

Determination of Radionuclides in Underground Water Sources Within the Environments of University of Cape Coast

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Abstract: Preliminary studies on groundwater samples from selected wells in University of Cape Coast and its surroundings in the Central region of Ghana have been carried out to determine the annual effective dose from intake of naturally occurring radionuclides. Measurements were carried out using gamma spectrometry. The average annual effective doses obtained in this study were 0.15 ± 0.04 mSv for Apewosika, 0.17 ± 0.03 mSv for Amamoma, 0.14 ± 0.01 mSv for Kokoado and 0.17 ± 0.03 mSv for Kwaprow respectively. The values calculated were about 1.7 times higher than WHO guidance levels of 0.1 mSv/y from intake of radionuclides in water. ²³²Th and ⁴⁰K levels are lower than the world average values whilst ²³⁸U levels are slightly higher. The total annual effective dose in the study area is lower than the ICRP recommended public dose limit of 1 mSv per year.

Key words: Activity concentration, annual effective dose, p-values, radionuclides, underground water, University of Cape Coast

INTRODUCTION

Studies have shown that activity concentrations of natural radionuclides in groundwater are connected to the activity concentrations of uranium and thorium and their decay products in the ground and bedrock. This is due to reaction of the water with the ground and bedrock and releasing quantities of dissolved components that depend on the mineralogical and geochemical composition of the soil and rock. Chemical composition of the water depends on the degree of weathering of the rock, redox conditions and the residence time of groundwater in the soil and bedrock (Vesterbacka, 2007).

Knowledge of the distribution of radionuclides levels in the environment is important for assessing the radiation exposure to the public. Potential health hazards from natural radionuclides in water have been considered worldwide; and many countries have adopted the World Health Organization (WHO) recommended guideline activity concentration values of different radionuclides in drinking water (WHO, 2004).

Radiological quality of drinking water depends on the presence of natural occurrence of radioactive elements, technological processes involving naturally occurring radioactive materials, and from medical and industrial use of radioactive materials (Trimble, 1968). Radionuclides in water is primarily a problem for water supplies which extract water from drilled holes in rocks or from springs

flowing through areas with crystalline rocks, which have somewhat higher uranium concentrations than the average bedrock. Rock types which often have enhanced uranium concentrations greater than 5 ppm of uranium (approx. 60 Bq/kg) include the following: granites, syenites, pegmatites, acid volcanic rocks, and acid gneisses. Wells in areas with these rock types 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, which is to be expected since these types of rocks generally, have low uranium concentrations (Akerblom and Lindgren, 1997).

Supply of potable water to the Cape Coast municipal area and surroundings is one of the critical challenges that confront a developing country like Ghana. Studies have shown that, although places where potable pipe-borne water is available at all, the supply is generally inadequate to meet demand for water. Thus, boreholes and wells have sprung up in many areas in the communities around University of Cape Coast where about 70% of the student population reside.

Radiological health hazards associated with natural radionuclides and their progenies due to the consumption of ground water has become a global issue in recent times. Information gathered have shown that much have not

