Research Journal of Environmental and Earth Sciences 5(2): 85-93, 2013
DOI:10.19026/rjees.5.5642
ISSN: 2041-0484; e-ISSN: 2041-0492

Submitted: November 09, 2012 Accepted: January 11, 2013 Published: February 20, 2013

Research Article

Assessment of Natural Radioactivity Level in Groundwater from Selected Areas in Accra Metropolis

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Abstract: The aim of this present study was to assess natural radioactivity levels in selected groundwater (boreholes and wells) used as domestic purposes in particular and drinking as well in some communities in Adentan and Abokobi areas in Greater Accra region of Ghana. This was achieved by first measuring the activity concentration of ^{222}Rn, ^{40}K and ^{232}Th in groundwater samples using High-Purity Germanium (HPGe) detector. These concentrations of ^{40}K, ^{222}Rn and ^{232}Th were used with their ingested dose conversion factors to estimate annual effective dose for Adult members of public due to consumption of the groundwater. The estimated average annual effective dose due to consumption of ^{40}K, ^{222}Rn and ^{232}Th in the water samples from Adentan and Abokobi were 113.007±3.940 and 76.568±2.321 μSv/y, respectively. These were compared with the estimated average annual dose due to ingestion of nuclides in water by the WHO (100 μSv/y) and the estimated average dose due to ingestion of radionuclides in food and water (290 μSv/y) by UNSCEAR (2000). They are found within the range even though Adentan value is slightly higher than the WHO average value. The results show that consumption of groundwater may not pose any radiological health hazard to the public.

Keywords: Annual effective dose, groundwater, radionuclides activity concentration

INTRODUCTION

Natural radioactivity origins are from the decay of natural radionuclides and their products in the earth's crust and cosmic radionuclide from outer space (UNSCEAR, 1988, 2000). The high geochemical mobility of these radionuclides in the environment allows them to move easily and to contaminate the environment which human come into contact (Egunyinka *et al*., 2009).

The presence of natural radionuclides in water depends on geological and geographical nature of the water's origin (Isam Salih *et al*., 2002; El-Mageed *et al*., 2011; Shashikumar *et al*., 2011). For groundwater (boreholes and wells), it depends on their presence and contents in lithologic of solids aquifer where water is stored (Nour, 2004; El-Mageed *et al*., 2011). The dissolution and the amounts of these natural radionuclides in groundwater system during water/rocks-soils interaction depends on the geochemical characteristics of rocks and soil as well. Because some dissolved radioactive elements from soils can leach through groundwater system during precipitation. Other factors that control their occurrence and distribution in groundwater are hydro-geological conditions of groundwater and geochemistry of each radionuclide (Shashikumar *et al*., 2011).

Considering the presence of natural radionuclides in groundwater system, the associated radiation health risk to human due to internal exposure through ingestion of radionuclides in water known as carcinogenic and the level of risk involved which is not clearly defined. There is a need to assess natural radioactivity levels in groundwater resources in order to protect members of the public against high radiation dose due to intake.

According to literature, only few studies have been carried out to investigate natural radionuclides in Ghana groundwater resources (Awudu *et al*., 2010; Darko *et al*., 2010; Faanu *et al*., 2011). As a result, radiological quality of water supplies in Ghana is not only unknown, there is no baseline data of activity concentration of natural radionuclides in groundwater in Ghana. Continuous assessment of natural

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radioactivity levels in groundwater can be useful for the Radiation Protection Board, Environmental Protection Agency and other stakeholders in the water industry in Ghana as a direct input in the monitoring of environmental contamination and public health studies.

The goal of this study was to assess natural radioactivity levels in selected groundwater (boreholes and wells) used as domestic purposes in particular and drinking as well in some communities in Adentan and Abokobi areas in Greater Accra region of Ghana. This was achieved by first measuring the activity concentration of ^{222}Rn, ^{40}K and ^{232}Th in groundwater samples using gamma-ray spectrometric technique. The annual effective dose was also estimated since it represents an accurate evaluation of radiation dose received by the population due to intake.

MATERIALS AND METHODS

Background of the study areas: Adentan and Abokobi areas are located in one of the districts of Greater Accra Region of Ghana. The geological settings in the greater part of Accra are underlain by the Dahomeyan formations and Togo formations as well. The Fig. 1 shows the geology of the study areas.

