Measurement Of Radionuclides Levels In Borehole Water At Ga East Municipality In The Greater Accra Region Of Ghana

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***Abstract*—Measurement of radionuclides levels was carried out on twenty selected boreholes within the Ga East Municipality in the Greater Accra Region of Ghana using Gamma Spectrometry. High Pure Germanium Detector was employed to quantify the radionuclides of interest. The activity concentrations of Radium - 226 Thorium - 232 and Potassium - 40 the samples ranged from 0.13±0.08 to 0.90±0.21 Bq/L, 0.10±0.06 to 3.24±0.28 Bq/L and 1.24±0.16 to 19.99±4.73 Bq/L, respectively. The mean activity concentration values of Radium- 226, Thorium - 232 and Potassium - 40 were 4.06±0.22, 0.93±0.14 and 6.10 ±1.15 Bq/L, respectively. The total committed annual effective doses due to intake of natural radionuclides in the borehole water was estimated to be 0.20±0.05 μSv/yr, which was far below the World Health Organization recommended limit of 100 μSv/yr. However, two of the boreholes exceeded the WHO recommended limit for total committed annual effective dose. The results obtained in this study showed that the inhabitants of Ayi Mensah, a suburb of the Ga East Municipality were not exposed to 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 studies.**

Keywords- ***Activity Concentrations; Gamma Spectrometry; Ghana Standard Authority; Radionuclides; Annual Effective Doses.***

1. INTRODUCTION

The investigation of population exposure to radiation resulting from the consumption of water is determined by measuring the radioactivity levels in the borehole. The decay of an excited atomic nucleus is known as radioactivity. Naturally occurring radioactive materials (NORMS) and man –made or artificial sources are the two main sources of radiation exposure. The two main pathways by which NORMs enter the body are through ingestion and inhalation. The rise of internal exposure of organs and tissues in the human body is caused by the decay of ingested and inhaled radionuclides. The average worldwide exposure to natural sources in drinking water and foods is 0.29 $mSvy^{-1}$ (i.e. 0.17 $mSvy^{-1}$ from ^{40}K and about 0.12 $mSvy^{-1}$ from Uranium and Thorium) (United Nations Scientific Committee on the Effects of Atomic Radiation 2000). Boreholes are usually drilled to the bedrock where the water-mineral interactions produce significant natural radionuclide levels (Jibiri & Okeyode, 2011). This is due to the existence of naturally occurring radioactivity levels in borehole water, which is evident in the rising global cancer burden (Ashraf, 2003 & Kanavos, 2006).

Boreholes in areas with rock types such as pegmatites, syenites, granites, acid volcanic rocks, and acid gneisses could contain ground water with radon concentrations of 50–500 Bq/L or considerably higher. Water from sedimentary rocks such as limestone, sandstone, and shales, as well as igneous rocks, volcanic intermediate and basic rocks usually have radon concentrations of 5–70 Bq/L because of the low uranium concentrations.

Water plays an important role in society and it is essential for human health, environmental sustainability and economic development. Yet, water scarcity is a critical global issue, even more pronounced in the developing world (De Fraiture; Wichelns; et al. 2007). Africa, which has the fastest growing population of all the continents, with approximately 13% of the world's populace (Braune , XuY, 2008) has about one third of its total population lacking access to adequate water supply (Water Aid, 2017). However, boreholes usually have higher radionuclide concentrations with significant effective concentration doses than hand-dug wells (Ahmed 2004; Dinh Chau; Dulinski; Jodlowski al. 2011; Kurttio, Harmoinen; Saha; Salonenet al.2006; Vesterbacka and Makelainen 2005).

2. Materials and method

2.1. Study Area

Ayi-Mensah is a village in the Ga East Municipal District of the Greater Accra Region of Ghana. It is located on latitude 5º 47'N and longitude 0º 11'w". The community is located between Oyarifa and Kitaase. The inhabitants make up a population of about 1,200, including children (watercharity.com › ayi-mensah-borehole-project-ghana).

About 80% of the people engage in peasant farming and the other 20% are involved in trading and other business activities. Women especially, engage in petty trading along the streets to fend for their families.

The selected boreholes for the present study were located in the Ayi – Mensah locality in the Accra Metropolis. The map of the study area is as shown in Figure 1.