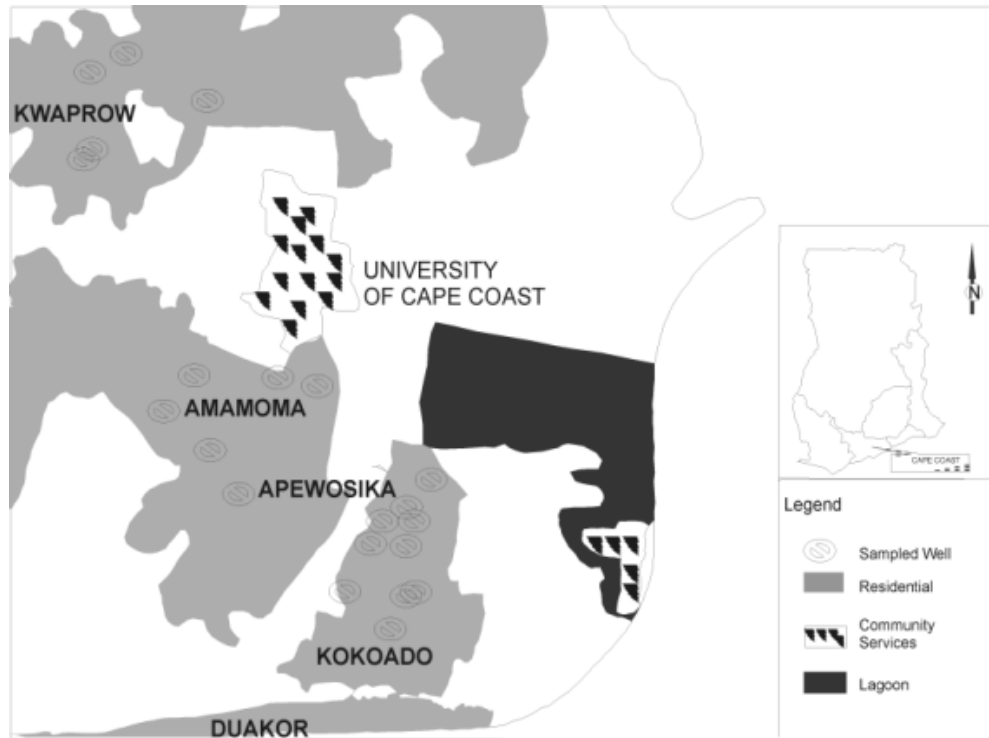


Fig. 1: Map of the Study area showing the University of Cape Coast and its surroundings

been done in this area in Ghana. The public is unaware of potential hazards associated with drinking water contaminated with naturally occurring radioactive materials (NORMS).

The studies were carried out in the dry season where demand for ground water reaches its peak. During this period, treated water serving the metropolis reduces and attention is shifted to underground water.

Description of the study area: The study area is the University of Cape Coast and its surroundings as shown in Fig. 1. It is bounded on the south by the Gulf of Guinea, on the West by the Komenda-Edina-Aguafo-Abrem District, East by the Abura-Asebu-Kwamankese District and North by Twifo Hemang Lower Denkyira District. It lies between longitude $1^{\circ}00'$ - $1^{\circ}15'$ West and Latitude $5^{\circ}30'$ North. It has a total land area of 9826 km².

Geologically, the area is dominated by batholiths and is generally undulating with steep slopes. There are valleys of various streams between the hills, with Kakum being the largest stream. The minor streams end in wetlands, the largest of which drains into the Fosu Lagoon at Bakano. In the northern part of the metropolis, however the landscape is generally low lying and is suitable for the cultivation of various crops. The metropolis has double maxima rainfall. The major rainy season occurs between May to July and minor rainy

season falls within November to January. It is a humid area with mean monthly relative humidity varying between 85 and 99%. The sea breeze has a moderating effect on the local climate. The present vegetation of the metropolis consists of shrubs of about 1.5 m high grasses and a few scattered trees. The soils of the metropolis are generally lateritic and are derived from the weathered granite and schist. The soil profile shows a topsoil of about 0.33 mm. In the valleys and swampy areas, fine sandy deposits occur extensively.

Hydro-geology of the study area: The study area is categorised under the series of Cape Coast granitoids which contain potash-rich, muscovite-biotite, granite, biotite schist and granodiorite geological setting. The Cape Coast-type granitoids mainly consists of large, syntectonic, foliated granitoid batholiths that typically intrude the Birimian sedimentary strata. Typical lithologies include quartz diorites, tonalities and trondhjemites, granodiorites, adamellites and granites. The Cape Coast granitoids have extensive contact metamorphic aureoles with mineral assemblages that indicate pressures of at least 4 kb and temperatures around 500°C (Hirde *et al.*, 1992). The hills are generally overlain by sandy and clayey silts while the valleys are overlain by clayey gravel with lateritic soils exposed in a number of areas.

Groundwater occurrence in the study area is controlled by matrix flow. Borehole yields for average size well (125 mm diameter) reaching a mean depth of 52 m is generally in the range 0.7–27.5 m³/h with a mean value of 2.7 m³/h. Transmissivity values are generally low due to high clay content of the regolith. They vary from 0.23m²/h (in the clayed regolith) to 4.0 m²/h in the fissured zones

METHODOLOGY

Sampling and sample preparation: A total number of 20 water samples were collected from wells within four communities around University of Cape Coast, in the Central Region of Ghana namely: Amamoma, Apewosika, Kwaprow and Kokoado for analysis within the period of November and April. All the water sources are used for domestic purposes. The sampling sites were wells for which precise information on depth and casing lengths are unavailable. Water samples from the wells were measured during the period where the weather conditions during the sampling period were fairly stable. The pH, temperature and conductivity of the water samples were measured on the field during the sampling period using a portable water-analysis kit. The stability and precision of the measurements were found to be nominal and are within 5% of the mean of data for pH, temperature and conductivity.

Water was collected into 1.5 L polyethylene plastic bottles and a few drops of hydrochloric acid were added to bring the pH to an appreciable level of 2 in order to prevent adherence of the radionuclides to the walls of the containers. The bottles were filled to the brim without any head space to prevent trapping of gas. The bottles were tightly covered with the lids and labeled appropriately. The samples were transported to the laboratory and prepared into 1 L Marinelli beakers and stored in a refrigerator prior to analysis.

