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Assessment of Radionuclides in Borehole Water in the Adenta Municipality of Greater Accra Region

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ABSTRACT

Direct gamma spectrometry study was carried out within the Adenta municipality in the greater Accra Region of Ghana to ascertain a baseline radioactivity levels of naturally occurring radioactive materials in borehole water at the Adenta Municipality. The average activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in twenty boreholes were measured. The activity concentration of ^{226}Ra, ^{232}Th and ^{40}K in the samples ranged from0.27 ±0.05Bq/L to 1.83 ±0.55Bq/L, 0.11±0.06Bq/L to 4.29±0.27Bq/L and 1.24 ±0.16Bq/L to 28.75 ±4.82Bq/L respectively.The average activity concentration values were 0.77±0.42, 0.93±0.62 and 9.77±4.55 Bq/L respectively. The total committed annual effective doses due to intake of natural radionuclides in the borehole water was estimated to be 40.29±48.82µSv/yr, which is far below the World Health Organization recommendation limit of 100µSv/yr. However, four of the boreholes exceeded the WHO recommended limit for total committed annual effective dose. The results obtained in this study shows that some of the inhabitants in Adenta municipality were expose to a significant radiological health hazards due to drinking water from the boreholes in the municipality. The results from this study will serve as a baseline data for future research in the study area.

Introduction

Water plays a vital role in the society and it is essential for human health, economic development, and environmental sustainability. Yet, water scarcity is a critical global issue, even more pronounced in the developing world [1]. Africa, which have the fastest growing population of all the continents, with approximately 13% of the world's populace [2], have about one third of its total population lacking access to adequate water supply [3]. Due to rapid population growth and urbanization which has surpassed local government efforts to expand basic water services, in many urban African cities, piped water access to a large section of the urban population have been limited and in some cases, even eliminated [4]. Consequently, in many of these cities, the inhabitants who do not have reliable water supply depend on water vendors, sachet water and or groundwater for drinking, domestic and agricultural purposes. [2] Despite the water crisis in Africa "the African continent have up to date used only five percent (5%) of its available water resources" while the majority of the untapped water resource remains underground.

In Ghana, more than three million people do not have access to safe drinking water due to pollution of water sources and poor water delivery systems [5, 6]. Therefore, groundwater comprising boreholes (drilled wells), hand-dug wells and dugouts have become the most cost-effective and reliable source of water for many rural and urban communities [7]. However, hand-dug wells and dugouts are usually turbid and contain high nitrate and coliform counts, hence; they are often used for agricultural purposes rather than domestic purposes. Borehole water is therefore considered as the safest for drinking and other domestic purposes [8, 9].

Nevertheless, a number of studies have shown that boreholes usually have higher radionuclide concentrations with significant effective doses than surface water and hand-dug wells [10, 11]. This is due to the fact that boreholes are usually drilled to the bedrock where the water-mineral interactions in the aquifer may produce significant natural radionuclide levels [12]. Radionuclide exposure is associated with the increasing radiation damage and risk to humans [13], evident in the rising global cancer burden [14, 15]. Due to the existence of naturally occurring radioactivity in borehole water, greater concerns for the radiological quality of borehole water have led to an increased global demand for data.

The main objective of this study was to assess the radiological safety of selected boreholes in the Adenta Municipality of the Greater Accra Region in Ghana.

Materials and Methods

The study was conducted in the Adenta municipality in the Accra Metropolis of Greater Accra Region, Ghana. Adenta is one of the sixteen districts in Greater Accra Region and lies 10 kilometers to the North- east of Accra, specifically located on latitude 5' 43' north and longitude 0' 09' west. Adenta Municipal Area had a population of 78,215 as at the 2010 Housing and Population Census in Ghana. Adenta abounds in several rivers; prominent among them are the Nugbete River in Nmaidjor and the Ogbojo stream. Perennial water shortage is characteristic of the Municipality.