Dahomeyan formations consist of four lithologic belts of granitic and mafic gneiss. The mafic gneisses are relatively uniform oligoclase andesine, hornblende, salite and garnet gneisses of igneous parentage and generally tholeitic composition. The granite gneisses interlayer with the mafic gneiss and are believed to be metamorphosed volcaniclastic and sedimentary rocks. The persistent bands of the nepheline gneiss in the system appear to be metamorphosed calcalkaline igneous rocks. The granite gneiss is the lowest unit in the system (Banoeng-Yakubo *et al*., 2010).

Togo formations is dominantly a metamorphic and highly comprised of three distinctive lithology assemblages which quartzites are the main rock types followed by the strongly tectonised phyllites and serpentinite (Ahmed *et al*., 1977; Banoeng-Yakubo *et al*., 2010). Other rock types of the Togo Formations include sandstones, shales, quartz schist, silicified limestones, talc mica schist (Richmond *et al*., 2010; Darko *et al*., 2010).

Adentan is located in the area where the major solids aquifers or rocks types are Dahomeyan series mentioned above with undifferentiated (mainly schists and gneisses). Abokobi is located in the area where the major rocks types are Togo Formations mentioned above and voltaian system with undifferentiated (mainly siliciclastics, unlow or low metamorphosed) (Martin *et al*., 2005). Other geological formations in Abokobi include the Dahomeyan Formations (Martin *et al*., 2005).

Sample collection and preparation techniques: In order to cover the study areas, a pre-field survey was done to know the number of boreholes and hand dup wells available in the areas and frequently used by the population at the time of sampling for domestic purposes particularly and drinking as well. The sampling campaigns were carried out between November 2011 and January 2012 and the weather conditions at the time of sampling were fairly stable. The places where samples were collected were marking by using a Global Positioning System (GPS). These are depicted in a given Fig. 1 with their sample ID (ADW and ABW for Adentan and Abokobi samples, respectively). A total of (26) groundwater samples were collected from boreholes and wells covering some communities in Adentan and Abokobi. In this way, (10) groundwater samples from Adentan site and (16) groundwater samples were from Abokobi site. The pH, temperature and electrical conductivity of water samples were measured on field using Metrolin model 691 pH-meter for the pH and temperature and a portable HACH conductivity for the electrical conductivity of water samples.

Samples were obtained after allowing water to run fully at least 10 min before in order to remove stagnant water from the pump. Samples were then collected into 2 L of polyethylene gallons and a few drops of ultra-pure nitric acid (60%) were added to bring the pH to an appreciable level of 2 to prevent adherence of radionuclide to the walls of the containers and to liberate dissolved metals from exchange sites on dissolved organic particles (Gürsel *et al*., 2000). Each gallon was filled to the brim without any head space to prevent minimized radon loses, tightly sealed and labelled. The samples were then stored in the laboratory for preparation into 1 L Marinelli beakers and analysis. Before sampling, the containers were carefully watched with diluted nitric acid and rinsed three times with the distilled water. Before use, the Marinelli beakers were first soaked with diluted nitric acid, washed, rinsed with distilled water and left dry in the oven to prevent contamination.

Gamma-ray detection system and samples measurement: The samples were measured with a high resolution gamma-ray spectrometer consisting of an n-type ORTEC high-purity germanium detector Model GMX40P4 in a vertical configuration. The system is coupled to a desktop computer based PCA-MR 8192 Multi-Channel Analyzer (MCA) provided with ORTEC Maestro 32 MCB configuration software for spectrum acquisition, evaluation and analysis. The detector crystal has a diameter of about 63.0 mm and the length of about 65.0 mm with the following specifications: resolution (FWHM) at 1.33MeV ^{60}Co is 1.95 keV and relative efficiency at 1.33MeV ^{60}Co is 40%. The crystal is housed in an aluminium canister with a 0.5 mm thick beryllium entrance window. The detector is cooled with liquid nitrogen at -196°C (77K) provided in a 25 L Dewar and operates on a reverse bias voltage of 4800V.

