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Annual effective dose of radon in groundwater samples for different age groups in Obuasi and Offinso in the Ashanti Region, Ghana

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Abstract

The study presents radon (222Rn) activity concentration in the groundwater samples and their annual effective dose exposure in Offinso and Obuasi in the Ashanti Region for different age groups. Radon measurement was made using Durridge RAD-7 H2O technique. In Obuasi, mean 222Rn concentration in groundwater was 0.09 ± 0.01 Bq l−1, mean annual effective dose due to ingestion for adult, child and infant were 0.64 ± 0.11 μSv yr−1, 1.28 ± 0.21 μSv yr−1 and 4.46 ± 0.73 μSv yr−1 respectively and the mean annual effective dose due to inhalation was 0.28 ± 0.05 mSv yr−1 for the dry season whereas in the rainy season the mean 222Rn concentration in groundwater was 0.08 ± 0.01 Bq l−1, the mean annual effective dose due to ingestion for adult, child and infant was 0.56 ± 0.09 μSv yr−1, 1.13 ± 0.18 μSv yr−1, 3.94 ± 0.62 μSv yr−1 respectively and the annual effective dose due to inhalation was 0.24 ± 0.04 mSv yr−1. In Offinso, the mean 222Rn concentration in groundwater was 0.14 ± 0.05 Bq l−1, mean annual effective dose due to ingestion for adult, child and infant was 1.03 ± 0.37 μSv yr−1, 2.06 ± 0.74 μSv yr−1, and 7.20 ± 0.74 μSv yr−1 respectively and the mean annual inhalation dose a mean of 0.46 ± 0.16 mSv yr−1 for the dry season. In the rainy season, the mean indoor 222Rn concentration in groundwater was 0.13 ± 0.04 Bq l−1, mean annual effective dose due to ingestion for adult, child and infant was 1.26 ± 0.31 μSv yr−1, 1.89 ± 0.61 μSv yr−1 and 6.62 ± 2.15 μSv yr−1 respectively and the mean annual effective dose due to inhalation was mean of 0.41 ± 0.13 mSv yr−1. The mean annual effective doses of all the samples are lower than the reference level of 0.1 mSv yr−1 for drinking water of WHO and EU Council. It has been concluded that drinking water of the study area is generally safe as far as radon related health hazards are concerned apart from a few isolated cases. It has been found that radon levels within the region have a positive correlation with depth of the water sources.

Introduction

The quality of water is an important parameter for environmental studies and thus it is necessary to have regulations guiding natural radioactivity in drinking water [1]. The existence of radionuclides in drinking water gives rise to internal exposure, directly via their decay processes, through ingestion and inhalation and indirectly, when they are combined as part of the food chain [2]. Measurement of radioactivity in drinking water helps to ascertain the risk of exposure to radiation from daily consumption of water [1]. Radon is a radioactive, colorless, odorless, and tasteless gas that is formed through the breakdown of uranium in soil and rocks.

Studies on radon and its correlation with the type of geology is ongoing in different parts of the world [3–5]. In big cities, water processing in large municipal systems aerates the water, which allows radon to escape, and delays the use of water until most of the remaining radon has decayed [6]. Groundwater has become the source
of drinking water for most inhabitants of both rural and urban settlements due to water shortage which has been hitting most parts of cities [7]. It has been estimated that lack of clean drinking water and sanitation services leads to water-related diseases globally and between five to ten million deaths occur annually, primarily of small children [8]. Population growth and urbanization have put a lot of pressure on water resources in the world. This has resulted in adequate public water supply. Drilling of boreholes has now become the norm in most urban areas [7].

The presence of radon in groundwater is predominantly due to the decay of radium (226Ra) found in rock and soils. Radon can also be generated within water distribution systems with high radium concentrations from radium adsorbed iron pipe scales [9]. Public exposure to waterborne 222Rn and its short-lived decay products may occur through ingestion (drinking water containing 222Rn) and by inhalation (breathing 222Rn gas in indoor/outdoor air which has been released from household water), both mechanisms posing a potential health risk [10–15]. Once in the building, water with an elevated level of radon can cause radon to diffuse into the indoor atmosphere and increase the overall radon levels [16]. There is also evidence from epidemiology and modeling studies that ingestion of radon can cause stomach cancer [17–20]. To protect the public from consequences of excessive exposure to radiation due to radon in their environment [21], mainly from the risk of lung cancer, it is necessary to understand the levels of radon in each source including household water, particularly water from groundwater sources.