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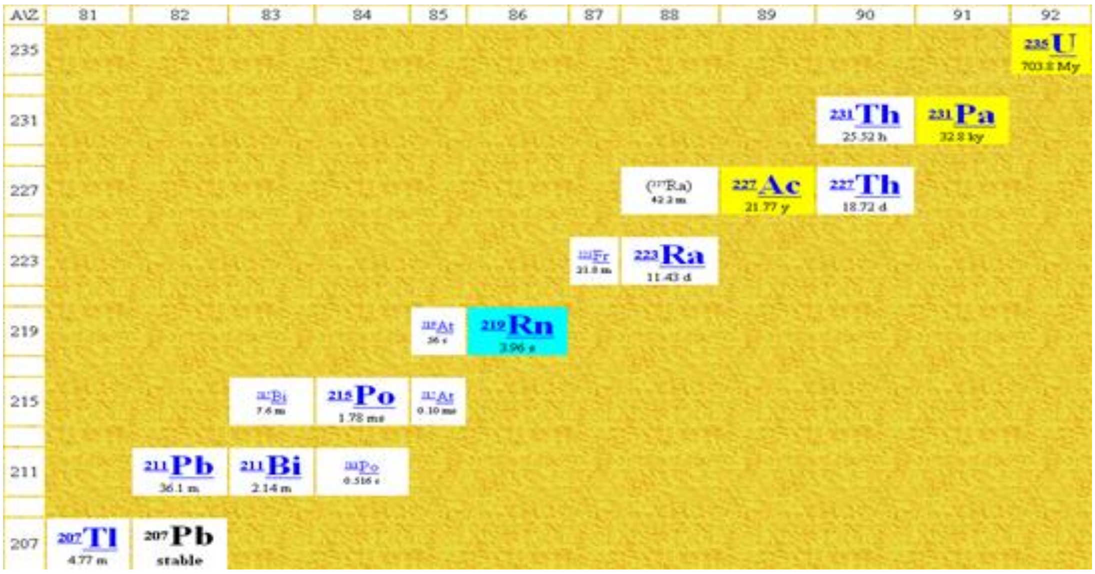