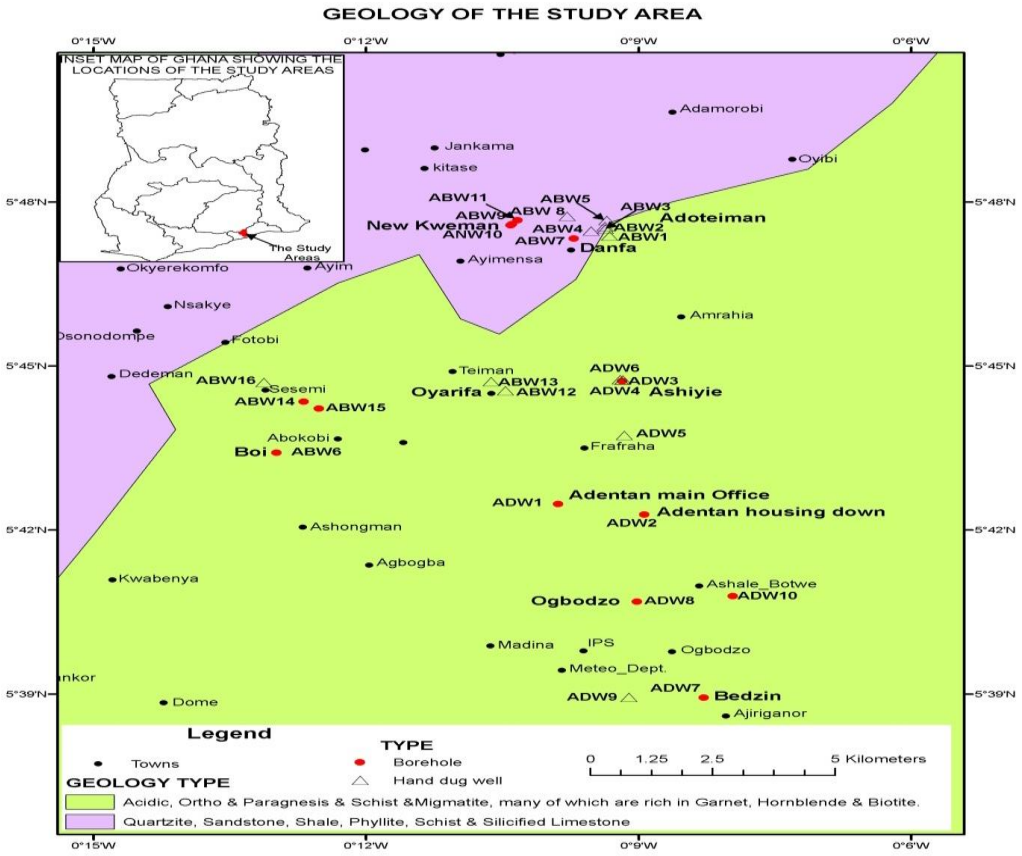

Fig. 1: Geology map of the study areas showing the sampling points with the samples ID

It is located inside a cylindrical lead shield with internal diameter of 24 cm and height of 60 cm. The lead shield is lined with various layers of copper, cadmium and Plexiglas each of 3 mm thick used to prevent the detector from external background radiation.

The gamma spectrometry system was calibrated for energy and efficiency before measurements of the samples. The detector calibration for energy and efficiency calibration was carried out using multi-radionuclide standard solution of density of 1.0 g/m^3 in 1 L Marinelli beaker manufactured by Deutsher Kalibrierdient (DKD-3) QSA Global GmBH, Germany. This was done after counting and acquiring of the spectrum of mixed radionuclide standard solution.

Each prepared water sample was placed on top of the HPGe detector and counter under the same condition as the standard solution for 43.200 sec. An already washed empty 1 L Marinelli beaker was counted every week for the same counting time (43,200 sec) under identical geometry to determine the background radiation level of the laboratory environment and corrections carried out where appropriate.

