Water in Mining Areas of Plateau State". 48 samples of ground water were collected from both boreholes and wells and the sampling was randomly selected in two liters plastic container, the samples were prepared and later analyzed for gross alpha

and beta activity concentrations using MPC-2000-DP, a gasless alpha and beta proportional counter. The results obtained in their work showed that the alpha activity for borehole water samples ranges from 0.11 to 1.55 Bq/l and 0.01 to 12.59 Bq/l for well water samples. They also evaluated the hazard indices and excess lifetime cancer risk. The results obtained for borehole water samples of alpha emitting radionuclides were 0.157, 0.039 0.548×10^{-3} mSv/yr for Annual Effective Dose Equivalent (AEDE), Annual Gonnadal Equivalent Dose (AGED) and Excess Cancer Lifetime Risk (ECLR) respectively while for beta emitting radionuclides were 0.134, 0.668 and 4.68×10^{-2} mSv/yr for AEDE, AGED and ELCR respectively and for well water samples the results obtained were 0.335, 0.084 and 1.172×10^{-3} mSv/yr for AEDE, AGED and ELCR respectively while for beta emitting radionuclides the obtained results were 0.393, 1.964 and 1.375×10^{-3} mSv/yr for AEDE, AGED and ELCR respectively. They observed that almost all the areas were above recommended level and they concluded that the locations have potential radiological hazard which may be due to the mining activities that take place in that area[4]. Another study was carried out on "Determination of Gross α and β Activity Concentration and Estimation of Adults and Infants Dose Intake in Surface and Ground Water of Ten Oil Fields Environment in Western Niger Delta of Nigeria". 10 water samples were collected from oil field environment and analyzed for gross alpha and beta activity using 8 channel gas flow proportional counter. The Alpha activity measured ranges from 0.01±0.002 to 0.7±0.01 (0.15±0.003) Bq/l, 0.01±0.003 to 0.5±0.01 (0.1±0.003) Bq/l and 0.02±0.001 to 35.1±1.1 (4.1±0.1) Bq/l while beta activity concentration ranged from 1.1±0.04 to 13.2±0.1 (6.0±0.1) Bq/l, 0.7±0.1 to 54.7±1.3 (8.9±0.2) Bq/l and 0.7±0.03 to 151.2±1.8 (40.1±0.9) Bq/l for well, tap and river waters respectively. They went further to study annual effective dose per year due to alpha activity for adults and infants; the results obtained were 76.4±1.8 and 20.9±55 μSv/yr, 54.6±1.3 and 14.9±0.4 μSv/yr, and 2118±70 and 584±19.2 μSv/yr in well, tap, and river water samples respectively. The results obtained for the alpha and beta activity were slightly above the maximum recommended level set by WHO and that of dose intake were below the ICRP guidelines for safe drinking water except for one sample location which was above the ICRP standard. They concluded that the water samples were radiologically contaminated especially samples collected from river water and they finally suggested that an alternative water supply should be provided for the people living around the locations [5]. Studies have been done on "Gross Alpha and Beta Activity Concentrations in Portable Drinking Water in Ado-Ekiti Metropolis and the Committed Effective Dose". They evaluated the gross alpha and beta activity and annual effective dose. The results for gross alpha and beta activity ranges from 20 to 357.8 mBq/l. Annual effective dose for children and adults were 0.15 and 0.03 mSv/yr respectively and the values were below the permissible limit set by WHO of 0.1 mSv/yr[6]. Despite many works within the country but yet there is little data on radioactivity recorded in the north western part of Nigeria. This is due partly to the fact that measurements of radioactivity are done without estimation of effective dose and excess lifetime cancer risk or ascertaining the radionuclides contributing to that radioactivity recorded. It is therefore necessary to examine radioactivity level of drinking water in Jigawa state because the water used for drinking and other domestic activities in Dutse has not undergone any treatment and to further study the annual effective dose for all age categories.

The aim of the study is to determine the level of radioactivity concentration of drinking water collected from Dutse town of Jigawa State, Nigeria. The specific objectives of the study are to examine the gross alpha and beta activity in the water and to detect the areas of elevated activity if any. In addition, to estimate the annual internal exposure due to intake of radionuclides for infants (≤ 1year), Children (1-12 years) and adults (> 12 years) and compare the obtained results with International Commission on Radiological Protection (ICRP) of value 0.1 mSv/yr.

II. Research Methodology

2.1 Counting Equipment

The gross alpha and beta counting equipment used in this work was the MPC-2000, a Low Background alpha and beta counter. The equipment is a gasless proportional counter with ultra-thin window. The sample was placed in a planchet and later placed in a sample carrier and the carrier was then placed on the sample drawer and closed for the purpose of gross alpha and beta counting, the counting was done automatically according to the selected count mode when the appropriate sample parameters were inputted [4].