Analysis of water samples: The samples were analysed using an ORTEC high resolution gamma-spectrometry system. The spectrometer consists of a High Purity Germanium (HPGe) detector couple to a desk top computer provided with Maestro 32 MCB configuration software for spectrum acquisition and evaluation. The detector crystal has a diameter of about 36 mm and thickness of about 10 mm. The crystal is housed in an aluminium canister with a 0.5 mm thick beryllium entrance window. A lead shield, built with 5 cm thick lead brick surrounds the detector to prevent it from external background radiation reaching the detector. The detector is coupled to a Canberra 1510 signal processing unit which contains the power supply, amplifier and analog to digital converter. Digitized counts were collected in a Canberra S100 multi-channel analyzer. The Germanium

detector is connected to an Uninterrupted Power Supply (UPS). The detector is cooled with liquid nitrogen at -196°C (77 K) provided in a 25 L Dewar. The ambient temperature around the detector varied between 16°C and 27°C during the period of measurement. The relative efficiency of the detector is 25 % with energy resolution of 1.8 keV at gamma ray energy of 1332 keV of ⁶⁰Co.

The energy and efficiency calibrations of the detector were performed using mixed radionuclide standard of density of 1.0 g/cm³ in a 1.0 L Marinelli beaker manufactured by Deutscher Kalibrierdienst (DKD-3), QSA Global GmbH, Germany. Background counts were taken for the same period and corrections carried out where appropriate. The samples were counted for 86400 seconds.

The specific activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K in Bq/L for the water samples respectively were determined using the following expression (Uosif *et al.*, 2008; Darko and Faanu, 2007; Darko *et al.*, 2008). The ²³⁸U activity was determined by taking the mean activity of the two separate photo peaks of the daughter nuclides: ²¹⁴Pb at 352.0 keV and ²¹⁴Bi at 609.3 keV, ²³²Th was determined using photo peaks of ²²⁸Ac at 911.1 keV and the photopeak of ²¹²Pb at 583.1 keV and ⁴⁰K was directly determined using 1460.8 keV photopeak. According to published reports, the activity concentration (Bq/L) in the water samples is given by (Awudu *et al.*, 2010).

$$A_{sp} = \frac{N_{sam}}{P_E \cdot \epsilon \cdot T_c \cdot M} \quad (1)$$

where, N_{sam} - background corrected net counts of the radionuclide in the sample, P_E - gamma ray emission probability (gamma yield), ϵ - total counting efficiency of the detector system, T_c - sample counting time, and M - mass of sample (kg) or volume (L).

The annual effective dose (mSv/y) from ingestion of radionuclide in water samples was calculated on the basis of the mean activity concentrations of the radionuclides. The daily water consumption rate was considered to be 2 L/day and the conversion factor or dose per unit intake by ingestion for naturally occurring radionuclides for adult members of the public was taken to be 4.5×10^{-5} mSv/Bq for ²³⁸U, 2.3×10^{-4} mSv/Bq for ²³²Th and 6.2×10^{-6} mSv/Bq for ⁴⁰K were used.

The annual effective dose $H_{ing}(W)$ was computed from the expression below (ICRP, 1996):

$$H_{ing}(W) = \sum_{j=1}^3 DCF_{ing}(U, Th, K) \cdot A_{sp} \cdot I \quad (2)$$

where, $DCF_{ing}(U, Th, K)$ - Dose conversion coefficients of the radionuclides in Sv/Bq, A_{sp} - Specific activity

Table 1: Activity concentrations and annual committed doses in samples of water from different wells at Apewosika area

Sample code	Activity concentration (Bq/L)			Annual effective dose (mSv)	pH
	²³⁸ U	²³² Th	⁴⁰ K		
APW ₁	0.44	0.33	9.36	0.11	6.21
APW ₂	0.44	0.86	8.36	0.20	6.82
APW ₃	0.09	0.76	9.26	0.17	7.33
APW ₄	0.45	0.47	6.55	0.12	5.42
APW ₅	0.75	0.50	7.32	0.14	6.85
Average±SD	0.41	0.58	8.17	0.15±0.04	6.53

SD = Standard deviation

Table 2: Activity concentrations and annual committed doses in samples of water from different wells at Amamoma area

Sample code	Activity concentration (Bq/L)			Annual effective dose(mSv)	pH
	²³⁸ U	²³² Th	⁴⁰ K		
AMW ₁	0.54	0.60	7.66	0.15	5.52
AMW2	0.39	0.94	7.87	0.21	6.02
AMW3	0.27	0.74	10.69	0.18	5.85
AMW4	0.35	0.54	8.21	0.14	5.96
AMW5	0.32	0.62	7.71	0.15	6.34
AMW6	0.33	0.78	10.47	0.19	5.53
Average±SD	0.37	0.71	8.77	0.17±0.03	5.87

Table 3 Activity concentrations and annual committed doses in samples of water from different wells at Kokoadu area.