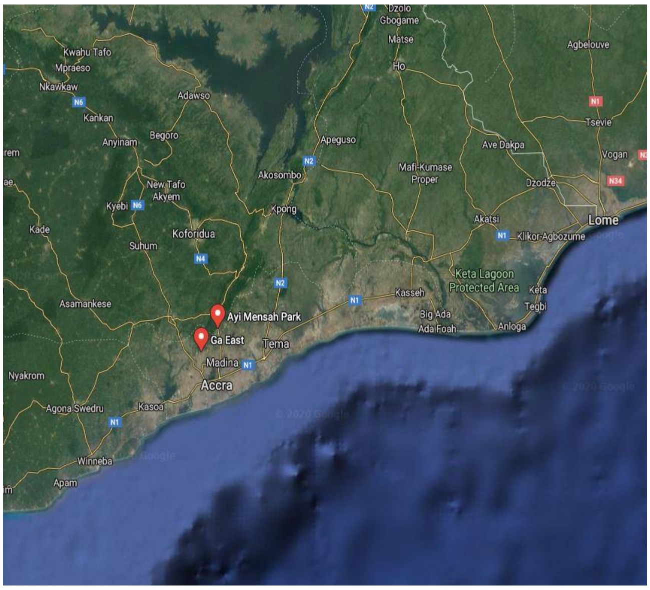

Figure 1: Map of the Study Area (Google Earth Image).

2.2 Sample Collection and Measurement of Physical Parameters

Twenty boreholes were randomly selected within the study area which were representative. Samples were collected at a depth of 25m from the boreholes into pre-clean (5L) gallons and labeled. 0.1M nitric acid was used to acidify the gallons before transferring the water samples. This was to prevent the radionuclides from adhering to the inner walls of the gallon, tightly sealed and labelled. The gallons were filled to the brim without any head space and also to prevent trapping of carbon dioxide (CO_2) gas. The temperature, pH, conductivity and total dissolved solids (TDS) of each sample was measured using the HI98129 portable Water Quality Test Kit (Hanna Instruments, USA). The pH probe was calibrated with pH 4 buffer, pH 7 buffer and pH 10 buffer solution to check for the basicity, neutral and acidity of the water contents. Distilled water was used to rinse the probe between each measurement before recording the data. The samples were then transported to the gamma spectrometry laboratory at the Ghana Atomic Energy Commission for preparation, storage and analysis.

2.3 Sample Preparation for Analysis

One liter of the sample was transferred into a Marinelli beaker, covered and sealed with a plastic tape. It was allowed to stand for 3–4 weeks to establish secular equilibrium between the long-lived parent radionuclides and their short-lived daughters before analysis. The mass and weight of the samples were recorded. Gamma spectrometry was used to analyze all the samples. A reference solution supplied by the International Atomic Energy Agency (IAEA) was used to calibrate the system to identify and quantify the radionuclides of interest.

2.4 Calibration of the Gamma Spectrometer

The IAEA reference solution used to calibrate the system consists of the following radionuclides with the corresponding energies; ^{241}Am (59.54 keV), ^{109}Cd (88.03 keV), ^{57}Co (122.06 keV), ^{139}Ce (165.86 keV), ^{203}Hg (279.20 keV), ^{113}Sn (391.69 keV), ^{85}Sr (514.01 keV), ^{137}Cs (661.66 keV), ^{60}Co (1173.2 keV and 1332.5 keV) and ^{88}Y (898.04 keV and 1836.1 keV).

The energy calibration was detected by using 4 radionuclides; ^{241}Am, ^{57}Co, ^{137}Cs and ^{60}Co as was previously reported by Gilmore & Hemingway (1995).

The concentrations of the radionuclides in the samples were determined by employing a high resolution hyper pure germanium (HPGe) detector with a relative efficiency of 30% relative to a 3" x 3" NaI (Tl) scintillator. The energy resolution of the detector was 2 keV at 1.332 MeV of a ^{60}Co source. The detector was placed in a lead shield to reduce the background radiation originating from the building materials and surrounding cosmic rays. Advanced Multi-Channel analyzer (MCA) emulation software (Genie-2000) was used for data acquisition, storage, display and analysis of the acquired gamma-spectra. Each sample was placed on the shielded HPGe detector and counted for an accumulating time of about 36000 secs. Before measurement of the samples, the environmental gamma background radiation in the laboratory was determined with an empty cylindrical container of the same geometry as the sample containers under identical measurement conditions. The measured background activity was then subtracted from the measured activity of each sample.