Figure 1. Decay Scheme of Uranium-235

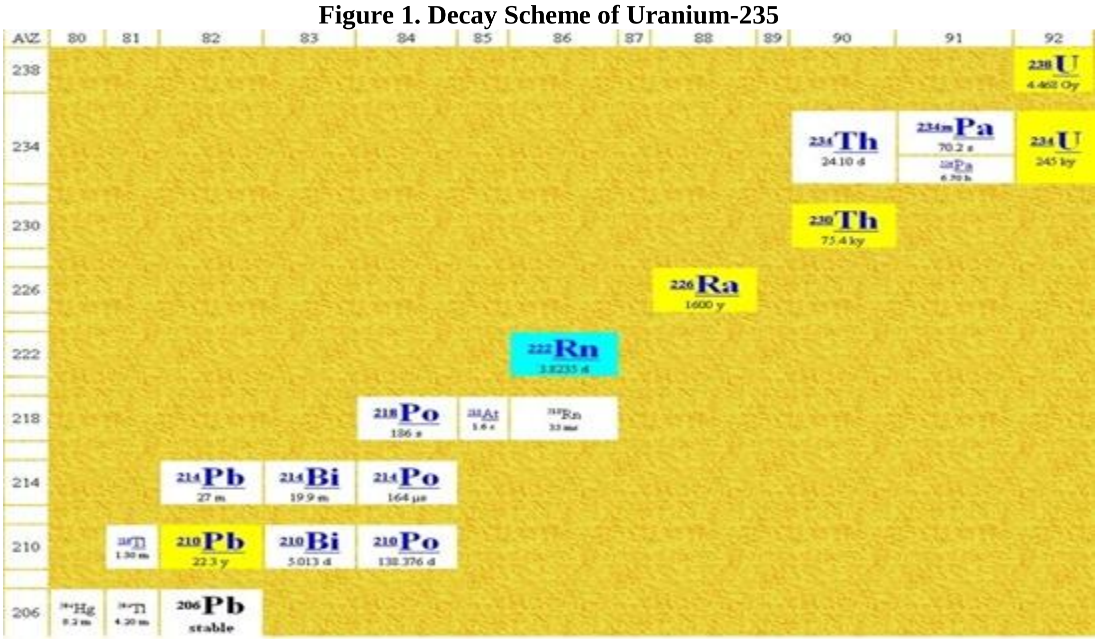

Figure 2. Decay Scheme of Uranium-238

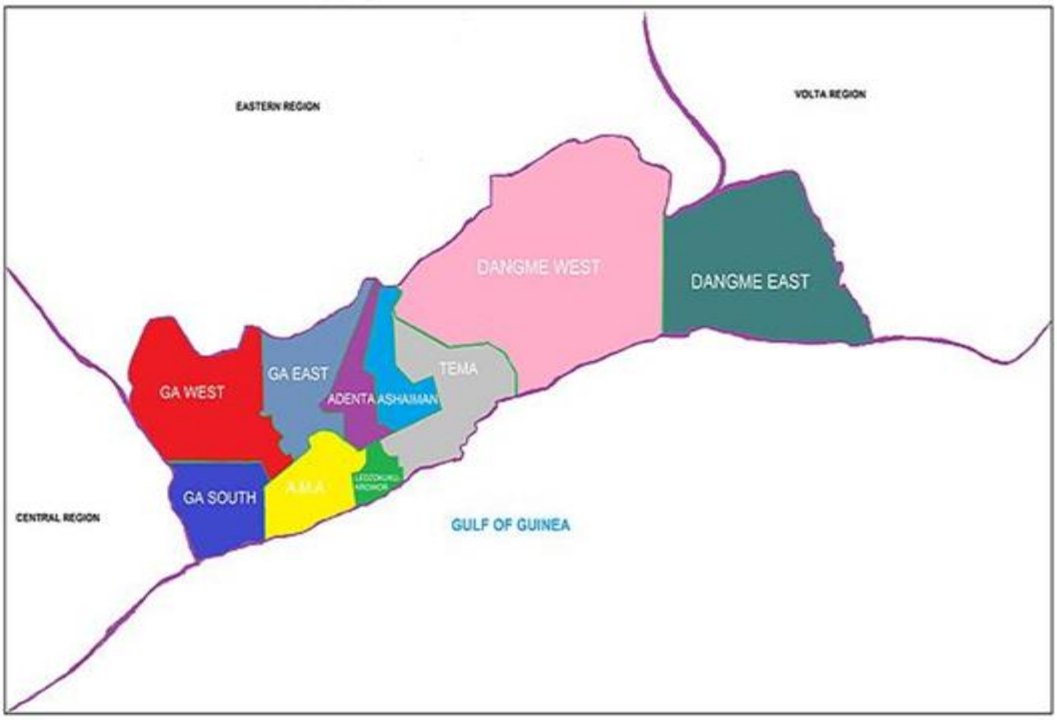

Figure 3. Map showing the Study Area

Adenta hardly gets pipe borne water, due to this; most of the residents rely on poly tanks, and concrete-built tanks to store water. The residents also harvest rainwater during the rainy seasons. The rock type of the area is metamorphic in the eastern parts but sedimentary in the southern part of the municipality. Adenta falls within the wet semi-equatorial climate region with two rain fall maxima, but the wet seasons are more marked. The first rainy season is from May to June with the heaviest rainfall usually recorded in June while the second rainfall season is from September to October. The area recorded an average temperature of 26°C during the year. Below is a map in Fig 3 showing the study are.

Figure 4. Borehole Water Samples analysis using High Pure Germanium detector in the lab

Figure 5. Borehole water being analyzed

Results

Sampling Coordinates

The study was done to investigate activity concentration of twenty (20) different borehole water samples in different locations at the Adenta Municipality. Table 1 shows the sample IDs and the coordinates of the boreholes from which they were collected.

Table1. Coordinates of selected boreholes in the Adenta Municipality

Sample ID	Coordinates	
	Latitude	Longitude
BW$_1$	5°33'18.20"N	0°17'50.12"W
BW$_2$	5°33'24.30"N	0°17'60.24"W
BW$_3$	5°35'16.24"N	0°17'45.16"W
BW$_4$	5°33'18.25"N	0°17'50.19"W
BW$_5$	5°33'25.26"N	0°17'50.17"W
BW$_6$	5°32'22.25"N	0°17'48.15"W
BW$_7$	5°33'20.22"N	0°17'50.12"W
BW$_8$	5°33'18.23"N	0°17'55.14"W
BW$_9$	5°33'19.26"N	0°17'50.16"W
BW$_{10}$	5°32'26.27"N	0°17'48.16"W
BW$_{11}$	5°33'18.23"N	0°17'54.15"W
BW$_{12}$	5°33'29.25"N	0°17'42.15"W
BW$_{13}$	5°35'20.26"N	0°17'55.19"W
BW$_{14}$	5°33'17.35"N	0°17'60.29"W
BW$_{15}$	5°33'24.30"N	0°17'60.24"W
BW$_{16}$	5°32'23.26"N	0°17'39.17"W
BW$_{17}$	5°33'22.20"N	0°17'56.13"W
BW$_{18}$	5°33'17.24"N	0°17'52.15"W
BW$_{19}$	5°33'15.26"N	0°17'64.17"W
BW$_{20}$	5°32'30.20"N	0°17'50.19"W