Sample code	Activity concentration (Bq/L)			Annual effective dose(mSv)	pH
	²³⁸ U	²³² Th	⁴⁰ K		
KOW ₁	0.66	0.82	6.48	0.19	5.72
KOW ₂	0.78	0.25	7.18	0.10	6.23
KOW ₃	0.49	0.58	7.06	0.15	5.25
KOW ₄	0.54	0.44	9.00	0.13	6.92
KOW ₅	0.83	0.53	6.71	0.15	7.01
Average±SD	0.66	0.52	7.23	0.14±0.01	6.23

Table 4: Activity concentrations and annual committed doses in samples of water from different wells at Kwaprow area

Sample code	Activity concentration (Bq/L)			Annual effective dose(mSv)	pH
	²³⁸ U	²³² Th	⁴⁰ K		
KWW ₁	0.66	0.77	6.73	0.18	5.70
KWW2	0.78	0.52	9.26	0.15	6.01
KWW3	0.94	0.53	9.01	0.16	5.90
KWW4	0.71	0.36	7.33	0.12	6.26
KWW5	0.54	0.89	10.52	0.21	5.14
Average±SD	0.73	0.61	8.57	0.17±0.04	5.80

concentrations of radionuclides in the water samples in Bq/L, I-Radionuclide intake in litres per year, assuming 2 L average water intake per day for 365 days/y (730 L/y).

RESULTS AND DISCUSSION

Table 1-4 show the locations and the results of the calculated activity concentrations of ²³⁸U, ²³²Th and ⁴⁰K in the water samples, effective dose and pH of the water at the time of sampling.

The activity concentration in well water from Apewosika recorded average activity concentrations of 0.41, 0.58 and 8.17 Bq/L for ²³⁸U, ²³²Th and ⁴⁰K, respectively. Amamoma also recorded average activity concentrations of 0.37, 0.71 and 8.77 Bq/L for ²³⁸U, ²³²Th and ⁴⁰K, respectively. Kokoadu well water samples recorded average activity concentrations of 0.66, 0.52 and 7.23 Bq/L for ²³⁸U, ²³²Th and ⁴⁰K, respectively. Kwaprow

estimated average activity concentrations of 0.73, 0.61 and 8.57 Bq/L for ²³⁸U, ²³²Th and ⁴⁰K, respectively.

Table 2 and 4 show that the average activity concentrations of ²³²Th obtained in wells from Amamoma and Kwaprow area are slightly higher than the World Health Organization (WHO) maximum acceptable concentrations of 0.6 Bq/L (WHO, 2004). Higher activity concentrations in hand-dug well water may be due to the longer contact time of groundwater with soil and bedrock, during which minerals dissolve in the groundwater. Additionally, the mineralogical and geochemical composition of the soil and rock, chemical composition of water, degree of weathering of the rock and redox conditions also contribute to high activity concentrations (Vesterbacka, 2007).

The annual committed effective dose to an adult due to ingestion of radionuclides in groundwater from

Table 5: Correlation analysis using Pearson correlation matrix method

	Apewosika	Amomoma	kokoadu	kwaprow
Apewosika	1			
Amomoma	0.952*	1		
p-value	0.013			
kokoadu	-0.732	-0.613	1	
p-vale	0.160	0.272		
kwaprow	-0.113	-0.134	0.502	1
p-vale	0.857	0.830	0.388	