2.2 Sampling Frame

The area under study is the Dutse town, the capital city of Jigawa state, Nigeria. The study is limited to underground water sources in local boreholes and hand-dug wells used by people for drinking, domestic activities, irrigation and animal husbandry. A total of 24 samples were collected from 24 different sampling sites in Dutse town namely: FUD, Gidan Dubu Yadi, Bakwato 1, Bakwato 2, Tashar Danwake, Fatara, Kargo, Garu/Emir palace, Fagoji 1, Fagoji 2, Zai, Jigawa Sarki, Kachi, Limawa, Galamawa, Dasina, Takur Adua, Jigawar Tsada, Takur Site, Dan Masara, Mopol Base, G-9 Site and Aminu Kano Way/Cikin Gari. The method adopted for the sampling is stratified random sampling [7].

2.3 Sampling Procedure

The sampling procedure involves the following: the samples were collected in a plastic container which was initially washed thoroughly using distilled water and rinsed three times with the water being collected. The aim was to minimize the contamination from the original content of the sample container. The containers have marks on them indicating one liter, an air space of about 1% was left on the top to allow for thermal expansion. 10 ml of concentrated nitric acid was added to each sample immediately after collection so that it will reduce the pH, minimize precipitation and absorption by the wall containers and prevent the growth of micro-organisms. The samples were tightly covered using masking tape and kept in the laboratory for analysis.

2.4 Sample Preparation

One liter of sample was measured into a beaker and evaporated to almost dryness using hot plate and transferred into petric dishes and placed under infrared light source to completely dry the residues. The appropriate quantity of the residues were measured according to ISO standard which in this case was 0.077g. A few drops of vinyl acetate were put on the residues in the planchet to make them stick in order to avoid scattering during counting. They were later placed in the laboratory for analysis. The Sample Efficiency (SE) is estimated using:

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

where SE = Sample efficiency, w_1= weight of empty planchet, w_2 = weight of planchet plus residues obtained after evaporation and w_3 = weight of empty planchet – weight of residue

2.5 Counting and Analysis

The counting equipment is automated. The protocol involves entering preset time, counting voltage and number of counting cycles. Also, the counter characteristics (efficiency and background) volume of sample used and sampling efficiency specified. Results are displayed as raw count, (count/min) count rate, activity, and standard deviation [8]. The 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

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

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

$$\sigma = \sqrt{\frac{\sum (x-\mu)^2}{N}} \text{ and } \sigma = \sqrt{[\frac{R_s}{t_s} + \frac{R_b}{t_b}]} \quad (4)$$

R_s = Sample counting rate
R_b= Background counting rate
t_s= Sample counting time
t_b = Background counting time

$$CR = 1.96\sigma \quad (5)$$

Where CR = Counting Error

2.6 Statistical Analysis

In order to analyze the activity measured, statistical analysis employed are estimation of the central tendencies and deviations, correlation analysis and histograms [9]: the geometric mean is given as:

$$\text{Geometric Mean} = \sqrt[n]{(x_1, x_2 \ldots x_n)} \quad (6)$$

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

2.7 Annual Effective Dose (ACED)

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 [4]:

$$AED = MA \times IW \times CF \quad (7)$$

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

- Annual water consumption for infant (≤ 1 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

III. Results And Discussion

The gross alpha and beta radioactivity in drinking water samples collected from Dutse town of Jigawa state, Nigeria were studied and analyzed using Microsoft excel. The study covered alpha activity, beta activity and estimated committed effective dose for all age categories ranging from infants of less than one year to adults.