The four main sources of water in the Offinso municipality are borehole (groundwater), river, stream and pipe borne water. Majority of households (43.0%) drink water from pipe borne and that of Obuasi municipality are borehole, protected well, public tap and pipe borne water. About half of households (53.3%) drink water from boreholes [22]. Radon gas released from water will contribute to the total concentration of indoor air with about 1%–2%. Due to the more contact of groundwater water with igneous and sedimentary rocks, concentration of radioactive contents in these waters can be higher than surface water sources [23–25].

Many international organizations have introduced some regulations concerning permissible concentrations of this radionuclide in drinking water. The maximum contamination level (MCL) for radon in drinking water is 11 Bq L−1 [26] and a guidance level of 100 Bq L−1 by World Health Organization [27]. In this work RAD7 manufactured by Durridge, USA was used for radon in water measurement [28]. The equipment RAD7 is a versatile instrument that can be used as the basis of a measurement system specific to radon. There are several methods already developed for measurements of radon in water. Examples are Gamma Spectroscopy (GS), Lucas cell (LC) and Liquid Scintillation (LS). In comparison with the methods mentioned above, the RAD H2O provides a method as accurate as the method Liquid Scintillation. It is portable, read faster and does not require intense studies. The use of equipment RAD7 also eliminates the need to use toxic chemicals [28].

The purpose of this survey is to contribute to the data compilation concerning the presence radon–222 in groundwater in various regions of Ghana. Among the specific objectives is to determine the radon in groundwater in Obuasi, a mining town and Offinso, a non-mining town in the Ashanti Region and the risk associated with the different age groups.

### Study area

**Offinso municipality**

Offinso Municipality lies between longitudes 10° 60 W and 10° 45 E as well as latitudes 70° 20 N and 60° 50 s as shown in Figure 1. It shares common boundaries with Techiman Municipal Assembly to the North, Sunyani Municipal Assembly to the West, Ejura Sekyere Odumasi District Assembly to the East and the Offinso Municipal Assembly to the South. The land has three main underlying rock types upon which soil is formed. They are of the Voltain, Birimian and the Granite rock types. The Voltain rock type is found in the northeastern part of the Municipality whilst the Birimian rock type, mainly schist and gneiss, is found in the south-western part around Bonsua, Kensere, Gambia and Wawase. Granite is found in the southern and south-eastern portions, stretching from Nyamebekyere through Anyinasuso to Tutuase [22].

**Obuasi municipality**

The Municipality is located between latitudes 5 °35N and 5 °65N, and longitudes 6°35′W and 6°90′W. It covers a total land area of 220.7 square km. It is in the South-Western part of the Ashanti Region as shown in Figure 2. It is 64 km from Kumasi, the regional capital. The Municipality is bounded on the south by Upper Denkyira District of the Central Region, East by Adansi South, West by Amansie Central, and North by Adansi North. Obuasi is the Administrative Capital where the famous and rich Obuasi Gold Mine, now Anglo Gold Ashanti is located.

Rocks in the Municipality are mostly of Tarkwain (Pre-cambrian) and Upper Birimian formation which are noted for their rich mineral bearing potentials. Areas around Birimian and Tarkwain zones known as reefs are noted for gold deposits [31].
Materials and method

Sixty-four (64) groundwater samples from each town was sampled during the dry season in the month of February 2014 and June 2014 for the rainy season. Samples were taken after five-ten minutes of operating the wells using the submerged bottle method. Well-washed bottles of 250 ml were used for sampling and sealed with a cap underwater immediately so that radon may not get out of it. All bottles were labelled with date and time of sample collection. Samples were then placed in Ziplock bags and stored in an ice chest to maintain the field temperature of the sample. Information such well name, well number, site, date of sample collection and exposure period. The collected samples were immediately transported to Nuclear Track Detection Laboratory (NTD) of National Nuclear Research Institute (NNRI).

A calibrated portable continuous radon monitor, RAD7 (Durridge Company, USA) [28] was used for measurements. Figure 3 shows the schematic diagram of the RAD7 setup for radon in water measurements [28].

In the setup, 250-mL sample bottle was connected to RAD-7 detector via bubbling kit and desiccant tube to establish a closed air loop. An internal air pump (with flow rate of about 1 L min$^{-1}$) in the RAD-7 was activated every 5 min for 1 min to purge/degass/aerate and circulate radon present in the water into the closed air loop, so that radon released to air stream can finally enter RAD-7 analyzer after passing through desiccant tube and air filter. An air filter is used at the entrance of the RAD-7 to prevent dust particles and charged ions from entering the radon chamber.