2. 5 Activity Concentrations Calculation from Spectral Data

Activity concentrations in $\mathrm{BqL^{-1}}$ for all the borehole samples were calculated using equation 1.

$$Asp = \frac{N_{sam}}{P_E \cdot \varepsilon \cdot T_c \cdot M} \quad (1)$$

Where; N_{sam}- background corrected net counts of the radionuclide in the sample, PE - gamma ray emission probability (gamma yield), ε - total counting efficiency of the detector system, Tc - sample counting time M - mass of sample (kg) or volume (L). (Oresengum, Decker & Sanderson, 1993).

2.6 Assessment of Committed Effective Dose

The committed effective dose of the total radionuclides activities in water was estimated using equation 2; adapted from an ICRP Report (ICRP, 1991). Mean concentration in water was used to calculate the committed effective dose (Sv/year). Consumption of water was estimated as two liters (2 L) per day. The dose conversion factors used for ingestion of naturally occurring radionuclides for adult members of the public were 4.5 x 10^{-5} mSv Bq^{-1} for ^{226}Ra, 2.3 x 10^{-4} mSvBq^{-1} for ^{232}Th and 6.2 x 10-6 mSvBq^{-1} for ^{40}K (ICRP, 1993). The committed annual effective dose relation is as follows:

$$ET = \sum (A_w * DCF_w) * I_w \quad (2)$$

Where I_w is the water consumption rate which is 730 Ly^{-1}, DCFw is the dose conversion factor ($SvBq^{-1}$) and A_w is the activity in the water (Bq/L).

3. RESULTS AND DISCUSSION

3.1 Physical measurement of borehole water

The temperature, pH, conductivity and total dissolved solids of the boreholes were measured as shown in Table 1. The temperature of the samples ranged from 21°C to 28 °C with sample identification code $AMBHW_7$ recording the lowest temperature (21 °C) and $AMBHW_{14}$ recording the highest temperature (28 °C). The average temperature of the boreholes was 24.7 °C. The pH ranged from 5.0 to 6.5 with an average of 5.76. $AMBHW_{18}$ recorded the lowest pH and $AMBHW_{13}$ recorded the highest pH value.

In the present study, no significant relationship was observed between temperature and pH. Suffice to state that high temperature enhances the growth of microorganisms such as *Legionella* and *E.coli* in water (WHO, 2008). Temperature is known to increase the concentration of inorganic constituents and chemical contaminants that may in turn influence the TDS and the taste of water. Additionally, $AMBHW_{15}$ recorded the lowest conductivity value of 178 µs/cm and $AMBHW_1$ recorded the highest conductivity of 222 µs/cm in Table 1. The Average conductivity for the twenty boreholes sampled was 205.6 µs/cm.

Additionally, TDS ranged from 89 to 125 ppm. $AMBHW_7$ recorded the highest value of 125 ppm and $AMBHW_{15}$ recorded the lowest (89ppm) in Table 1. The mean TDS was 102.8 ppm. There was a very strong positive correlation between TDS and conductivity. Conductivity is known to increase with increasing TDS and these parameters influence the concentration of radionuclides in water by increasing rock dissolution (WHO, 2008). Concentrations of TDS in water vary considerably in different geological regions owing to differences in the solubilities of minerals. A school of thought has proposed that TDS levels greater than 1200 mg/L will be objectionable to consumers (WHO, 2008). TDS and conductivity influence the level of radioactivity in water (Dins Chap; Dulinski; et al. 2011, thus these properties were assessed to help in the interpretation of the activity concentrations. The warmer the water, the higher the conductivity. The Ghana Standard Authority (GSA) recommended TDS level in drinking water is 1000 mg/L. From this study, it was observed that the average TDS is within acceptable limits in Ghana, (GS 175 -1:2009 3rd Edition).