The activity concentrations of ^{40}K and ^{232}Th were determined using the following expression in Eq. (1) (Oresengun *et al*., 1993; Uosif *et al*., 2008; Awudu *et al*., 2010; Faanu *et al*., 2011). The ^{232}Th activity concentration was determined by taking the mean activity concentration of the gamma-ray lines of the daughter's nuclides: ^{228}Ac at 911.20 keV, ^{212}Pb at 238.63 keV and ^{208}Tl at 214.53 keV. The ^{40}K activity concentration was directly determined from 1460.75 keV emission gamma-ray line:

$$A_{Sp} = \frac{N_{Sam} \exp(\lambda T_d)}{P_E \times \varepsilon(E_\gamma) \times T_C \times M} \quad (1)$$

where,

N_{Sam} = Background corrected net counts of radionuclide in the sample
T_d = Delay time between sampling and counting
exp (λT_d) = Correction factor between sampling and counting
P_E = Gamma-ray emission probability (gamma yield)
$\varepsilon(E_\gamma)$ = Counting efficiency of the detector
T_C = Sample counting time and M-volume of the sample (Oresengun *et al*., 1993)

The ^{222}Rn content or activity concentration was determined by measuring the parent radionuclide ^{226}Ra

from ^{238}U-decay series. The ^{226}Ra activity concentration was determined by taking the mean activity of the two gamma-rays of 351.92 keV for ^{214}Pb and 609.30 keV for ^{214}Bi using the Eq. (1). The ^{222}Rn concentration was then determined using the decay Eq. (2) from ^{226}Ra to ^{222}Rn (Darko *et al*., 2010):

$$A_{^{222}Rn} = A_{^{226}Ra}[1-\exp(-\lambda_{^{222}Rn}T_d)] \quad (2)$$

where,

$A_{^{222}Rn}$ & $A_{^{226}Ra}$: Activity concentrations in BqL^{-1} of ^{222}Rn and ^{226}Ra, respectively

$\lambda_{^{222}Rn}$: Decay constant of ^{222}Rn

Radiation dose estimation: In order to control radiation exposure to the public, estimation of total annual effective dose due to ingestion of ^{222}Rn, ^{40}K and ^{232}Th in water samples was done on the basis of the activity concentration and dose conversion factors of selected radionuclide using the following expression in Eq. (3):

$$H_{ing}(w) = \sum_{j=1}^{3} DCF_{ing}(^{222}Rn, ^{40}K, ^{232}Th) \times A_{Sp} \times I_w \quad (3)$$

where, DCF_{ing} -dose conversion factors by ingestion of selected radionuclides in water samples by adult members of the public living in the study areas were taken to be 3.5×10^{-9} Sv/Bq for ^{222}Rn, 6.2×10^{-9} Sv/Bq for ^{40}K and 2.3×10^{-7} Sv/Bq for ^{232}Th from IAEA (1996), ICRP (1996), UNSCEAR (2000) and WHO (2004), A_{Sp} is activity concentration of each selected radionuclide in water samples and I_w is daily water consumption rate considered to be 2L/day.

RESULTS AND DISCUSSION

Table 1 and 2 show the locations and some physical parameters of the groundwater samples. Table 3 and 4 show the activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th in water samples. The annual effective dose due to ingestion of selected radionuclides in the water sample is also depicted in Table 3 and 4.

The activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th in the groundwater samples from Adentan and Abokobi areas are depicted in Table 3 and 4. As seen, the activity concentrations of selected radionuclides varied from one sample to another. The activity concentration of ^{222}Rn measured in the samples from various locations in Adentan varied between 0.037±0.003 and 0.673±0.130 Bq/L with an average value of 0.392±0.032 Bq/L and Abokobi ranged from 0.076±0.016 to 0.338±0.013 Bq/L with a mean value of 0.220±0.009 Bq/L, respectively. The activity concentration of ^{40}K varied between 0.881±0.054 and 8.864±0.161 Bq/L with an average value of 3.671±0.211 Bq/L and from 0.721±0.453 to 6.915±0.320 Bq/L with an average of 2.589±0.407 Bq/L, respectively at Adentan and Abokobi, whilst ^{232}Th varied from 0.254±0.006 to 1.200±0.380 Bq/L with an average of 0.568±0.067 Bq/L in Adentan and Abokobi from 0.165±0.007 to 0.651±0.009 Bq/L with an average value of 0.394±0.012 Bq/L, respectively.