The detection efficiency of the RAD-7 decreases with increase in relative humidity, owing to the neutralization of Po ions by water particles. Hence, RAD H$_2$O requires that the desiccant, anhydrous CaSO$_4$ (which is commercially sold as Passive Drystick (model no. 12) by Durridge Co.), can be used to maintain humidity at level lower than 6%–10% in the radon chamber and also to dry the air stream before it enters the RAD-7 detector.

To ensure the quality control and reliability of the sampling and measurement methods, each sample was analyzed in 4cycles of 5 min each, with an initial aeration time of 5 min.

Initially, the pump runs for 5 min, aerating the sample and delivering the radon to the RAD-7. The system will wait a further 5 min and then it starts counting. During the 5 min of aeration, more than 95% of the available

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Figure 1. Map of Ghana showing Offinso Municipality [29].
Figure 2. Map of Ghana showing Obuasi study area. Reprinted from [30], with permission from authors.

Figure 3. A schematic diagram of the RAD7. With permission from the Durridge Company, Inc [28].
The start

From the tables 1 and 2, $^{222}$Rn concentration in groundwater varied from 0.04 Bq l$^{-1}$ to 8 SvBq l$^{-1}$. Annual effective dose due to ingestion for adult, child and infant varied from $0.09 \pm 0.16$ Bq l$^{-1}$ to 8 SvBq l$^{-1}$. UNSCEAR has estimated that the conversion factor for ingestion of radon in water is $10^{-5}$ for an adult, $10^{-4}$ for a child and $7 \times 10^{-4}$ SvBq l$^{-1}$ for an infant [34]. According to UNSCEAR, doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively [35].

Radon decay correction

During the radon in water analysis or if a sample is taken and analyzed some time later (rather than immediately), the sample’s radon concentration will decline due to the radioactive decay. Hence, it is essential that the resulting activity concentrations were decay-corrected back from the time the sample was drawn (time of sampling) to the time the sample was counted. The decay correction is a simple exponential function with a time constant of 132.4 h. The time elapsed for the sample collection and analysis will be corrected using the equation

$$C = C_0 e^{-\lambda t}$$

de where $C$ = measured concentration,

$C_0$ = initial concentration (to be calculated after the decay correction),

t = time elapsed since collection (days).

Usually decay correction is required to correct the radon result back to the sampling time. However, in the present study, the collected samples were immediately analyzed after the collection without any delay and hence decay correction was not calculated.

Annual effective dose calculation, ingestion ($H_{ing}$) and inhalation ($H_{inh}$)

The annual effective dose due to the ingestion of radon from groundwater ($H_{ing}$), was calculated according to equation (1) [32, 33]:

$$H_{ing}(mSv/yr) = C_{Rn} \times D_{ing} \times L$$

(1)

Where

$H_{ing}$—committed effective dose, mSv$^{-1}$

$C_{Rn}$—radon concentration in water, Bq$^{-1}$

$D_{ing}$—conversion factor, $1 \times 10^{-8}$ SvBq$^{-1}$

L—is annual water consumption by an adult in liters.

The daily water consumption by an adult of 2 l (730 litres per year) was used [34]. The conversion factor for ingestion of radon in water is $10^{-8}$ SvBq$^{-1}$ for an adult, $2 \times 10^{-8}$ SvBq$^{-1}$ for a child and $7 \times 10^{-8}$ SvBq$^{-1}$ for an infant [34].

The annual effective dose due to the inhalation of radon ($H_{inh}$), resulting from the radon concentration in drinking water, was calculated using the following relation by [25, 36]

$$H_{inh}(nSv/yr) = C_{Rn} \times R \times F \times T \times D$$

(2)

Where

$C_{Rn}$—radon concentration in water, in Bq$^{-1}$

R—air to water concentration ($10^{-4}$),

F—Equilibrium factor between indoor radon and its progeny (0.4),

T—Exposure time in hours ($8670$ h$^{-1}$),

D—Dose conversion factor 9 nSv (Bq$^{-1}$ m$^{-3}$)$^{-1}$ [35].