Physical Properties of Sampled Boreholes

The temperature, pH, TDS and conductivity of the boreholes were measured using a portable Hach meter on the field. The results obtained shows that the temperature of the samples ranged from 23.2 – 27.1°C with BW$_{18}$ recording the highest temperature (27.1°C) and BW$_8$ recording the lowest temperature (23.2°C) (Fig 6). The average temperature of the borehole was 25.9°C.

The pH ranged from 4.81-7.12 with an average of 6.24. BW$_{20}$ recorded the lowest pH and BW$_{14}$ recorded the highest (Fig 7). There was no significant relationship between the temperature and pH ($t=-1.0067$; $df=18$; $p=0.3274$; $r= -0.2309$).

TDS also ranged from 357-1301ppm, BW$_{17}$ recorded the highest value of 1301ppm and BW$_8$ recorded the lowest (357ppm) (Fig. 8). The average Total Dissolved Solids(TDS) was 689.25ppm. BW$_5$, BW$_{17}$ and BW$_{20}$ however recorded values higher than that of Ghana Standard Authority (GSA) recommended limit of 1000 mg/L.

BW$_{17}$ which recorded the highest TDS also recorded the highest conductivity (2600 µs/cm) and BW$_8$ which recorded the lowest TDS, and also recorded the lowest conductivity of 713 µs/cm (Fig 9). Average conductivity for the 20 boreholes sampled was 1356 µs/cm. There was a very strong positive correlation between TDS and conductivity value ($t=-29.57$; $df=18$; $p<0.0001$; $r=0.989865$).

Average Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K and their Annual Effective Doses

In the Adenta municipality, activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K in borehole water samples were measured and the results were obtained. The average activity concentrations were 0.77±0.42, 0.93±0.62 and 9.77±4.55 Bq/L for ^{226}Ra, ^{232}Th and ^{40}K respectively. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K ranged from 0.13±0.08 to 1.83±0.55Bq/L, 0.10±0.06 to 4.29±0.27Bq/L and

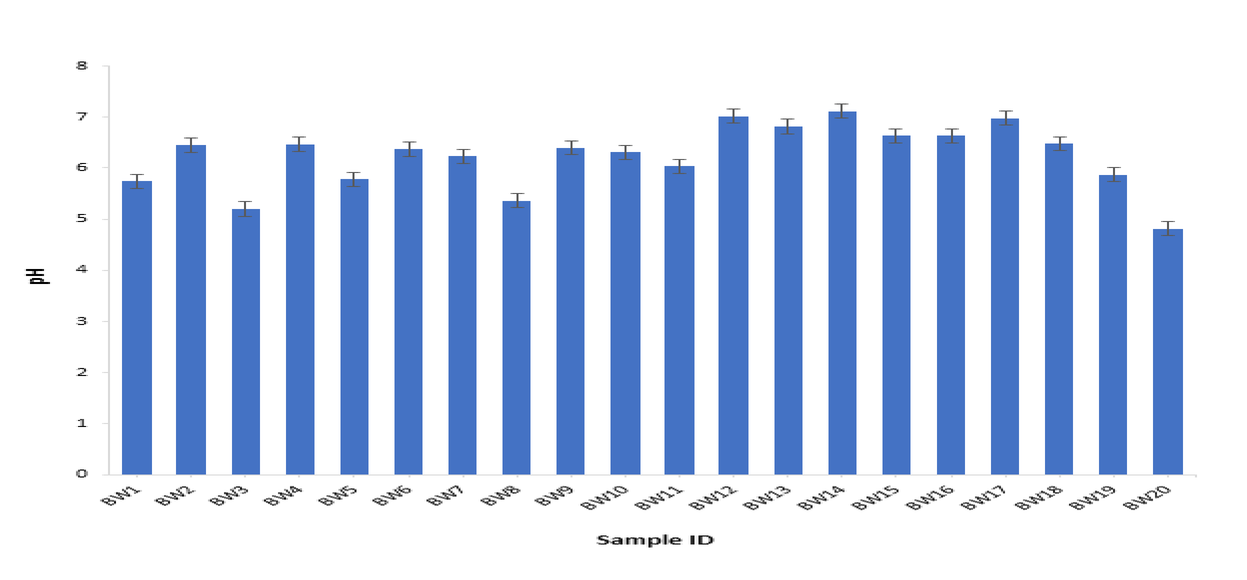

Figure 6. The temperature of borehole water samples collected in the Adenta Municipality