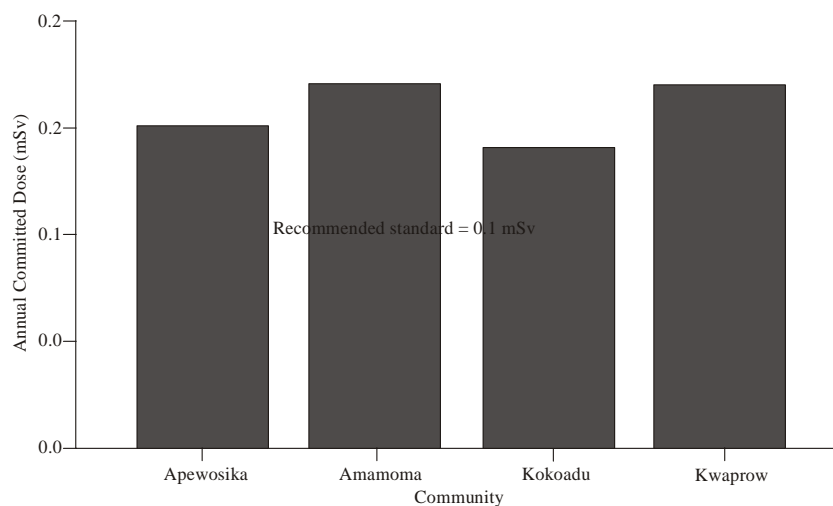


Fig. 2: Average annual committed dose calculated for the communities

Apewosika varied from 0.11 to 0.20 mSv with an average of 0.15 mSv, Amamoma varied from 0.15 to 0.21 mSv with an average of 0.17 mSv, Kokoado varied from 0.10 to 0.19 mSv with an average of 0.14 mSv and Kwaprow varied from 0.12 to 0.21 mSv with an average of 0.17 mSv, respectively.

According to World Health Organization (WHO) guidance level in drinking water on intake of radionuclide, an annual dose equivalent to any single organ or tissue should not exceed 0.1 mSv (WHO, 2004). This shows that, the calculated annual effective dose, due to ingestion of radionuclide in water to any individual adult's organ or tissue in the population group is higher than the average value set by World Health Organization (WHO, 2004) by a factor of about 1.7 for the highest dose obtained from the communities. Fig. 2 indicates that, within the four communities where the samples were taken, wells from Amamoma and Kwaprow recorded on the average, the highest annual effective dose followed by Apewosika and Kokoado respectfully. In each community, where the geological features are relatively the same, the activity concentrations varied. This phenomenon could be as a result of the groundwater formation, the discharge rate and the transport of radionuclides in the liquid phase. The high activity concentration values could also be due to the slight acidic conditions of the water samples. The pH values varied in the range of 5.14 to 7.33 with about 90% of the water samples slight acidic. The soil types of the study area are

generally lateritic and are derived from the weathered granite and schist. Studies elsewhere had established that these rock types are known to contain significant levels of NORM.

The Pearson Correlation Matrix Method of statistical package of social sciences (SPSS) was used to assess the correlations that exist between all radionuclides of the water samples for the various communities. Table 5 shows the results of the statistical analysis. The degree of confidence imposed or placed on this correlation coefficient value of any two communities was based on the estimated p-values. Correlation coefficients which have p-values less than 0.05 are considered significant. It was observed that even though Apewosika and Amamoma recorded on the average different committed effective doses, the results in Table 5 indicates clearly that there was no significant difference between them with a p-value of 0.952. However, there were significant difference between the other communities with respect to the P-values obtained.

From radiation protection point of view, even though the estimated committed effective doses in the water samples are slightly higher than the WHO recommended guideline levels, they might not pose any radiological health hazards to the public within and around the University of Cape Coast communities since these doses are below the recommended public annual dose limit of 1 mSv.

CONCLUSION

Groundwater is a major source of water during frequent water shortages in and around the University of Cape Coast. According to WHO recommendations, the limit for public exposure should be expressed as an effective dose of 1.0 mSv/y (WHO, 2004). In drinking water guidelines for radionuclides, a reference dose level of 0.1 mSv/y is used (UNSCEAR 2000), which is one-tenth of the public dose limit. The average annual effective doses obtained in this study were $0.15.0 \pm 0.04$ mSv for Apewosika, 0.17 ± 0.03 mSv for Amamoma, 0.14 ± 0.01 and 0.17 ± 0.03 mSv for Kwaprow, respectively. The values calculated were about 1.7 times higher than that of the European Union and WHO guidance levels of 0.1 mSv/y from intake of the radionuclides in water for the highest dose obtained. The ^{232}Th levels in the well water compared quite well with the world average. On the other hand the levels of ^{238}U were slightly higher than the world average whilst the levels ^{40}K were lower than the world average. Even though the value for the water samples is higher than the WHO guidance levels, it is still lower than the ICRP recommended public dose limit of 1 mSv per year for public exposure control.

It is recommended that further studies should be carried out to cover the whole municipality, which should also include epidemiological survey of incidences of radiation-related health effects to obtain a baseline data for future studies. A data bank of this nature is also an important tool in formulating local regulations for radioactivity levels in drinking water.

ACKNOWLEDGEMENT

The authors are grateful to the Radiation Protection Institute of the Ghana Atomic Energy Commission for the use of their facilities for this study.

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