Results and discussion

From the tables 1 and 2, $^{222}$Rn concentration in groundwater varied from 0.04 Bq l$^{-1}$ to 0.16 Bq l$^{-1}$ and a mean of $0.09 \pm 0.01$ Bq l$^{-1}$. Annual effective dose due to ingestion for adult, child and infant varied from $0.28 \mu$Sv yr$^{-1}$ to $1.14 \mu$Sv yr$^{-1}$, $0.57 \mu$Sv yr$^{-1}$ to $2.28 \mu$Sv yr$^{-1}$ and $1.98 \mu$Sv yr$^{-1}$ to $7.92 \mu$Sv yr$^{-1}$ respectively with a mean of $0.64 \pm 0.11 \mu$Sv yr$^{-1}$, $1.28 \pm 0.21 \mu$Sv yr$^{-1}$ and $4.46 \pm 0.73 \mu$Sv yr$^{-1}$ respectively. The annual
The annual effective dose due to inhalation varied from 0.12 mSv yr\(^{-1}\) to 0.45 mSv yr\(^{-1}\) with a mean of 0.28 ± 0.05 mSv yr\(^{-1}\) for the dry season.

In the rainy season, \(^{222}\text{Rn}\) concentration in groundwater varied from 0.03 Bq l\(^{-1}\) to 0.13 Bq l\(^{-1}\) with a mean of 0.08 ± 0.01 Bq l\(^{-1}\) the annual effective dose due to ingestion for adult, child and infant varied from 0.22 μSv yr\(^{-1}\) to 0.96 μSv yr\(^{-1}\), 0.44 μSv yr\(^{-1}\) to 1.91 μSv yr\(^{-1}\), 1.53 μSv yr\(^{-1}\) to 6.69 μSv yr\(^{-1}\) respectively with a mean of 0.56 ± 0.09 μSv yr\(^{-1}\), 1.13 ± 0.18 μSv yr\(^{-1}\), 3.94 ± 0.62 μSv yr\(^{-1}\) respectively. The annual effective dose due to inhalation varied from 0.09 μSv yr\(^{-1}\) to 0.41 μSv yr\(^{-1}\) with a mean of 0.24 ± 0.04 μSv yr\(^{-1}\) for the Obuasi municipality.

Descriptive statistics of \(^{222}\text{Rn}\) concentrations, the annual effective dose due to ingestion (\(H_{\text{ing}}\)) and inhalation (\(H_{\text{inh}}\)) of radon in groundwater in the dry and rainy seasons are shown in tables 1 and 2 for Obuasi and tables 2 and 3 for Offinso.

From tables 3 and 4, \(^{222}\text{Rn}\) concentration in groundwater varied from 0.04 Bq l\(^{-1}\) to 0.47 Bq l\(^{-1}\) with a mean of 0.14 ± 0.05 Bq l\(^{-1}\), the annual effective dose due to ingestion for adult, child and infant varied from 0.28 μSv yr\(^{-1}\) to 3.42 μSv yr\(^{-1}\), 0.56 μSv yr\(^{-1}\) to 6.83 μSv yr\(^{-1}\), and 1.97 μSv yr\(^{-1}\) to 23.91 μSv yr\(^{-1}\) respectively with a mean of 1.03 ± 0.37 μSv yr\(^{-1}\), 2.06 ± 0.74 μSv yr\(^{-1}\), and 7.20 ± 0.74 μSv yr\(^{-1}\) respectively. The annual inhalation dose varied from 0.12 mSv yr\(^{-1}\) to 1.48 mSv yr\(^{-1}\) and a mean of 0.46 ± 0.16 mSv yr\(^{-1}\) for the dry season.
222Rn concentration in groundwater in the rainy season varied from 0.04 Bq l\(^{-1}\) to 0.40 Bq l\(^{-1}\) with a mean of 0.13 ± 0.04 Bq l\(^{-1}\). The annual effective dose due to ingestion for adult, child and infant varied from 0.28 μSv yr\(^{-1}\) to 2.91 μSv yr\(^{-1}\), 0.55 μSv yr\(^{-1}\) to 5.81 μSv yr\(^{-1}\), and 1.94 μSv yr\(^{-1}\) to 20.34 μSv yr\(^{-1}\) respectively and a mean of 1.26 ± 0.31 μSv yr\(^{-1}\), 1.89 ± 0.61 μSv yr\(^{-1}\) and 6.62 ± 2.15 μSv yr\(^{-1}\) respectively. The annual effective dose due to inhalation varied from 10.12 mSv yr\(^{-1}\) to 1.26 mSv yr\(^{-1}\) and a mean of 0.41 ± 0.13 mSv yr\(^{-1}\).