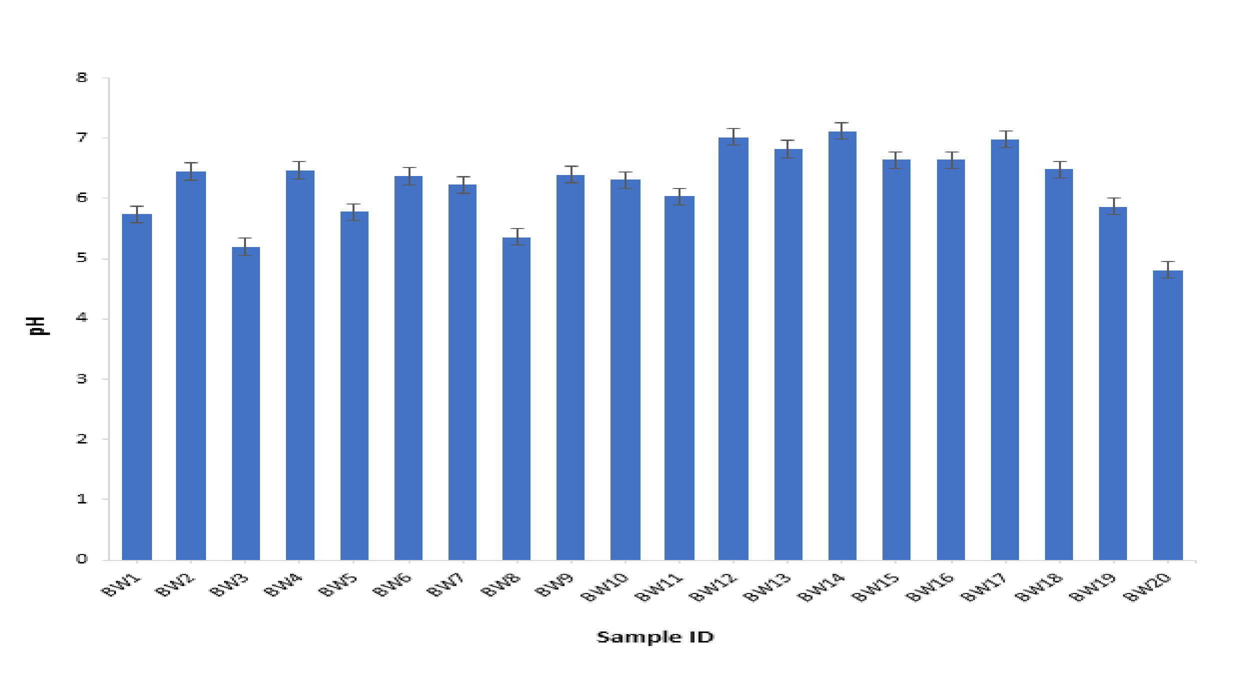

Figure 7. The pH of borehole water samples collected in the Adenta Municipality

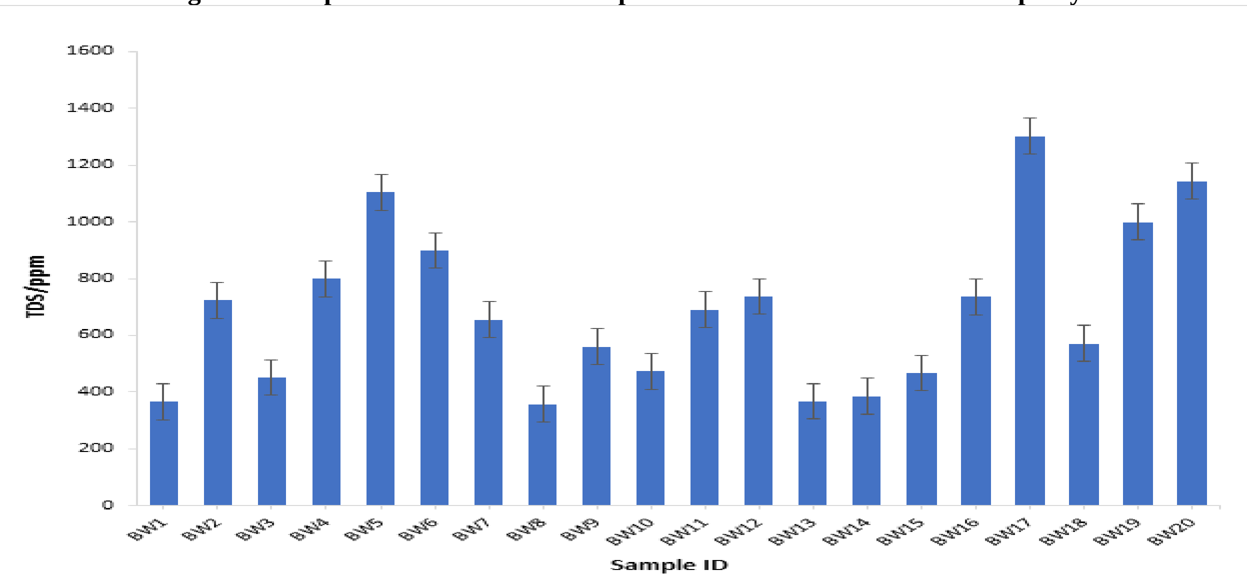

Figure 8.The Total Dissolved Solids