3.1 Measured Activity and Sample Locations

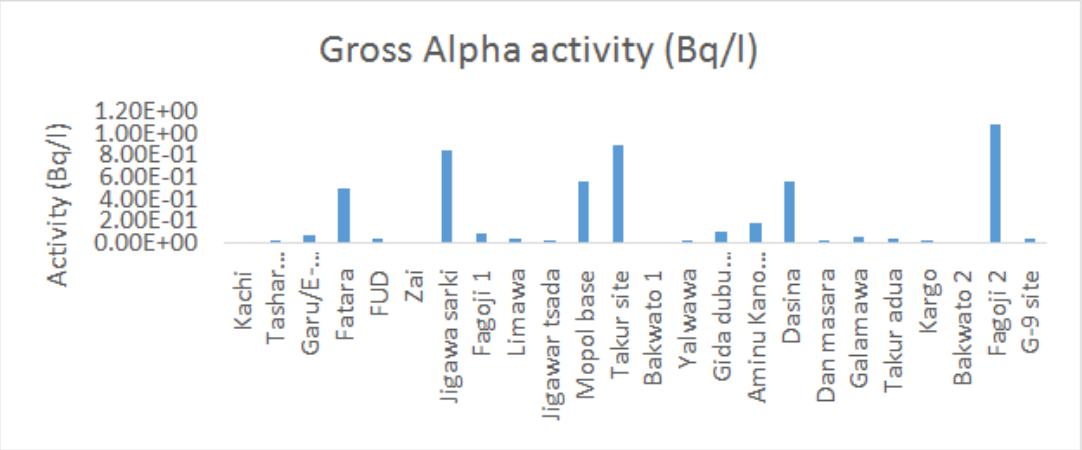

Fig. 1: Plot of Alpha Activity for Dutse Town, Nigeria

Fig. 1 shows the alpha activity for Dutse town, the capital city of Jigawa state, Nigeria. The chart shows that most of the locations were below the maximum recommended level for safe drinking water except for Jigawa sarki, Mopol base, Takur site, Dasina and Fagoji 2 with corresponding values of 0.83, 0.55, 0.88, 0.55 and 1.08 Bq/l which were above the maximum recommended level set by World Health Organization (WHO) of value 0.5 Bq/l.

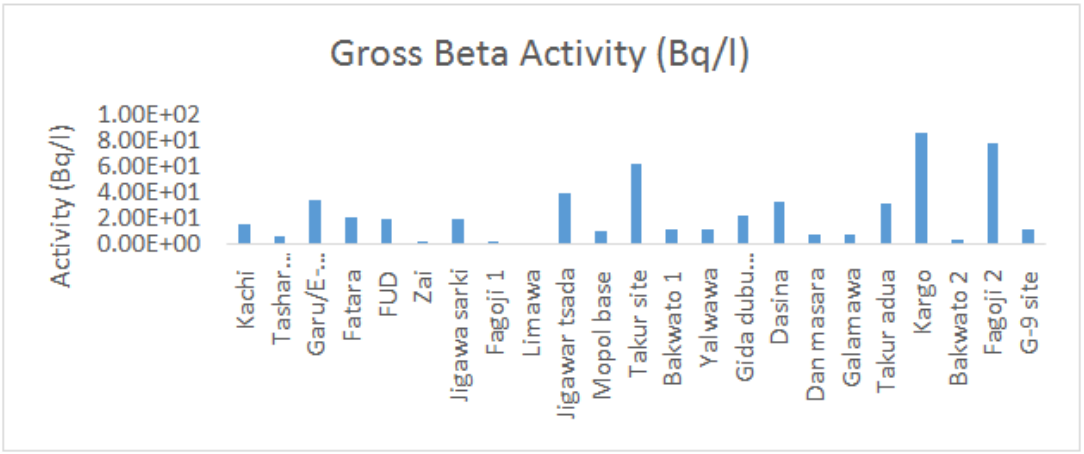

Fig. 2: Plot of Beta Activity for Dutse Town, Nigeria

Fig. 2 shows the plot of measured beta activity for Dutse town, the capital city of Jigawa State, Nigeria. The observed activity for almost all the locations were above the maximum permissible limit except for Limawa of value 0.009 Bq/l which was below the maximum recommended level set by WHO of 1.0 Bq/l for safe drinking water.

3.2 Annual Estimated Annual Effective Dose for all Age Categories

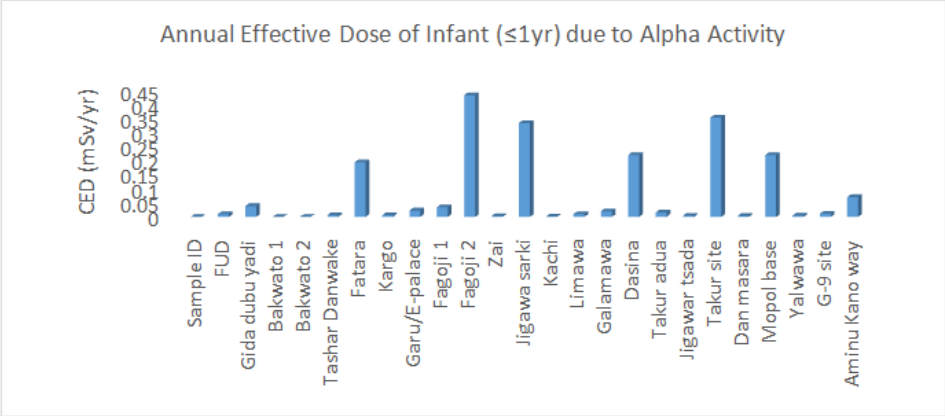

Fig. 3: Annual Effective Dose of Infant (≤ 1 yr) due to Alpha Activity for Dutse Town

Fig. 3 shows the chart for annual effective dose of Infants due to alpha activity. The chart indicates that some locations including Fatara, Fagoji 2, Jigawa sarki, Dasina, Takur site and Mopol base with corresponding values of 0.195, 0.434, 0.335, 0.221, 0.355 and 0.221 mSv/yr were above the guidelines for safe drinking water set by International Commission on Radiological Protection (ICRP) of value 0.1 mSv/yr for the general public while the rest of the locations were below the guidelines set by ICRP.

