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Radon Concentration in Water Sources in Pwalugu in the Upper East Region of Ghana

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ABSTRACT

Radon is a naturally occurring colourless, odourless, water-soluble gas produced by the radioactive decay of radium. Chronic exposure to radon is recognized as a health risk. Ingested water with elevated levels of radon can present a risk for developing internal organ cancers. Thirty (30) water samples collected from four different water sources (borehole, pond, hand–dug well and river) in Pwalugu and their environments were analysed using the Gamma Spectrometry System. The radon concentration varied from 29 ± 1.1 to 40 ± 2.1 µBq/L. These values fall below the maximum concentration level, of 0.148 Bq/L proposed by the US EPA. The highest concentration was recorded in borehole samples because of the nature of the geology and because no radon was lost due to aeration. The calculated annual effective dose by ingestion varied between 2.920×10^{-7} and 2.117×10^{-7} Sv/y which is below the recommended value of 1mSv/y.

Introduction

Water is one of the most abundant substances on earth and principal constituent of all living things. Water is used for domestic, industrial commercial and agricultural purposes. Thus it is important for water to be free from chemical, microbiological and radiological contamination such as radon. Radon is an element that contributes to radiological contamination of drinking water and poses a health risk because of its highest solubility in water among the noble gases. Since the late 1980s, it has been identified as a health concern.

Several studies have shown that the inhalation of decay products of radon increases the chances of lung cancer (Robillard et al, 1991, Steck et al 1992, Alavanja et al 1994, Lubin et al 1997, Lubin et al 1990 &Samuelsson et al 1988). Radon is a colourless, odourless radioactive gas that is a daughter element in the decay chain of uranium 238 (U- 238). Radon and the decay products emit particles that can damage lung tissues because of their high energy (Brooks, 1998). Thus, the alpha radiation emitted by radon and its progeny, polonium, is considered a significant health hazard by the United States Environmental Protection Agency because elevated levels and or extended duration of exposure can lead to lung cancer. Therefore, when radon accumulates in high concentrations in groundwater it poses a greater health risk for people. People are exposed to radon from groundwater in two ways: inhalation of radon that has been released from the water during household activities when the water is heated or agitated such as showering, washing clothes or washing dishes and ingestion by drinking.

Radon is a naturally-occurring, water-soluble gas produced from the radioactive decay of radium. Radon has the highest solubility in water of the noble gases. Radon has a mole fraction value of 0.00125 at 37°C and a half-life of 3.8 days, which is 15 times higher than that of helium or neon (Dickson, 1998 & Garba et al., 2010). Radium which emits radon is a radioactive metallic chemical element found in pitchblende and other uranium minerals. Virtually, all rocks contain some traces of uranium, and the highest amounts are found in granitic rocks. Thus, radon concentration is detected in areas underlain by granites, dark shales, pegmatites, syenites, light-coloured volcanic rocks, sedimentary rocks that contain phosphates and metamorphic rocks derived from these rocks (Gelman et al, 2003; Otton, 1999). The uranium content of sandstone and shale is variable if the sediment is derived from different sources. According to Faure (1999), shale contains more uranium on average than sandstone. At standard temperature and pressure, it has a density of $9.73 kg/m^3$ and freezes at 202K (Williams, D.C 2007). Since radon is a gas, it is very mobile in the environment and can easily move through fractures and openings in rocks and into pore spaces in an aquifer or soil. The amount of radon in groundwater is related to several factors including the amount of uranium in the source rocks, the location of radium atoms in the mineral gain and physical properties of the aquifer materials, e.g., porosity (Barnett et al, 2003).

The aim of this study is to determine the radon concentration in the water source that serves as the domestic water supply for the Pwalugu community and its surrounding areas. The study was carried out during the dry season between November and April when the weather was fairly stable.

Study area

Pwalugu is in the Talensi District of the Upper East Region of Ghana. It is located between latitude 10°35 and 10°47'N and longitude 00°38 and 00°52'E. Geologically, the area falls within the Birimian, Tarkwaian and Voltaian rocks of Ghana (Kesse, 1985). The Brimian rocks (metavolcanic and metasedimentary rocks) are intruded by granitoids. The meta-sedimentary rocks are mostly phyllites, schist and

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greywackey and are intruded by granitoids and pegmatite. The meta-volcanic rocks consist of the meta-basalt, meta-dacites, meta-rhyolite and volcaniclastics which are intruded by belt-type granitoids (http://www.ghanadistricts.gov.gh/. Accessed 30/08/13).