The seasonal average for RAD7 was 0.08 ± 0.01 Bq l\(^{-1}\) and 0.14 ± 0.05 Bq l\(^{-1}\) respectively for Obuasi and Offinso.

The reason for this low level is in the groundwater is attributed to the fact that, radon gas is easily released by the agitation in groundwater. Boreholes in the sampled areas had handheld pumps that were used to pump the water into a sampling bucket before sample bottles were filled. Through this process, part of the radon gas de-emanates during the flow of water from its source to the sampling bucket. Comparatively radon concentrations in groundwater for Offinso was higher than Obuasi for the two seasons. This high concentrations in Offinso as compared to Obuasi is due to the geology of the area which has granitic underlying rocks mainly granite as these types of rocks has appreciable amount of uranium as compared to the underlying rocks in Obuasi which is Birimian and has low amount of uranium [37]. Also, the geological structure, porosity of the soil, meteorological parameters can also be a contributory factor.

### Table 3.
A table showing 222Rn concentrations, the annual effective dose due to ingestion (H\(_{ing}\)) and inhalation (H\(_{inh}\)) of radon in ground water in the Offinso Municipality during the dry season using RAD7.

| Sampling location | Radon concentration in Bq l\(^{-1}\) | H\(_{ing}\) (μSv/yr) | H\(_{inh}\) (mSv/yr) |
|-------------------|------------------------------------|----------------------|---------------------|
|                   | Adults | Child | Infant | Adults | Child | Infant | Adults | Child | Infant |
| BS 1              | 0.16   | 1.14  | 2.28   | 7.97   | 0.49  |
| BS2               | 0.47   | 3.42  | 6.83   | 23.91  | 1.48  |
| D1                | 0.15   | 1.12  | 2.25   | 7.86   | 0.49  |
| D2                | 0.04   | 0.28  | 0.57   | 1.98   | 0.12  |
| AN1               | 0.08   | 0.57  | 1.14   | 3.99   | 0.25  |
| AN2               | 0.04   | 0.28  | 0.57   | 1.99   | 0.12  |
| ANT1              | 0.16   | 1.13  | 2.263  | 7.92   | 0.49  |
| ANT2              | 0.04   | 0.28  | 0.56   | 1.97   | 0.12  |
| AM                | 0.14   | 1.03  | 2.06   | 7.20   | 0.46  |
| GM                | 0.10   | 0.71  | 1.42   | 4.97   | 0.31  |
| Min               | 0.04   | 0.28  | 0.56   | 1.97   | 0.12  |
| Max               | 0.47   | 3.42  | 6.83   | 23.91  | 1.48  |
| SE                | 0.05   | 0.37  | 0.74   | 2.58   | 0.16  |

GM: Geometric mean, AM: Arithmetic Mean Min: Minimum, Max: Maximum, SE: Standard Error, BS: Bonsua, D: Dome, AN-Anyankaso, ANT: Antoa.

### Table 4.
A table showing 222Rn concentrations, the annual effective dose due to ingestion (H\(_{ing}\)) and inhalation (H\(_{inh}\)) of radon in ground water in the Offinso Municipality during the rainy season using RAD7.

| Sampling location | Radon concentration in Bq l\(^{-1}\) | H\(_{ing}\) (μSv/yr) | H\(_{inh}\) (mSv/yr) |
|-------------------|------------------------------------|----------------------|---------------------|
|                   | Adults | Child | Infant | Adults | Child | Infant | Adults | Child | Infant |
| BS 1              | 0.15   | 1.06  | 2.12   | 7.41   | 0.46  |
| BS2               | 0.40   | 2.91  | 5.81   | 20.34  | 1.26  |
| D1                | 0.16   | 1.13  | 2.26   | 7.92   | 0.49  |
| D2                | 0.04   | 0.28  | 0.57   | 1.99   | 0.12  |
| AN1               | 0.10   | 0.72  | 1.45   | 5.06   | 0.31  |
| AN2               | 0.04   | 0.28  | 0.57   | 1.99   | 0.12  |
| ANT1              | 0.12   | 0.9   | 1.8    | 6.29   | 0.39  |
| ANT2              | 0.04   | 2.77  | 0.55   | 1.94   | 0.12  |
| AM                | 0.13   | 1.26  | 1.89   | 6.62   | 0.41  |
| GM                | 0.09   | 0.69  | 1.38   | 4.82   | 0.39  |
| Min               | 0.04   | 0.28  | 0.55   | 1.94   | 0.12  |
| Max               | 0.40   | 2.91  | 5.81   | 20.34  | 1.26  |
| SE                | 0.04   | 0.31  | 0.61   | 2.15   | 0.13  |