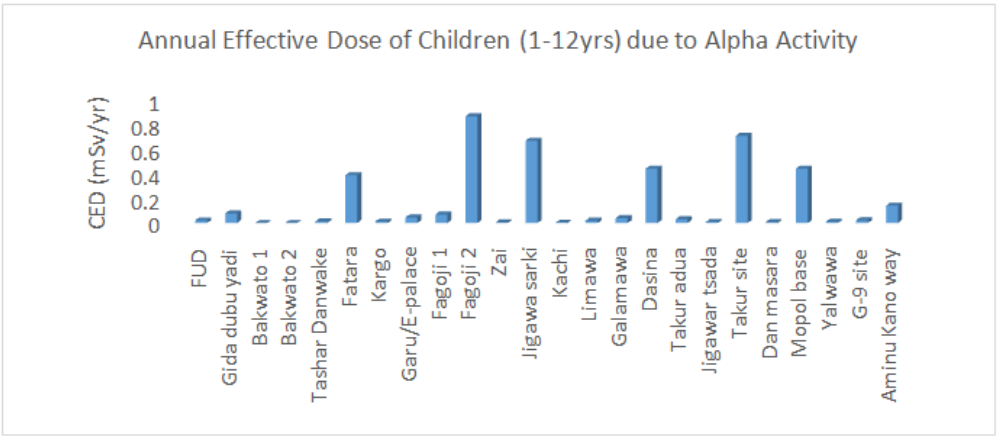

Fig. 4: Committed Effective Dose of Children (1-12 yrs) due to Alpha Activity for Dutse Town

Fig. 4 shows the chart for annual effective dose of children due to alpha activity for Dutse town, Nigeria. The result show that Fatara, Fagoji 2, Jigawa sarki, Dasina, Takur site, Mopol base and Aminu Kano way of values 0.39, 0.87, 0.67, 0.44, 0.71, 0.44 and 0.14 mSv/yr were above the guidelines recommended for the intake of radionuclides from drinking water set by ICRP of value 0.1 mSv/yr and the other locations were below the recommended level.

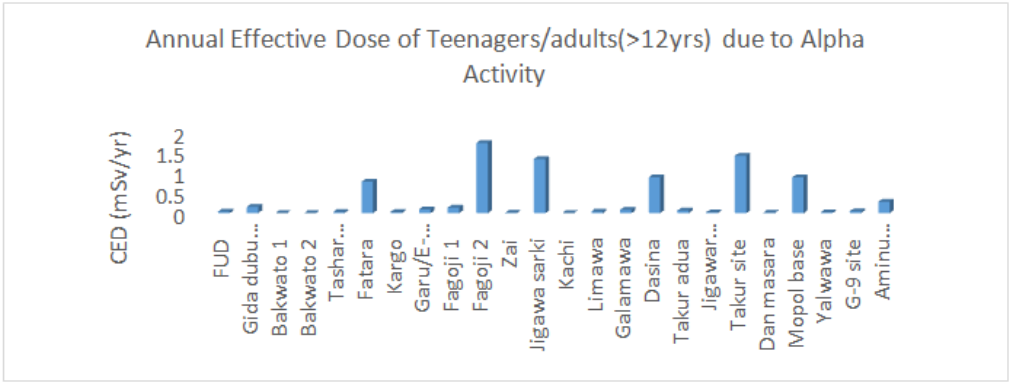

Fig. 5: Annual Effective Dose of Teenagers/Adults (>12 yrs) due to Alpha Activity for Dutse Town

Fig. 5 shows the chart for annual effective dose of Teenagers/Adults due to alpha activity for Dutse town. It could be seen that some areas indicated elevated dose and others showed lower dose. Areas with elevated doses includes: Gida dubu yadi, Fatara, Fagoji 1, Fagoji 2, Jigawa sarki, Dasina, Takur site, Mopol base and Aminu Kano way with corresponding values of 0.16, 0.78, 0.14, 1.74, 1.34, 0.88, 1.42, 0.88 and 0.28 were above the guidelines recommended for the intakes of radionuclides from drinking water set by ICRP of 0.1 mSv/yr.