The study area experiences two climatic conditions; a rainy season which is erratic and is from June to October, and a long dry season from October to May. The mean annual rainfall ranges between 88 mm and 110 mm. The area experiences a maximum temperature of 45°C in April and a minimum of 12°C in December. The vegetation is that of guinea savannah or modified guinea savannah (Dickson & Benneh, 1998).

Materials and Method

The materials for the survey were thirty (30) water samples collected from four different sources (boreholes, hand-dug wells, ponds and a river), 1.5-litre polyethene containers, and 1-litre Marinelli beakers, and gamma spectrometry facilities.

Radon measurement using gamma spectrometry

The laboratory analysis was conducted on the water samples, which were transferred into 1-liter Marinelli beakers and kept for four weeks before the analysis to enable the daughter radionuclides to attain secular equilibrium with the parent. The gamma-spectrometry system consists of a detector coupled to a desktop computer with Maestro 32 MCB configuration software for spectrum acquisition and evaluation. The detector crystal has a diameter of approximately 36mm and a thickness of approximately 10 mm. It is housed in an aluminium canister with a 0.5- mm thick beryllium entrance window. An approximately 5-cm thick lead brick surrounds the detector to prevent external background radiation. The radon concentration was obtained by counting after 30 days, where it will have virtually decayed and only radon in secular equilibrium remained with radium-226. The efficiency and energy calibrations were performed prior to the analysis. The water samples were counted for the presence of radionuclide with radium-226 for a counting time of 2000 seconds. The radon concentration in the samples was calculated by measuring the parent nuclide, which is radium in the water. The radium specific activity concentration (A) was calculated using the following relation (UNSCEAR 2000):

$$\mathbf{A} = \frac{\mathbf{Nexp}(-\boldsymbol{\lambda}\mathbf{T})}{\mathbf{P}\boldsymbol{\epsilon}(\mathbf{E}\boldsymbol{\gamma})\mathbf{TM}}$$

where

A – Specific activity concentration units (cps)

M – Mass of the sample units (litre)

N – Net counts for the sample in the peak range units (cps)

P – Emission probability

T – Counting time units (sec)

$\in E(\boldsymbol{\gamma})$ – Photo peak efficiency

T – Delay time between sampling and counting (sec)

Estimation of the annual effective dose by ingestion

The estimated annual effective dose by ingestion from the habitual consumption of water by dwellers was calculated as follows:

$$\mathbf{D_w = C_w \times CR_w \times D_{cw}}$$

where

D_w – the annual effective dose ($mSvy^{-1}$) due to ingestion of radionuclide from the water consumption.

C_w– the concentration of Rn-222 in the ingested drinking water (BqL^{-1})

CR_w – the annual intake of drinking water (Ly^{-1})

D_{cw} – the ingested dose coefficient for Rn-222 (10^{-8} $SvBq^{-1}$)

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) suggests that the estimated dose coefficient for the intake of Rn-222 from drinking water are 10^{-8} $SvBq^{-1}$ for an adult $2x10^{-8}$ $SvBq^{-1}$ for a child and $7x10^{-8}$ $SvBq^{-1}$for an infant (UNSCEAR, 2000). An annual effective dose of the intake of Rn-222 from drinking water was calculated by considering an adult daily water consumption of 2 litres. An average of 730 litres of water was estimated annually for an adult (Age>18yrs) (Cevik et al, 2006).

Results and Discussion

The results of the Radon concentration and annual effective dose in the various samples are shown in table 1. The radon concentration values in the samples range from 29±1.1 to 38±2.1 µBq/L, where the borehole samples have the highest concentration, followed by the samples from hand-dug wells, ponds and rivers, in that order. In general, the high concentrations recorded can be attributed to the geology of the area, which is mainly granite in nature, and the lack of aeration. This result is consistent with similar works studied done in other areas with similar geology by Asumadu –Sakyi et al, 2012.

Table 1. Concentration of Rn-222 and annual effective dose in the water sources.