in borehole water samples collected in the Adenta Municipality

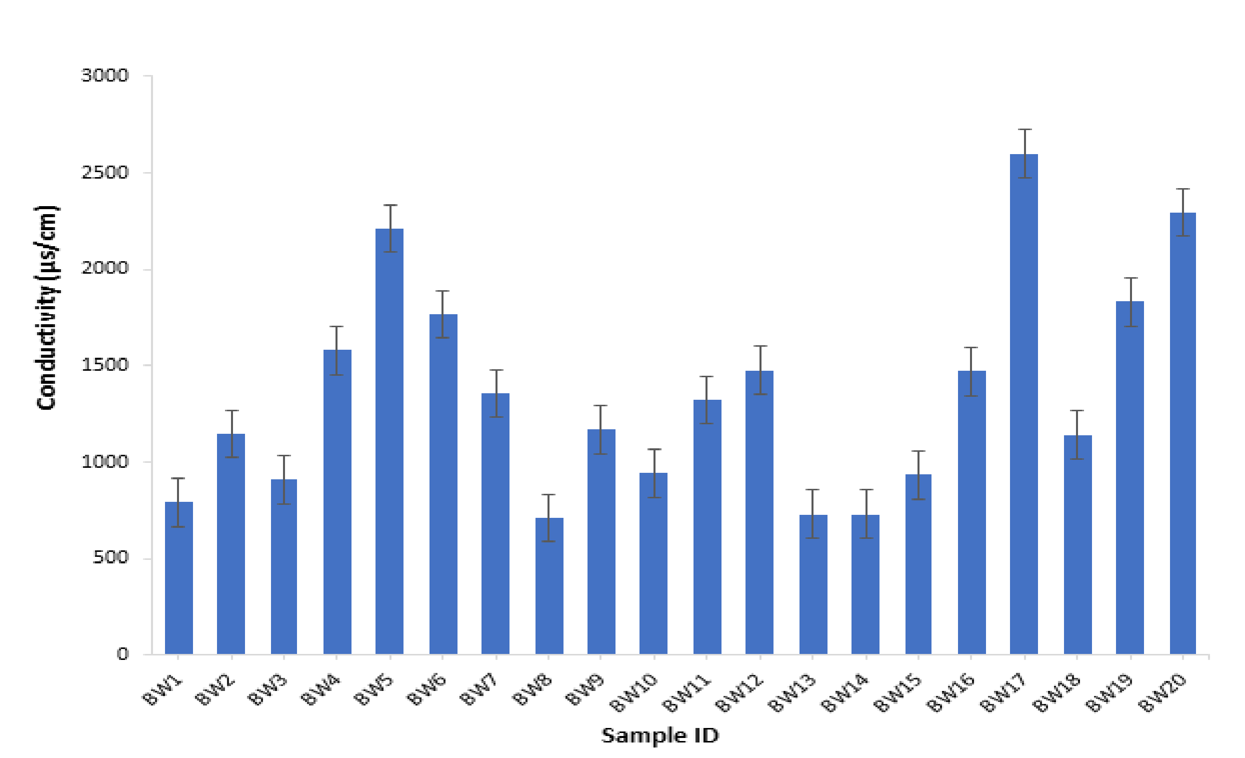

Figure 9. The Conductivity of borehole water samples collected in the Adenta Municipality