GM: Geometric mean, Min: Minimum, Max: Maximum, SE: Standard Error, BS: Bonsua, D: Dome, AN: Anyankaso, ANT: Antoa.
From Table 5, a comparison of the radon concentrations obtained in this research with other parts of the world indicates that $^{222}\text{Rn}$ activity concentration of the ground samples were lower. Therefore, radon in groundwater in the selected study area no threat to the lives of the people in this locality.

**Table 5.** Radon concentrations in various types of waters from other countries as compared to present study.

| Country          | Type of water (Bq L$^{-1}$) | Groundwater/well water | Tap water (public water) | Surface water | Rain water | References |
|------------------|-----------------------------|------------------------|--------------------------|---------------|------------|------------|
| China            |                             | 1.45–49.00             | LLD-29.00                |               |            | [27]       |
| Turkey           |                             | 1.42–53.64             | 0.91–12.58               |               |            | [38]       |
| Poland           |                             | 0.42–10.32             | 0.5–129.3                |               |            | [39]       |
| Romania          |                             | 1.5–4.4                | 0.3–129.3                |               |            | [40]       |
| Czech Republic   |                             |                        |                          | 0.5–1865      |            | [40]       |
| Japan            |                             | 0.03–29 500            | 0.07–157                 |               |            | [40]       |
| Sweden           |                             | 1–947                  | 1–845                    |               |            | [40]       |
|                  |                             | 0–9289                 |                          |               |            |            |
| Palestine        |                             | 0.42–0.89              | 0.25–1.23                | 0.46–1.14     | 0.26–1.51  | [40]       |
| Nigeria          |                             | 1.67–49.47             | 2.1                      |               |            | [41]       |
| India            |                             | 0.9–5.1                | 1.6                      |               |            | [7]        |
| Pakistan         |                             | 3.56–8.56              |                          |               |            | [42]       |
| Malaysia         |                             | 9.3                    |                          |               |            | [43]       |
| Ghana            |                             | 2.15–28.70             |                          |               |            | [44]       |
| Ghana            |                             | 5.40–46.7              |                          |               |            | [45]       |
| Present Work     |                             | 0.04–0.16e             |                          |               |            | Present study |
|                  |                             | 0.03–0.13f             |                          |               |            |            |
|                  |                             | 0.04–0.47g             |                          |               |            |            |
|                  |                             | 0.04–0.40h             |                          |               |            |            |

* a hand dug well.
* b drilled well.
* c Temperature of water at 5 °C.
* d Temperature of water at 15 °C.
* e Obuasi Dry season RAD7.
* f Obuasi rainy season RAD7.
* g Ofinso dry season RAD7.
* h Ofinso Rainy Season RAD7.

From Table 5, a comparison of the radon concentrations obtained in this research with other parts of the world indicates that $^{222}\text{Rn}$ activity concentration of the ground samples were lower. Therefore, radon in groundwater in the selected study area no threat to the lives of the people in this locality.

**Conclusions**

$^{222}\text{Rn}$ concentrations in groundwater from Obuasi Municipality was lower than Offinso Municipality for both seasons. $^{222}\text{Rn}$ concentrations in groundwater from the two municipalities were below the permissible value of 11 Bq L$^{-1}$ recommended by the USEPA and 100 Bq L$^{-1}$ recommended by the European Union and World Health Organization (WHO). The mean annual effective dose due to ingestion of $^{222}\text{Rn}$ in groundwater for infants and children were higher than adults. The annual effective dose due to inhalation of radon in groundwater was one order higher than radon from ingestion of groundwater. Therefore, it could be concluded that it is not the ingestion of radon in groundwater but inhalation of the radon escaping from groundwater which is a substantial part of radiological hazard due to the presence of the natural radionuclides from the uranium and thorium series in the groundwater. Although the mean values obtained from both municipalities were lower than the recommended value of 1 mSv$^{-1}$ (Villalba et al 2005), Bonsua in the Offinso Municipality had values of 1.48 mSv$^{-1}$ and 1.26 mSv$^{-1}$ for RAD7 in the dry and rainy season respectively.

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