These variations of activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th in one sample to another from Adentan and Abokobi areas indicate that the origins of these waters are not the same and that they come from different depths and pass through different geological layers. This irregular distribution of activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th in the groundwater may depend on their contents in rocks or solid aquifers in the areas where groundwater is located and the residence time of waters/rocks-soils in contact as well. It was noted that all the groundwater in Adentan are located in an area where the geological setting is Dahomeyan Formations consisting of different lithologic of solids aquifer, while those in Abokobi are located in a zone where the geological group is Togo Formations consisting of different solids aquifer or rocks types. The samples referred as ABW12 up to ABW16 are located in a zone where the rock types are Dahomeyan Formations even though they are in Abokobi site.

The average activity concentration of ^{222}Rn, ^{40}K and ^{232}Th in the groundwater in Adentan and Abokobi areas were also recorded in Table 3 and 4. These were compared and presented in Fig. 2. The average values of ^{222}Rn, ^{40}K and ^{232}Th in Adentan samples were

Table 1: Sample locations with physical parameters for water samples from Adentan

Sample location	Sample ID	Temperature (°C)	Conductivity (µS/cm)	pH
Adentan main office	ADW1	28.3	1888	6.37
Adentan market	ADW2	29.3	10420	6.40
Ashiyie	ADW3	27.5	3890	6.75
	ADW4	27.1	758	6.24
	ADW5	27.4	846	6.29
	ADW6	27.7	753	6.72
Bedzin	ADW7	27.8	3550	6.52
Ogbodzo	ADW8	28.7	9530	6.60
	ADW9	26.6	14540	7.09
Srahe village	ADW10	27.5	6830	6.55

Table 2: Sample locations with physical parameters for water samples from Abokobi area

Sample location	Sample ID	Temperature (°C)	Conductivity (µS/cm)	pH
Adoteiman	ABW1	29.7	773	9.80
	ABW2	28.6	518	8.99
	ABW3	29.7	1558	8.48
	ABW4	28.3	912	8.90
	ABW5	28.9	2026	8.26
Boi	ABW6	28.4	1464	7.94
Danfa	ABW7	29.3	365	7.72
	ABW8	29.2	769	6.12
New Kweiman	ABW9	28.8	1393	7.83
	ABW10	28.5	827	7.94
	ABW11	28.5	377	7.86
Oyarifa	ABW12	28.6	869	6.71
	ABW13	29.6	2875	6.52
Pantang	ABW14	28.2	701	5.22
	ABW15	28.3	652	5.87
Sesemi	ABW16	27.7	114.4	5.32

Table 3: Activity concentration and annual effective dose of ^{40}K, ^{222}Rn and ^{232}Th in water samples from Adentan

	Activity concentration (Bq/L)			Annual effective dose
Sample ID	^{40}K	^{222}Rn	^{232}Th	(µSv/y)
ADW1	3.017±0.187	0.037±0.002	0.526±0.019	102.057±2.337
ADW2	6.968±0.459	0.155±0.005	0.301±0.006	82.518±3.100
ADW3	0.881±0.053	1.673±0.130	1.200±0.380	209.660±6.421
ADW4	2.243±0.267	0.622±0.021	0.345±0.110	69.650±2.010
ADW5	1.896±0.027	0.687±0.024	0.564±0.027	105.005±4.801
ADW6	4.245±0.053	0.097±0.063	0.528±0.071	108.144±6.153
ADW7	0.881±0.053	0.298±0.044	1.003±0.019	173.133±3.544
ADW8	4.592±0.400	0.104±0.007	0.379±0.006	84.719±2.890
ADW9	3.124±0.454	0.175±0.001	0.254±0.006	57.185±3.120
ADW10	8.864±0.160	0.068±0.018	0.579±0.025	137.996±5.020
Minimum	0.881±0.054	0.037±0.003	0.254±0.006	57.185±3.120
Maximum	8.864±0.161	1.673±0.130	1.200±0.380	209.660±6.421
Average values	3.671±0.211	0.392±0.032	0.568±0.067	113.007±3.940
Standard deviation	2.460	0.479	0.291	45.293

Table 4: Activity concentration and annual effective dose of ^{40}K, ^{222}Rn and ^{232}Th in water samples from Abokobi