Table 1. Physical Parameters of selected boreholes

SAMPLE ID	Physical Parameters			
	TEMPERATURE (ºC)	*Hydrogen Potential*	*CONDUCTIVITY (µs/cm)*	*Total Dissolve Solids (ppm)*
$AMBHW_1$	27	5.9	222	111
AMBHW2	25	5.5	210	105
AMBHW3	24	5.6	200	100
AMBHW4	25	5.7	198	99
AMBHW5	25	5.1	204	102
AMBHW6	26	6.2	190	95
AMBHW7	21	6.3	250	125
AMBHW8	24	5.1	230	115
AMBHW9	23	5.4	218	109
AMBHW10	22	5.6	220	110
AMBHW11	24	6.1	194	97
AMBHW12	25	6.0	196	98
AMBHW13	27	6.5	180	90
AMBHW14	28	5.8	240	120
AMBHW15	26	5.9	178	89
AMBHW16	24	5.5	184	92
AMBHW17	22	5.3	196	98
AMBHW18	26	5.0	194	97
AMBHW19	27	6.2	202	101
AMBHW20	23	6.4	206	103

AMBHW: Is identification codes for the borehole samples of the study area.

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

Activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K recorded for the borehole water samples are presented in Table 2. Activity concentrations for ^{226}Ra, ^{232}Th and ^{40}K ranged from 0.12±0.02 to 1.68±0.12 Bq/L, 0.10±0.01 to 2.71±0.01 Bq/L and 1.20±0.02 to 6.34±0.02 Bq/L, respectively. The mean concentrations ranged from 0.78±0.06, 0.94±0.05 and 2.87±0.05 Bq/L. For ^{226}Ra, AMBHW$_7$ had the lowest activity concentration while AMBHW$_2$ had the highest activity concentration. The ^{226}Ra activity concentration obtained in this study was high compared to studies in some other countries. For example, Godoy & Godoy (2006) recorded a concentration of 0.014 Bq/L in a Brazilian study. Arndt & West, (2004) also reported an average ^{226}Ra activity concentration of 0.06 pCi/L from 98 wells in the State of Wisconsin. Subsequently, Jibiri & Okeyode, (2011) also obtained a mean ^{226}Ra activity concentration of 0.05Bq/L from 472 private wells in Finland. The recorded value for ^{232}Th in the present study was found to be high. Thus, AMBHW$_{20}$ recorded the highest value and AMBHW$_8$ recorded the lowest value. In Ghana, a previous study conducted in the Lake Bosumtwi basin and boreholes from selected towns around the basin also recorded mean ^{232}Th activity concentrations of 0.6 and 3.3 mBq/L for the Lake and the boreholes, respectively (Darko et al. 2011). Bonotto & Bueno (2008) reported a mean of 0.3 mBq/L in Guarani aquifer groundwater in Brazil, while Jia & Torri (2007) also reported a mean of 0.0013±0.006 mBq/L from drinking water in Italy. The lowest activity concentration value for ^{40}K was found in AMBHW$_9$ and the highest recorded value was found in AMBHW$_{12}$.

Table 2. Average activity concentrations and effective doses due to ^{226}Ra, ^{232}Th and ^{40}K in water samples in the study area

