Risk assessment of radon in some bottled water on the Ghanaian market

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Abstract

The demand for bottled drinking water on the Ghanaian market has increased despite being expensive. This can be attributed to the public perception that is of higher quality relative to other water sources. Risk assessment of radon in some bottled water on the Ghanaian market has increased despite being expensive. This can be attributed to the public perception that is of higher quality relative to other water sources.

1. Introduction

$^{222}$Rn is a natural radionuclide with a half-life of 3.8 days. It is colorless, tasteless, inert and odorless. $^{222}$Rn and its daughters, Po-214 and Po-218 are among the main and final products of the decay of Uranium 238 ($^{238}$U) chain, which can spread out of different sources such as surface and groundwater water, soil, igneous or sedimentary rocks [1, 2]. $^{222}$Rn has a half-life of 3.82 days and it is the most stable and abundant isotope of radon in nature. It decays by emitting an (α) particle of energy 5.49 MeV [3]. The World Health Organisation (WHO) recommended daily fluid intake, including moisture from food, for an average adult is approximately two liters (2 l) [4]. Naturally sourced bottled waters are by far the most popular choice for the middle and high class in Ghana [5]. The bottled water industry in Ghana is huge. Brands are springing up all over the place and the public is accepting the product in good faith obviously believing that what they are getting is better than pipe-borne water [5]. Groundwater which is the major source of water for bottled drinking waters is often assumed to be good for consumption once the water is clean, tastes and smells good. 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 [1, 6, 7].

Consuming waters which contain high concentrations of $^{222}$Rn would raise the effective dose received and the risk to lung and gastric cancer [8]. The World Health Organization (WHO) guidance level for $^{222}$Rn drinking water is 100 Bq l$^{-1}$ [9]. In the United States, Environmental Protection Agency’s (EPA) standard is 11 Bq l$^{-1}$ [10]. WHO and the European Committee have proposed the annually received effective dose of $^{222}$Rn to be 0.1 mSv y$^{-1}$ [6].

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If groundwater is used as drinking water, the radon content in the water must be considered. The two diseases of principal concern associated with radon are stomach cancer from ingestion and lung cancer from inhalation [11–14]. Countries like Denmark, Finland, Germany, Greece, Ireland, Sweden and the Czech Republic have national reference levels for radon in drinking water. Reference levels are in the range 20 to 100 Bq l$^{-1}$ which is in broad agreement with EU recommendations on the protection of the public against exposure to radon in drinking water supplies [15]. The Italian National Health Council has proposed a reference level of 100 Bq l$^{-1}$ be set for mineral water and that infants should not consume mineral water containing radon with a concentration above 32 Bq l$^{-1}$ [15]. Ghana as a country is yet to set a national reference level for water.

Drinking water has great importance in our food. Therefore, its availability, quality and regulation are important [16]. There is no knowledge about the radon content of bottled drinking water in Ghana. Several researchers have reported on radon concentrations in groundwater in Ghana [17–19] but none on bottled drinking water.

The aim of this research work is to presents the variation in radon concentration in 15 bottled water samples which popular on the Ghanaian market and estimate the associated effective dose received from by various age groups from ingestion compared with standard limits and bring awareness to policy makers and the populace about the health effects due to ingestion of radon dissolved in bottled drinking water.

1.1. Study area
The Greater Accra Region is the smallest of the 10 administrative regions in terms of area, occupying a total land surface of 3245 square kilometres or 1.4 per cent of the total land area of Ghana. Figure 1 shows the study area on
the Ghana map. In terms of population, however, it is the second most populated region, after the Ashanti Region, with a population of 4010 054 in 2010, accounting for 15.4 per cent of Ghana’s total population [21].

About two-thirds of Ghana is dominated by Paleoproterozoic Birimian rocks consisting of five evenly spaced volcanic belts trending northeast-southwest. The intervening basins between the volcanic belts are filled by sediments. The remaining one-third is made up of post-Birimian rock [22]. The supra-crustal rocks are highly deformed. However, the sedimentary rocks are particularly characterized by extensive folding. The lavas are mainly of basaltic composition, though andesitic, dacitic and rhyolitic rocks are also present. Some pattern of facies distribution is shown by the Birimian sedimentary basins from the margins towards the basin centres. The transition zone between the volcanic belts and the sedimentary basins is marked by chemical facies, which has of late been found to be the site of much of gold mineralization in Ghana [22].

2. Materials and method

2.1. Sampling

15 popularly known bottled drinking water was randomly selected from the market and/or stores in the Greater Accra region in July 2016 and given codes. Samples were collected in duplicates of 500 ml bottles. Considering the effect of temperature on the radiation of $^{222}\text{Rn}$, the samples were stored in thermos container to keep the temperature constant enroute to the Nuclear track Detection Laboratory of the National Nuclear Research Institute (NNRI), Ghana Atomic Energy (GAEC) for analysis. Samples were analysed immediately upon arrival to the laboratory using RAD–H$_2$O [23] as shown in figures 2–4. The RAD-7 has been factory calibrated by Durridge Company, USA [23].

2.2. Radon in water measurements

The RAD H$_2$O method employs a closed loop aeration scheme where the air volume and water volume are constant and independent of the flow rate. The operation of this device is based on principles such as (1) radon is ejected from a water sample using a bubbling kit, (2) ejected radon enters a hemisphere chamber by air circulation, (3) polonium decayed from radon is collected onto a silicon solid-state detector in a high electric field, and (4) concentration of radon in water sample is estimated from the count rate of polonium [23].