	Activity concentration (Bq/L)			Annual effective dose
Sample ID	^{40}K	^{222}Rn	^{232}Th	(µSv/y)
ABW1	2.349±0.507	0.260±0.008	0.545±0.013	102.722±2.470
ABW2	2.750±0.401	0.142±0.007	0.613±0.016	115.675±1.001
ABW3	1.842±0.454	0.178±0.001	0.428±0.010	80.619±0.340
ABW4	2.857±0.374	0.388±0.013	0.651±0.009	93.497±0.093
ABW5	0.934±0.454	0.170±0.003	0.386±0.018	69.496±1.047
ABW6	3.818±0.347	0.373±0.010	0.255±0.008	61.046±2.930
ABW7	2.430±0.400	0.168±0.026	0.368±0.040	73.186±8.600
ABW8	3.311±0.240	0.084±0.005	0.404±0.003	82.950±1.590
ABW9	1.602±0.454	0.283±0.010	0.263±0.004	52.168±2.760
ABW10	2.590±0.480	0.194±0.011	0.308±0.003	64.000±1.720
ABW11	3.284±0.400	0.325±0.006	0.490±0.005	97.976±1.000
ABW12	0.881±0.427	0.194±0.018	0.234±0.026	43.831±6.430
ABW13	6.915±0.320	0.073±0.016	0.520±0.019	118.713±1.435
ABW14	2.600±0.347	0.315±0.006	0.288±0.004	60.844±2.290
ABW15	2.536±0.454	0.199±0.002	0.387±0.003	77.028±2.490
ABW16	0.721±0.453	0.173±0.008	0.165±0.007	31.340±0.940
Minimum	0.721±0.453	0.073±0.016	0.165±0.007	31.340±0.940
Maximum	6.915±0.320	0.388±0.013	0.651±0.009	118.713±1.435
Average values	2.589±0.407	0.220±0.009	0.394±0.012	76.568±2.321
Standard deviation	1.416	0.092	0.136	23.995

slightly higher than those recorded in Abokobi samples. This could be an indication of higher content of radioactivity in geological setting in Adentan than those in Abokobi site because bedrock, soil and groundwater system are in interaction with each other. As a result of this interaction, some natural radionuclides may dissolve into groundwater from bedrock system and soil during their infiltration from surface into aquifer (Yuce *et al*., 2009). The higher average value of ^{40}K in the samples compared to ^{222}Rn (from ^{238}U-decay series)

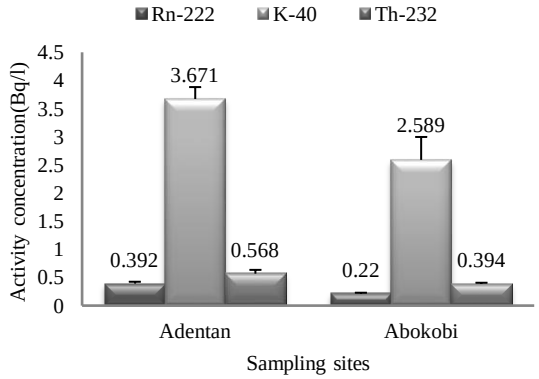

Fig. 2: Comparison of the average activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th in groundwater samples from Adentan and Abokobi sites

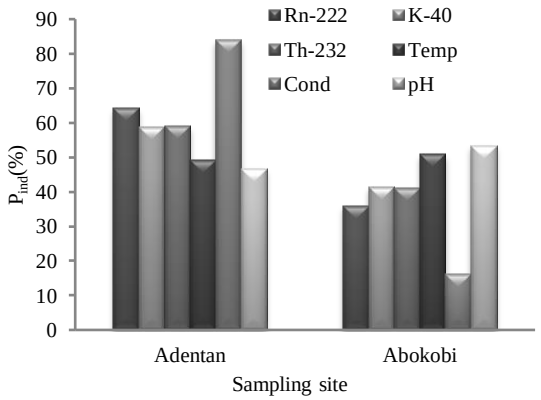

Fig. 3: Comparison of ^{222}Rn, ^{40}K, ^{232}Th activity concentrations with the temperature, conductivity and pH of water samples for both sampling sites
Each parameter was expressed as a percentage index, P_{ind} (%)