Sample ID	Activity concentration, Bq/L			
	^{226}Ra	***^{232}Th***	***^{40}K***	***Committed effective dose, µSvyear^{-1}***
AMBHW$_1$	0.70±0.14	1.76±0.08	2.53±0.20	0.33
AMBHW$_2$	1.68±0.12	1.61±0.12	5.23±0.11	0.35
AMBHW$_3$	0.58±0.11	0.12±0.03	3.11±0.08	0.05
AMBHW$_4$	0.62±0.09	0.14±0.05	2.88±0.04	0.06
AMBHW$_5$	0.22±0.07	1.34±0.06	1.52±0.07	0.24
AMBHW$_6$	1.09±0.05	0.30±0.04	3.41±0.08	0.10
AMBHW$_7$	0.12±0.02	0.41±0.02	1.31±0.01	0.08
AMBHW$_8$	1.38±0.03	0.10±0.01	1.21±0.1	0.07
AMBHW$_9$	1.13±0.08	0.50±0.03	1.20±0.02	0.13
AMBHW$_{10}$	0.91±0.03	0.12±0.06	4.22±0.03	0.07
AMBHW$_{11}$	0.83±0.02	2.11±0.07	2.62±0.05	0.39
AMBHW$_{12}$	0.52±0.04	0.17±0.09	6.34±0.02	0.07
AMBHW$_{13}$	0.31±0.13	0.33±0.05	3.74±0.03	0.08
AMBHW$_{14}$	0.43±0.06	0.28±0.04	1.48±0.04	0.07
AMBHW$_{15}$	0.75±0.04	1.25±0.03	5.25±0.06	0.26
AMBHW$_{16}$	0.94±0.02	1.41±0.02	1.66±0.04	0.28
AMBHW$_{17}$	0.57±0.03	1.26±0.04	1.39±0.02	0.24
AMBHW$_{18}$	1.15±0.04	1.33±0.03	2.24±0.03	0.27
AMBHW$_{19}$	1.27±0.01	1.58±0.02	4.22±0.04	0.33
AMBHW20	0.44±0.02	2.71±0.01	1.85±0.02	0.48
Average	0.78±0.06	0.94±0.05	2.87±0.05	0.20
Standard deviation	0.41	0.79	1.54	0.13
Range	0.12-1.68	0.10-2.71	1.20-6.34	0.05 – 0.48
Guideline levels (WHO, 2004)	10.00	1.00	N/A	100.00

AMBHW= sample codes for the water samples.

3.3. Committed Annual Effective Dose

Annual effective doses due to intake of radionuclides were calculated using the World Health Organization consumption rates of 2 L of water per day (ICRP, 1991) which corresponds to 730 L/year. According to the WHO Guidelines, all radionuclides except for tritium and radon should not exceed 100µSv/yr. The calculated mean annual effective dose for this study was 0.20 µSv/yr, and this is below the recommended guideline. Activity concentrations of ^{226}Ra, ^{232}Th and ^{40}K were used to calculate the committed effective dose as a result of direct consumption of the borehole water. The committed effective dose ranged from 0.05 to 0.48 µSv/year with a mean value of 0.20±0.05 µSv/yr. $AMBHW_{11}$ gave the lowest effective dose while $AMBHW_7$ recorded the highest annual effective dose. The investigation revealed that borehole water with identification $AMBHW_7$ gave the maximum internal exposure to its consumers. ^{40}K contributed the largest dose to the annual effective dose. This may be attributed to the rock formation at the study area.