1.24±0.16 to 31.73±4.73Bq/L respectively.BW_6 had the lowest activity concentration of ^{226}Ra while BW_{17} had the highest concentration. The highest and lowest activity concentration values of ^{232}Th were found in samples with identifications BW_{20} and BW_8 respectively while the highest activity concentration of ^{40}K was found in sample with BW_{19} and the lowest in BW_{15}.

For ^{226}Ra, BW_2, BW_{12}, BW_{13}, BW_{14} and BW_{17} exceeded the WHO recommended limit of 1.0 Bq/L. Also, BW_4, BW_5, BW_{10}, BW_{13}, BW_{18}, BW_{19} and BW_{20} exceeded the WHO recommended limit of 1.0 Bq/L for ^{232}Th.

The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K was used to calculate the committed annual effective as a result of direct consumption of the borehole water.The committed annual effective dose ranged from 3.44 to 144.48 µSv/year with an average value of 40.29±48.82µSv/yr. BW_{19} recorded the highest annual effective dose while BW_1 gave the lowest effective dose. This shows that water from the borehole with identification BW_{19} gave the highest internal exposure to its consumers. ^{40}K contributed the largest dose to the annual effective dose.

The WHO recommended limit for committed annual effective dose is 100 µSv/yr. However, BW_2, BW_7, BW_{19} and BW_{20} recorded doses higher than the recommended limit .

Discussion

Physical Properties of boreholes at the Adenta Municipality

The measurement of natural radioactivity in our environment allows us to determine and assess the population's risk of exposure to radiation [15]. Studies have shown that some physical properties of water such as TDS and conductivity in fluences the level of radioactivity in the water samples [10]. These properties were determined to help in the interpretation of activity concentrations. Physical properties also give additional information about the quality of the water.

Temperature is known to increase the concentration of inorganic constituents and chemical contaminants that may influence the TDS and the taste of the water.Generally, cold water is more palatable than warm water. High temperature also enhances the growth of microorganisms such as *Legionella* bacteria and *E. coli* in water [16]. Also, pH decreases with increasing temperature. In this study, however, no significant relationship was observed between temperature and pH. Conductivity is also affected by temperature; the warmer the water, the higher the conductivity. Conductivity is also known to increase with increasing TDS and these parameters influences the concentration of radionuclides in water by increasing rock dissolution [17]. This was demonstrated in this study from the strong positive correlation between TDS and conductivity.

According to [18], the activity concentration levels for different radionuclides in groundwater depend on the geological conditions of the area and TDS values. TDS comprises inorganic salts (principally calcium, magnesium, potassium, sodium, bicarbonates, chlorides and sulfates) and small amounts of organic matter that are dissolved in water. Concentrations of TDS in water vary considerably in different geological regions due to the differences in solubilities of the minerals [19]. Alpha counts decreased sharply upon reaching TDS value of 150 ppm and an approximately constant value of counts reached after that [20] also studied the effect of TDS on the relative alpha efficiencies, for samples containing 230Th, 241Am and 244Cm. Their experimental results indicated a linear reduction of the relative efficiencies with increasing sample density and independent of alpha particle energy [16]. The recommended TDS in drinking water by GSA is 1000mg/L. From this study, it can be observed that the average TDS is within acceptable limits but some of the boreholes recorded values higher than the GSA recommended level and should not be used as drinking water until further treatment is achieved. Also all the boreholes sampled for this study are not expected to produce accurate alpha counts due to TDS values exceeding 150ppm[19].The reported temperature ranging from 22.4-25.1ºC, pH ranging from 6.7-8.3 and TDS ranging from 980-5200 in 7 wells from Adenta. However, the relatively smaller TDS range obtained in this study could be attributed to the fact that boreholes generally have lower TDS values than wells [9].