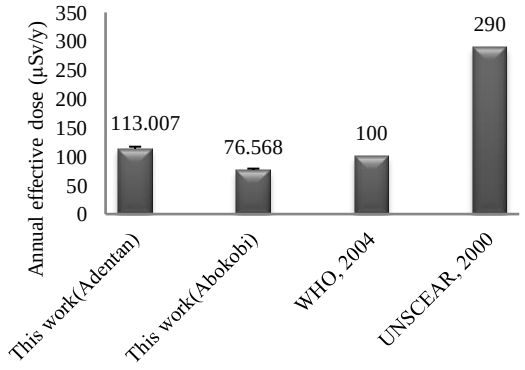

Fig. 4: Comparison of the average annual effective dose due to intake of radionuclides in groundwater from Adentan and Abokobi sites with the estimated average values set by WHO (2004) and UNSCEAR (2000), respectively

and ^{232}Th values is due to its higher percentage abundance in the environment whereas ^{238}U, ^{232}Th and decay products are lower in the environment and usually expressed in parts per million (ppm). It was also noted that in samples from both study sites, the average values of ^{232}Th exceeded that of ^{222}Rn. This could be attributed to several factors that governed their occurrence in groundwater such as the geology, the mineralogy and the geochemistry of rock or solids aquifer and soil in Adentan and Abokobi sites.

For the purpose of comparison, the activity concentration of ^{222}Rn, ^{40}K and ^{232}Th have been obtained from literature for groundwater from other parts of the world and presented in Table 5. The average values of ^{222}Rn, ^{40}K recorded in the present investigation are seen to be lower than those obtained in other countries as well as the recorded values of ^{222}Rn in some sites in the Greater Accra Region of Ghana including Adentan site by Darko *et al.* (2010) and Cape Coast University Environments by Faanu *et al.* (2011). The average values of ^{232}Th recorded in the present study are lower than published values by other countries except those obtained in Egypt by Nour (2004) and Bangladesh Chittagong Region by Alam *et al.* (1999). The values thus compare favourably with the recorded average values published by other countries selected from the worldwide investigation of natural radioactivity in groundwater. The average values of the activity concentrations of investigated radionuclides in the present study were also compared with the guidelines activity concentrations values of radionuclides in drinking water recommended by the World Health Organisation (WHO). These were found to be below the guidelines values recommended by the World Health Organisation (WHO, 2004).

To compare the activity concentration of ^{222}Rn, ^{40}K and ^{232}Th with the temperature, conductivity and pH, given in Table 1, 2, 3 and 4. Each of the parameters was normalized to unity and expressed as a percentage index, P_{ind} (%) (Darko *et al.*, 2010). The temperature, conductivity and pH were assumed to have some bearing on the activity concentration of ^{222}Rn, ^{40}K and ^{232}Th and hence radiological quality of the water. Comparing the trends in the three physical parameters with the activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th as shown in Fig. 3, however, reveals nothing conclusive probably due to the geological locations or close proximity of the study areas. Both study areas also have slightly different geological formation and similar meteorological conditions. Variations in parameters may also be due to statistical fluctuations since the study areas are very close to each other. A long time study would be necessary to investigate the dependence of ^{222}Rn, ^{40}K and ^{232}Th activity concentrations on these physical parameters and other importance.

The estimated values of the annual effective dose due to ingestion of ^{222}Rn, ^{40}K and ^{232}Th in water received by adult members of the public living in

Table 5: Comparison of measured activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th with data from different countries

	^{222}Rn (Bq/L)		^{40}K (Bq/L)		^{232}Th (Bq/L)		
Country	Average	Range	Average	Range	Average	Range	References
Egypt	-	-	-	-	0.050	-	Nour (2004)
Malaysia (Panang)	-	0.580-2.540	-	-	-	-	Muhammed *et al*. (2011)
Bangladesh	4.460	-	4.160	-	0.190	-	Alam *et al*. (1999)
Korea	-	0-300	-	-	-	-	Cho *et al*. (2004)
Nigeria	-	-	13.540	0.350-29.010	-	-	Ajayi and Owolabi (2008)
Poland	-	12-63	-	-	-	-	Walencik *et al*. (2006)
Ghana (Apewosika)	-	-	8.170	6.550-9.360	0.580	0.330-0.860	Faanu *et al*. (2011)
Ghana (Amamoma)	-	-	8.770	7.180-10.690	0.710	0.540-0.940	
Ghana (Kokoadu)	-	-	7.230	6.480-9.000	0.520	0.250-0.820	
Ghana (Kwaprow)	-	-	8.570	6.730-10.520	0.610	0.360-0.890	
Ghana (Dome, Kwabenya and Adentan)	8.100	2.150-28.700	-	-	-	-	Darko *et al*. (2010)
Ghana (Adentan)	0.392	0.037- 0.673	3.671	0.881-8.864	0.568	0.254-1.200	Present work
Ghana (Abokobi)	0.220	0.076 -0.338	2.589	0.721-6.915	0.394	0.165-0.651	Present work