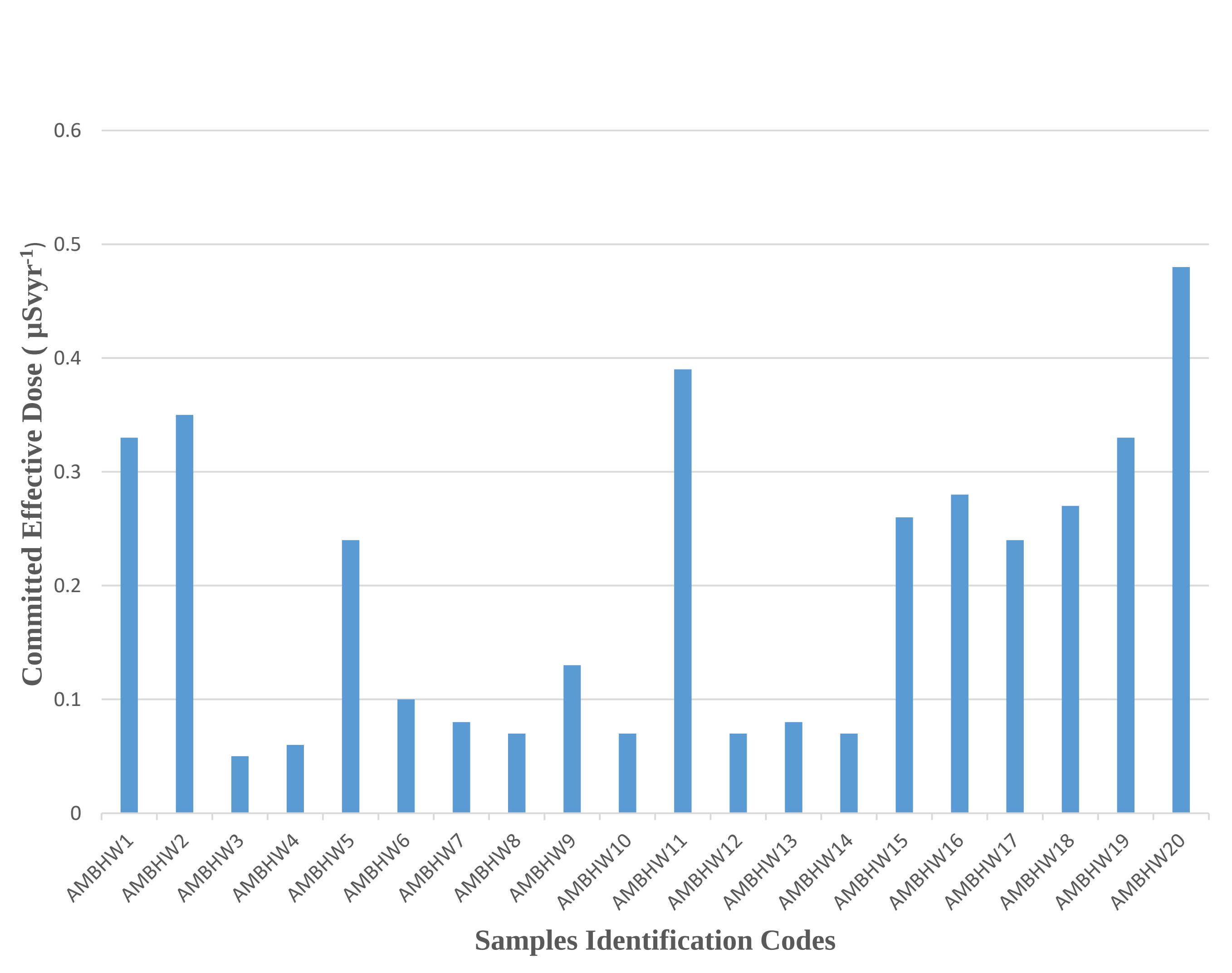

Figure 2: A Bar Graph of Committed Effective Dose vs Samples

4. CONCLUSION

Measurement of radionuclide levels and their estimated annual effective doses in water samples collected from boreholes at the Ga East Municipality in the Greater Accra Region of Ghana was determined using gamma-spectrometry. The activity concentrations of Radium – 226, Thorium - 232 and Potassium - 40 ranged from 0.12±0.02 to 1.68±0.12 Bq/L, 0.10±0.01 to 2.71±0.01 Bq/L and 1.20±0.02 to 6.34±0.02 Bq/L, respectively. The average mean concentrations ranged from 0.78±0.06, 0.94±0.05 and 2.87±0.05 Bq/L. The committed annual effective dose to an adult individual due to intake of natural radionuclides in the selected borehole water samples was estimated to be 0.20 µSv/yr which was far below the (WHO, 2004) recommended limit of 100 µSv/yr. Borehole water samples in the Ga East Municipality of the Greater Accra Region of Ghana are safe and have no radiological impact on the inhabitants living there. The data gathered in this study would provide base-line radiometric values for borehole water in this region which can be used to evaluate the possible changes in future.

5 . CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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APPENDIX A

Table 1: Borehole Samples of the Study Area with Respect to Their Committed Effective Doses.

SAMPLE ID	COMMITTED EFFECTIVE DOSE, ($\mu Svyr^{-1}$)
$AMBHW_1$	0.33
$AMBHW_2$	0.35
$AMBHW_3$	0.05
$AMBHW_4$	0.06
$AMBHW_5$	0.24
$AMBHW_6$	0.10
$AMBHW_7$	0.08
$AMBHW_8$	0.07
$AMBHW_9$	0.13
$AMBHW_{10}$	0.07
$AMBHW_{11}$	0.39
$AMBHW_{12}$	0.07
$AMBHW_{13}$	0.08
$AMBHW_{14}$	0.07
$AMBHW_{15}$	0.26
$AMBHW_{16}$	0.28
$AMBHW_{17}$	0.24
$AMBHW_{18}$	0.27
$AMBHW_{19}$	0.33
$AMBHW_{20}$	0.48

AMBHW: Is identification codes for the borehole samples of the study area