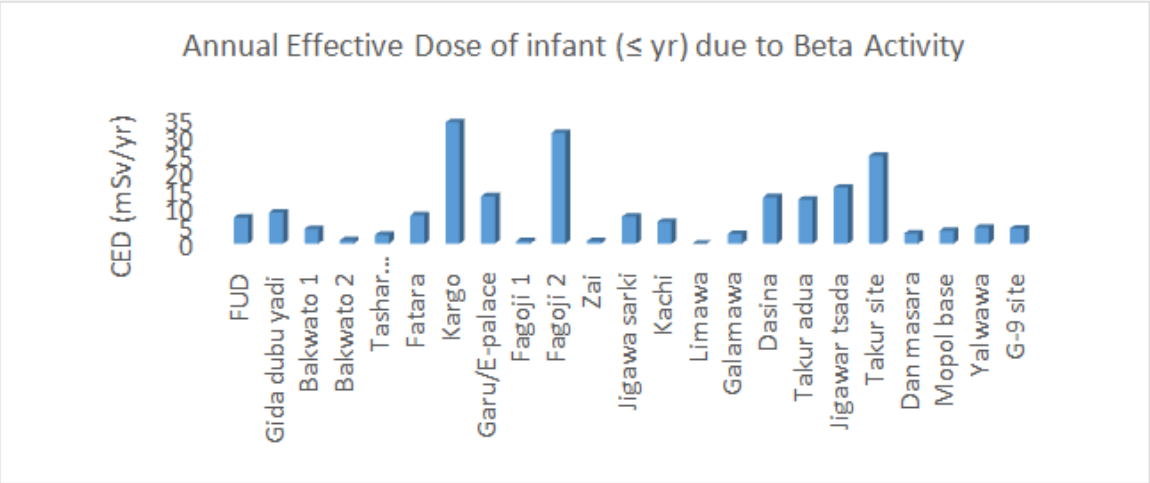

Fig. 6: Annual Effective Dose of Infant (≤ 1 yr) due to Beta Activity for Dutse Town

Fig. 6 shows the bar chart of annual effective dose of Infants due to beta activity for locations in Dutse town. The results show that almost all the sample locations were above the guidelines recommended for intake of radionuclides from drinking water except for Limawa with value 0.004 mSv/yr which is less than the guidelines recommended by ICRP of value 0.1 mSv/yr. The effective dose computed for Aminu Kano way with corresponding value of 2523.23 mSv/yr was remove from the plot due to its larger magnitude. The aim was to make the lower effective doses visible in the chart.

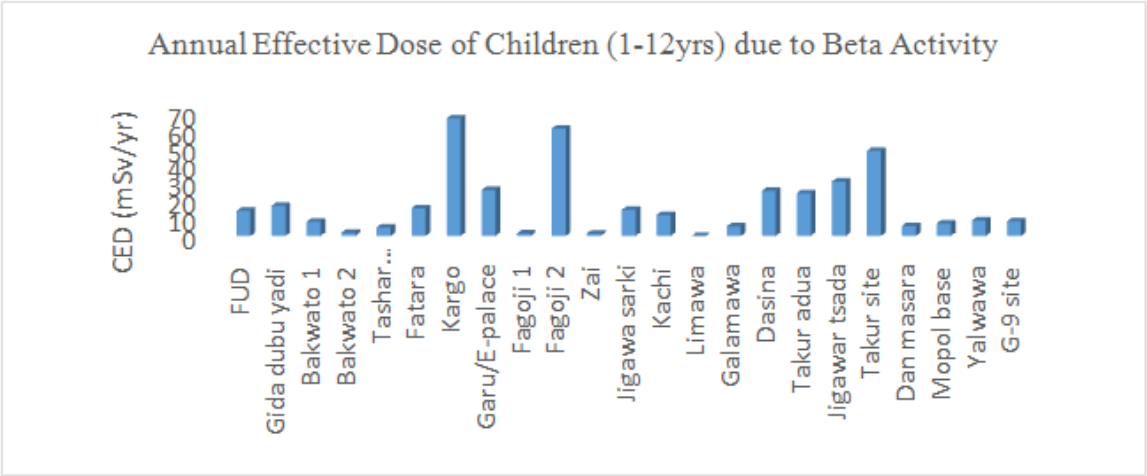

Fig. 7: Annual Effective Dose of Children (1-12 yrs) due to Beta Activity for Dutse Town

Fig. 7 shows the bar chart of annual effective dose of children due to beta activity. The chart indicates that almost all the locations are above the guidelines recommended for the intake of radionuclides from drinking water except for Limawa of value 0.007 mSv/yr which is below the recommended level set by ICRP of value 0.1 mSv/yr. One value was removed from the chart to enhance the visibility of lower effective doses. The value was that of Aminu Kano way with corresponding effective dose of 5046.45 mSv/yr.