Sample	Latitude	Longitude	Concentration µBq/L	Annual Effective dose mSv/y
Pond 1a	10°37'N	00°50'E	31 ± 1.6	2.263×10^{-7}
Pond 1b	10°35'N	00°38'E	33 ± 1.6	2.409×10^{-7}
Pond 1c	10°41N	00°47'E	29 ± 1.6	2.117×10^{-7}
Pond1d	10°40'N	00°43'E	32 ± 1.3	2.272×10^{-7}
Pond 1e	10°38'N	00°40'E	33 ± 1.3	2.409×10^{-7}
Pond 1f	10°36'N	00°41'E	31 ± 1.3	2.263×10^{-7}
River 1a	10°37'N	00°50'E	29 ± 1.1	2.117×10^{-7}
River 1b	10°35'N	00°38'E	30 ± 1.1	2.190×10^{-7}
River 1c	10°40'N	00°43'E	28 ± 1.1	2.044×10^{-7}
Hand-dug well 1a	10°37'N	00°50'E	34 ± 1.7	2.482×10^{-7}
Hand-dug well 1b	10°35'N	00°38'E	36 ± 1.7	2.628×10^{-7}
Hand-dug well 1c	10°41'N	00°47'E	32 ± 1.7	2.336×10^{-7}
Hand-dug well 1d	10°40'N	00°43'E	35 ± 1.4	2.555×10^{-7}
Hand-dug well 1e	10°38'N	00°40'E	36 ± 1.4	2.628×10^{-7}
Hand-dug well 1f	10°36'N	00°41'E	34 ± 1.4	2.482×10^{-7}
Borehole 1a	10°37'N	00°50'E	38 ± 2.1	2.774×10^{-7}
Borehole 1b	10°35'N	00°38'E	40 ± 2.1	2.920×10^{-7}
Borehole 1c	10°41'N	00°47'E	36 ± 2.1	2.628×10^{-7}
Borehole 1d	10°40'N	00°43'E	37 ± 1.6	2.701×10^{-7}
Borehole 1e	10°38'N	00°40'E	39 ± 1.6	2.847×10^{-7}
Borehole 1f	10°36'N	00°41'E	35 ± 1.6	2.555×10^{-7}
Borehole 1g	10°45'N	00°42'E	38 ± 1.5	2.772×10^{-7}
Borehole 1h	10°45'N	00°42'E	40 ± 1.5	2.920×10^{-7}
Borehole 1i	10°44'N	00°42'E	37 ± 1.5	2.701×10^{-7}
Borehole 1j	10°39'N	00°45'E	37 ± 1.4	2.701×10^{-7}
Borehole 1k	10°47'N	00°41'E	38 ± 1.4	2.774×10^{-7}
Borehole 1l	10°47'N	00°43'E	36 ± 1.4	2.628×10^{-7}
Borehole 1m	10°47'N	00°43'E	38 ± 1.8	2.774×10^{-7}
Borehole 1n	10°45'N	00°41'E	40 ± 1.8	2.920×10-7
Borehole 1o	10°39'N	00°45'E	36 ± 1.8	2.628×10^{-7}

The uranium content, grain size and permeability of the host rock and the nature and extent of fracturing in the host rock may be contributed to the high radon concentration. The boreholes have the highest concentrations (35 ± 1.6 to 40 ± 2.1µBq/L) because there may be little or no loss of radon because there is a lack of aeration and the water is more stagnant. Similar reasons could be assigned to the higher concentrations of samples from the hand-dug well (34± 1.4 to 36±1.7µBq/L). The samples from ponds have moderately low concentrations (29±1.6 to 33±1.7µBq/L), possibly because of the large surface area, which is exposed to aeration. The samples collected from the river have the lowest activity concentration (29 ±1.1 µBq/L) because of the aeration and agitation of the water caused by the river flow. According to the United States Environmental Protection Agency, the safe level of radon in drinking water is 4 pCi/L (0.148 Bq/L), which implies that the measured values for different samples are below the action level and consequently safe for drinking purposes. The estimated annual effective dose is 2.117- 2.920 $x10^{-7}$mSv/y. Since the annual effective dose depends on the activity concentration, the samples with high concentrations have high annual effective doses. The annual effective doses recorded for the samples do not exceed the recommended value of 1mSv/y; hence, the water is safe for drinking purposes.

Conclusion

Gamma spectrometry was used to analyse the radon concentrations of thirty (30) water samples from four (4) water sources. The concentrations varied because of the geology of the area, aeration and agitation of the water. The stagnant nature of boreholes and hand-dug wells prevents the loss of radon because of the lack of aeration. The determined radon concentration was in the following: order boreholes > hand-dug wells > ponds > rivers. All radon concentrations in the study were below the recommended level of 0.148 Bq/L which indicates that various water sources are safe for drinking. The annual effective dose by ingestion of various samples is below the recommended value of 1 mSv/y.

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Authors' contributions

Conceived and design the experiment: AS, MP&FKQ
Performed the experiments: FKQ, MP&AS
Analyzed the data: MP& AS
Wrote the paper: AS, MP&FKQ

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