Average Activity Concentration of ^{226}Ra, ^{232}Th and ^{40}K

The average activity concentration for ^{226}Ra, ^{232}Th and ^{40}K were 0.77±0.42, 0.93±0.62 and 9.77±4.55 Bq/L, with activity concentration ranging from 0.13±0.08 to 1.83±0.55Bq/L, 0.10±0.06 to 4.29±0.27Bq/L and 1.24±0.16 to 31.73±4.73Bq/L respectively.

The ^{226}Ra activity concentration obtained in this study was high compared to other studies in some other countries [22]. Average 226Ra activity concentrations of 0.05Bq/L from 472 private wells in Finland, [17] were also considered. Moreover, a concentration of 0.014Bq/L in Brazil and reported an average ^{226}Ra activity concentration of 0.06pCi/l from 98 wells in the State of Wisconsin. A study on groundwater samples in Spain were obtained and an average ^{226}Ra activity concentration of 0.03Bq/L was also obtained respectively [23, 24].

Similarly, the mean ^{232}Th activity concentration obtained in this study is relatively high compared to other studies. In Upper Egypt [10] a reported mean activity of 1.1±0.62pCi/l for artesian wells in Qen a used for drinking and 1.39±0.6 pCi/l for open wells in Safaga and Quseir, were considered [25] furthermore, a study shows a reported mean of 0.0013±0.006mBq/l from drinking water in Italy and [26] also a reported mean of 0.3mBq/l in Guarani aquifer groundwater in Brazil. In Ghana [27], a study was conducted in the Lake Bosumtwi basin and boreholes from selected towns around the basin were also obtained, a mean activity concentrations of ^{232}Th were obtained and the results indicated as 0.6 and 3.3mBq/l for the Lake and the boreholes respectively.

For ^{40}K, the mean activity concentration of 9.77±4.55Bq/L obtained in this study was also higher compared to studies conducted in other parts of Ghana and in other countries [27]. A report shows that, Lake Bosomtwi had a ^{40}K mean activity concentration of 0.0897Bq/L and the boreholes in the surrounding villages had a mean of 0.086Bq/L [26]. However, WHO conducted a study around the operational area of the Ashanti Gold field of Ghana prior to the processing of gold ore at the mine, a report shows a mean activity concentration ^{40}K of 14.7±30.5Bq/L, ranging from 0.6-121.7Bq/L[28]. These variations in the water samples of the present study compared to those obtained in other studies could be as a result of the different geological characteristics of the soils and rocks in the geographical locations of the groundwater system. The average activity concentrations of the radionuclides measured did not exceed the WHO recommended limit but some boreholes were higher than the recommended limit.

Committed Annual Effective Dose

The annual effective doses due to intake of radionuclides were calculated using the World Health Organization consumption rates of two litres (2L) of water per day [21] which corresponds to seven hundred and thirty litres(730 L) per year. According to the WHO Guidelines [21], the total annual effective dose from all radionuclides except for tritium and radon should not exceed 100µSv/yr. The calculated mean annual effective dose for this study was 40.29 µSv/yr and this was below the recommended limit. However, some boreholes recorded values higher than this recommended limit and are not radiologically safe for drinking.

Conclusion

Natural radioactivity in water samples collected from boreholes in the Adenta Municipality in the greater Accra region of Ghana has been measured using gamma-spectrometry system. The activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K ranges from 0.27±0.05 to 1.83±0.55 Bq/L, 0.11±0.06 to 4.29±0.27 Bq/L and 1.24±0.16 to 28.75±4.82 Bq/L respectively. The average activity concentration values were 0.77±0.42, 0.93±0.62 and 9.77±4.55 Bq/L for ^{226}Ra, ^{232}Th and ^{40}K respectively.

The committed annual effective dose to an adult individual due to intake of natural radionuclides in the borehole water was estimated to be 40.29±48.82µSv/yr which was far below the WHO recommended limit of 100µSv/yr. However, some boreholes recorded values above the recommended limit. We therefore conclude that not all the boreholes in the Adenta Municipality were safe for drinking, this implies that, some inhabitants in the Adenta municipality may be exposed to a significant radiological health hazard due to drinking water from boreholes in the municipality.

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Conflict of interest

The authors duly agreed that, there is no conflict of interest as far as the publication of this research work is concerned.

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