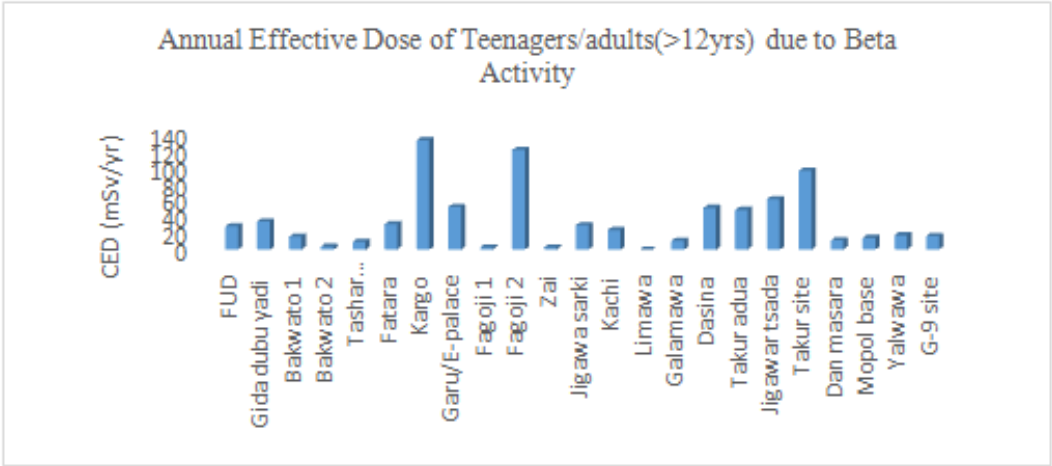

Fig. 8: Annual Effective Dose of Teenagers/Adults (>12 yrs) due to Beta Activity for Dutse Town

Fig. 8 shows the bar chart of annual effective dose of teenagers/adults due to beta activity. The results indicate elevated doses for almost all the locations except for Limawa of value 0.01 which is below the guidelines recommended for the intake of radionuclides from drinking water set by ICRP of value 0.1 mSv/yr. The value for Aminu Kano way with corresponding value of 10092.91 mSv/yr was intentionally excluded from the chart due to its larger magnitude.

3.3 Comparison of Estimated Annual Effective Dose with ICRP Standard

It could also be seen that a comparative study between the measured annual effective dose with the recommended level set by ICRP were observed as shown in the Figs. 9 and 10 respectively.

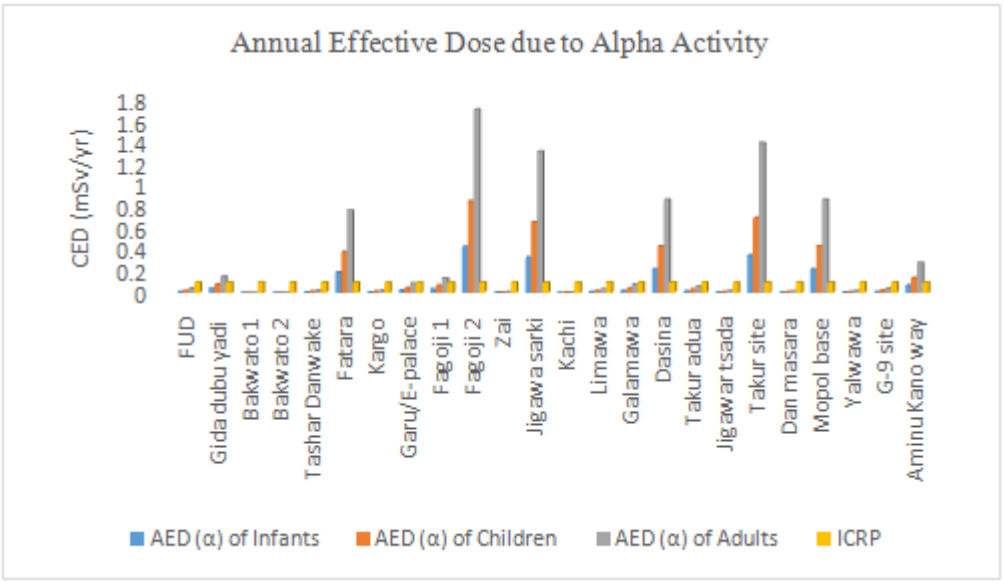

Fig. 9: Plot of Annual Effective Dose due to Alpha Activity for all Age Categories

Fig. 9 shows the comparison between the estimated annual effective dose due to alpha activity and recommended level set by ICRP. The figure indicates that estimated dose for adults was highest followed by children and lastly infants. This is due to the fact that the volume of intake of water per annum varies across the age categories. The area with the highest dose was fagoji 2 with estimated dose for adults of 1.74 mSv/yr. which was far above recommended guidelines of ICRP. Some areas were below the recommended guidelines, these areas were FUD, Bkwato1, Tashar danwake, Garu/Emir palace, Kargo, Zai, Limawa, Galamawa, Takur adua, Jigawar tsada, Dan masara, Yalwawa and G-9 site respectively.