Adentan and Abokobi areas are given in Table 3 and 4, respectively. It was noted that the annual effective dose received by adults as a result of ingestion of ^{222}Rn, ^{40}K and ^{232}Th in the groundwater in Adentan and Abokobi site varied from 57.185±3.120 to 209.660±6.421 μSv/y with an average value of 113.007±3.940 μSv/y and from 31.340±0.940 to 118.713±1.435 μSv/y with an average value of 76.568±2.321 μSv/y, respectively. The overall estimated average value of the annual effective dose due to intake of radionuclides received by an adult in both study areas was 94.79±3.13 μSv/y.

According to the World Health Organisation (WHO) guidance level in drinking water on intake of radionuclides, the annual effective dose due to intake of radionuclides should not exceed 0.1 mSv/y (100 μSv/y) (WHO, 2004). This shows that the calculated average annual effective dose due to ingestion of radionuclides in water to any individual adult in the population group living in Adentan is slightly higher than the average value set by the WHO whereas the average values obtained in the samples from Abokobi is lower than the average value set by the World Health Organisation.

Considering the recommended value of the annual effective dose due to ingestion of radionuclides through drinking water and food estimated by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the estimated worldwide average annual effective dose is 0.29 mSv/y (290 μSv/y) with a typical range of 0.2 to 0.8 mSv/y (200 to 800 μSv/y) (UNSCEAR, 2000). All the values obtained in this study are observed to be within the typical range of 0.2 to 0.8 mSv/y (200 to 800 μSv/y) established by the UNSCEAR (1988). Hence, the calculated average values in both study areas are lower than the average value set by the UNSCEAR (2000). Figure 4 shows the comparison of the calculated average annual effective doses obtained in this study with the estimated average values set by the WHO (2004) and the UNSCEAR (1988).

CONCLUSION

Natural radioactivity levels in selected groundwater in Adentan and Abokobi in the Greater Accra Region of Ghana has been assessed using gamma-ray spectrometry (HPGe). The calculated activity concentrations of ^{222}Rn, ^{40}K and ^{232}Th were compared with other values published in other countries selected from the literature and observed to be within the range. The average values obtained were also below the guidelines values recommended by the WHO (2004).

In order to assess public exposure due to intake of radionuclides through water, the annual effective dose received by adult member of the public in Adentan and Abokobi were estimated. The recorded average values in Adentan and Abokobi were 113.007±3.940 and 76.568±2.321 μSv/y, respectively. The estimated average effective dose over a year for an adult in Adentan is slightly higher than the average value of 0.1 mSv/y (100 μSv/y) recommended by the World Health Organisation (WHO), whilst the average value received by adult in Abokobi is below the recommended value by the WHO (2004). Even though the average annual effective dose in water samples from Adentan was slightly higher than the WHO guidelines value, the values were still lower than the average value of 0.29 mSv/y (290 μSv/y) due to ingestion of radionuclides in drinking water and food recommended by UNSCEAR (2000) for public exposure control to natural radiation.

From the Radiation Protection point of view, the average annual effective dose in the samples from Abokobi is below the guideline levels. Also the average annual effective doses are within the recommend public average annual dose limit due to ingestion of radionuclides. These indicate that ingestion of groundwater from the study areas might not pose any significant radiological health hazards. Since the study covered only a limited part of the areas, further studies should be extended to cover the whole country in order to obtain the national global picture of the public exposure to natural radioactivity due to ingestion of radionuclides in water, which should include the epidemiological survey of incidences of radiation-related health effects.

ACKNOWLEDGMENT

This study was support by the IAEA through AFRA fellowship TC Project RAF/0/031. The authors wish to express their gratitude to IAEA/AFRA-HLSC

members for the financial support. The Ghana Atomic Energy Commission is also commended for the use of laboratory facilities.

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