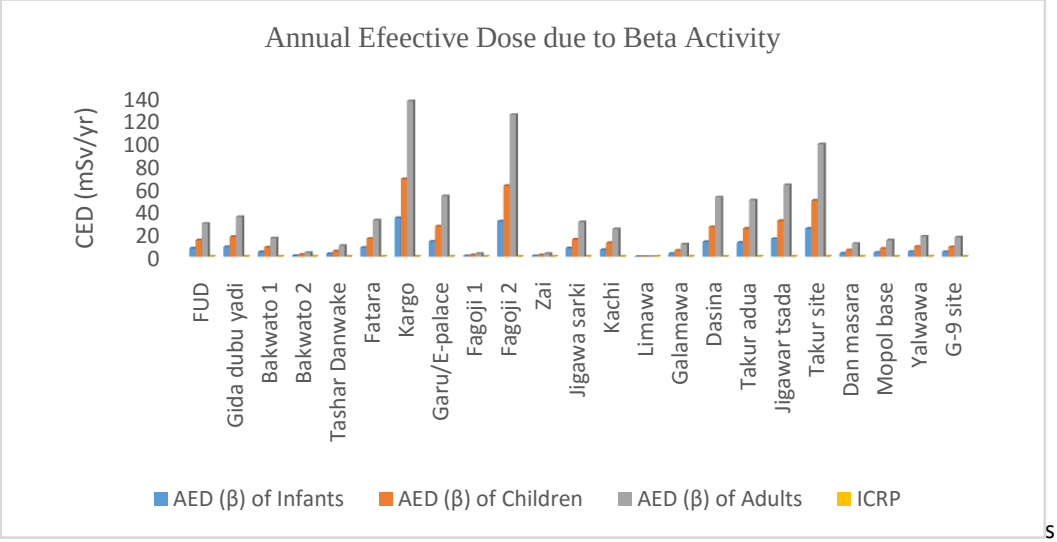

Fig. 10: Plot of Annual Effective Dose due to Beta Activity for all Age Categories

Fig. 10 shows the comparison between the estimated annual effective dose due to beta activity and recommended level set by ICRP. The figure shows that almost all the sample locations were above the ICRP value except for Limawa which was below the ICRP standard for nearly all the age categories. The maximum estimated effective dose was observed at Kargo with value 135.99 mSv/yr. It can be noticed that Aminu Kano way is not captured in the plot. This is due to its large values for all the age categories compared to other locations. The values computed for Aminu Kano are 2523.23, 5046.45 and 10092.91 mSv/yr for infants, children and adults respectively.

3.4 Comparison of Results with nearby Locations

The results obtained in this work was compared with other nearby results of similar works in the country. The first comparison was made between annual effective doses obtained in this work with the results obtained from nearby locations. The essence was to establish if there is any correlations between the results obtained with other areas as shown in table 1 below. The second comparison was made between the measured radioactivity concentration with other areas within the country to make similar observation as shown in figure 11 and 12 below.

Table 1: Comparison of the Results Obtained with Other Location within the Country

Annual Effective Dose (mSv/y)							
	Alpha			Beta			
Locations	Adults	Children	Infants	Adults	Children	Infants	Sources
Sokoto	0.068	-	-	1.046	-	-	[10, 11]
Plateau	1.938	0.963	0.485	2.375	1.187	0.594	[4]
Niger Delta	0.076	-	0.209	-	-	-	[5]
Ado Ekiti	0.03	-	0.15	-	-	-	[6]
Dutse	0.337	0.169	0.084	455.22	227.61	113.81	This work

Table 1: shows the comparison between the estimated annual effective doses with other locations in Nigeria. The estimated annual effective dose of alpha emitting radionuclides for adults in Dutse was greater than that of Sokoto, Niger Delta and Ado Ekiti and it was also above the guidelines recommended for intake of radionuclides in water set by ICRP of 0.1 mSv/yr. The result obtained was only less than the one estimated in the mining area of Plateau which was expected to be higher than any other area. For the children; annual effective dose of alpha emitting radionuclides estimated in Dutse town was extremely less than that of mining area in Plateau but it was above the recommended level set by ICRP of 0.1 mSv/yr. For Infants; the annual effective dose of alpha emitting radionuclides estimated in Dutse town was extremely less than all the other areas in comparison which includes Ado Ekiti, Niger Delta and Plateau and it was below the guidelines recommended by ICRP of value 0.1 mSv/yr.

Comparing the results obtained for annual effective dose of beta emitting radionuclides, it was observed that the results obtained for Dutse town were extremely larger than all the other locations including the results obtained in the mining area of Plateau state. The estimated dose was very high and exceeded the guidelines recommended by ICRP of 0.1 mSv/yr for good quality of water suitable for consumption and other domestic activities.

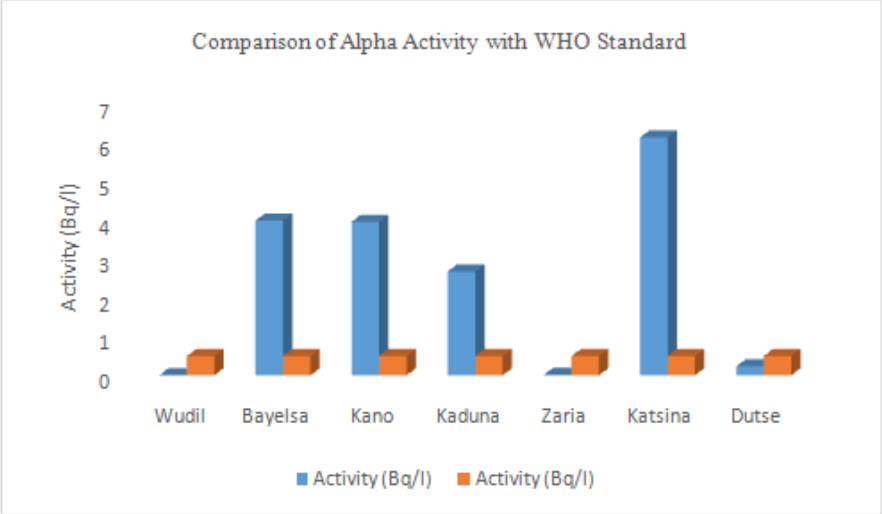

Fig. 11: Comparison of Measured Alpha Activity with Other Locations in Nigeria and WHO Standard[1, 12, 13, 14, 15].

Figure 11 shows the comparison of measured alpha activity with other locations in Nigeria and WHO standards. The plot indicates that the measured alpha activity in Dutse town was only greater than that of Wudil and Zaria, all other areas were larger than that of Dutse town. The result obtained for Dutse town was also below the maximum recommended level set by WHO as indicated in the figure. Other locations including Bayelsa, Kano, Kaduna and Katsina were all above the recommended level set by WHO.

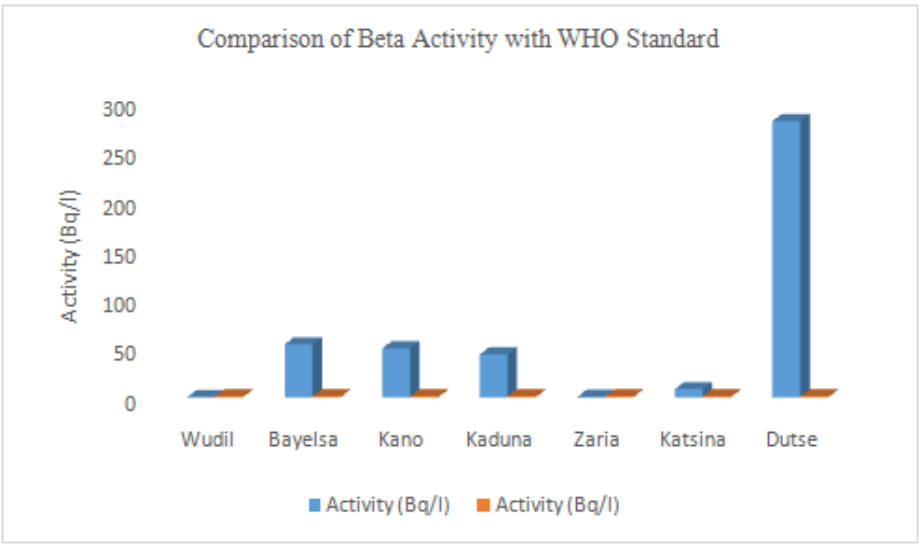

Fig. 12: Comparison of Measured Alpha Activity with Other Locations in Nigeria and WHO Standard [1, 12, 13, 14, 15].

Figure 12 shows the comparison of measured beta activity in Dutse town with other locations in Nigeria and WHO standard. It could be seen that the result obtained in Dutse town is higher than any other locations in comparison. It was also observed that only two locations were below the maximum recommended level set by WHO. All other locations were above WHO standard for safe drinking water. With this comparison it could also be seen that the beta activity obtained in Dutse town was very high compared to any other location in comparison.

IV. Conclusion

The results for the gross alpha measured ranged from 0.0031 to 1.08 Bq/l and beta activity ranged from 0.008 to 6284.5 Bq/l. It could be seen that only few areas were above the maximum recommended level set by World Health Organization (WHO) of 0.5 Bq/l for alpha activity and almost all the locations were above the maximum recommended level set by WHO of value 1.0 Bq/l for beta activity. An attempt has been made to

estimate the annual effective dose of alpha emitting radionuclides and beta emitting radionuclides for all age categories. The results indicate that, for alpha emitting radionuclides; the annual effective dose varied from 0.0 to 1.736 mSv/yr, 0.0 to 0.442 mSv/yr and 0 .0 to 0.434 mSv/yr for adults (>12 years), children (1-12 years) and infants (≤ 1year) respectively. While that of beta emitting radionuclides varied from 0.014 to 10092.91 mSv/yr, 0.007 to 5046.45 mSv/yr and 0.004 to 2523.23 mSv/yr for adults (>12 years), children (1-12 years) and infants (≤ 1year) respectively. Most of the locations exceeded the guidelines for the intake of radionuclides in water of value 0.1 mSv/yr. It is concluded that most of the sample locations are radiologically contaminated. Therefore, it is recommended that alternative water supply should be provided or the water from these locations should be treated before consumption and use for other domestic activities.

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