For the setup 250-ml sample bottle was connected to RAD-7 detector via bubbling kit and desiccant tube to establish a closed air loop (figure 3). 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 (figures 2–4) and circulate radon present in the water into the closed air loop, so that radon released to air stream can finally enter RAD-7 to be counted. For 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. During the 5 min of aeration (figure 4), about 95% of radon is
removed from the water and the radon concentration in the water automatically determined by the RAD-7. At the end of the run, a summary is printed out, showing the average radon reading from the four cycles counted, a bar chart of the four readings, and a cumulative spectrum. This procedure considers the calibration of the RAD-7, the size of the sample vial, time of the analysis and the total volume of the closed air loop, as seen in set up (figure 2).

2.3. Annual effective dose
The annual effective dose, $H_{\text{ing}}$ due to the ingestion of radon from water, was calculated according to equation (1)\textsuperscript{[24,25]}

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

Where

- $H_{\text{ing}}$: committed effective dose, mSv$^{-1}$
- $C_{\text{Rn}}$: radon concentration in water, Bq$^{-1}$
- $D_{\text{ing}}$: conversion factor, $1 \times 10^{-8}$ SvBq$^{-1}$
- $L$: annual water consumption by an adult in liters.

The daily water consumption by an adult of 2 litres (730 litres per year) was used.\textsuperscript{[26]} UNSCEAR has estimated that 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\textsuperscript{[26]}. According to UNSCEAR, doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively\textsuperscript{[27]}.

3. Results and discussion
Radon concentration measurements have been measured in fifteen (15) popular bottled drinking water samples from Greater Accra Region, Ghana, using RAD7 detector. Currently, the 222Rn concentration in drinking water is not regulated in Ghana. The United States Environmental Protection Agency (USEPA) proposes a maximum contaminant level (MCL) of 11.1 Bq l$^{-1}$ for radon in drinking water\textsuperscript{[28]}. The European Union (EU) Commission non-binding recommendation in 2001 on the protection of the public against exposure to radon in drinking water supplies\textsuperscript{[29]} is 100 Bq l$^{-1}$ for public or commercial drinking water supplies and 1000 Bq l$^{-1}$ for individual or private water supplies. World Health Organization (WHO) has recommended a treatment level of 100 Bq l$^{-1}$ for radon in drinking water supplies\textsuperscript{[30]}.

3.1. Evaluation of radon concentration
Table 1 represents the radon concentration levels along with their respective annual effective dose exposure for the various ages. The range and mean radon concentration of 222Rn in all samples were 0.026–0.093 Bq l$^{-1}$ and

\begin{table}[h]
\centering
\begin{tabular}{|c|c|c|c|c|c|}
\hline
Sample id & Relative humidity & Radon concentration Bq l$^{-1}$ & Adults & Children & Infants \\
\hline
1 & 0.08 & 0.05 & 3.29E-01 & 6.57E-01 & 2.30 \\
2 & 0.1 & 0.03 & 2.48E-01 & 4.96E-01 & 1.74 \\
3 & 0.09 & 0.07 & 4.89E-01 & 9.78E-01 & 3.42 \\
4 & 0.11 & 0.06 & 4.31E-01 & 8.61E-01 & 3.01 \\
5 & 0.07 & 0.05 & 3.58E-01 & 7.15E-01 & 2.50 \\
6 & 0.10 & 0.09 & 6.50E-01 & 1.30 & 4.55 \\
7 & 0.07 & 0.08 & 6.06E-01 & 1.21 & 4.24 \\
8 & 0.08 & 0.06 & 4.53E-01 & 9.05E-01 & 3.17 \\
9 & 0.08 & 0.09 & 6.35E-01 & 1.27 & 4.45 \\
10 & 0.10 & 0.09 & 6.57E-01 & 1.31 & 4.60 \\
11 & 0.10 & 0.04 & 3.21E-01 & 6.42E-01 & 2.25 \\
12 & 0.07 & 0.07 & 4.75E-01 & 9.49E-01 & 3.32 \\
13 & 0.07 & 0.06 & 4.53E-01 & 9.05E-01 & 3.17 \\
14 & 0.11 & 0.07 & 4.89E-01 & 9.78E-01 & 3.42 \\
15 & 0.08 & 0.09 & 6.79E-01 & 1.36 & 4.75 \\
16 & 0.10 & 0.03 & 1.90E-01 & 3.80E-01 & 1.33 \\
\hline
MEAN & 0.06 & 4.66E-01 & 9.33E-01 & 3.26 \\
\hline
STANDARD ERROR & 0.01 & 3.77E-02 & 7.55E-02 & 2.64E-01 \\
\hline
SKEWNESS & -0.18 & -1.82E-01 & -1.82E-01 & -1.82E-01 \\
\hline
KURTOSIS & -0.88 & -8.80E-01 & -8.80E-01 & -8.80E-01 \\
\hline
\end{tabular}
\caption{A table showing the various radon concentrations in bottled water and them corresponding annual effective dose to Adults, Children and infants.}
\end{table}
0.064 ± 0.005 Bq\ l^{-1} Bq\ l^{-1} respectively. The concentration of $^{222}$Rn difference could be due to differing water source, temperature, production process and storage time.

From table 1, it was observed that the radon concentration in the various bottled water samples are well below the allowed 11 Bq\ l^{-1} MCL proposed by USEPA [28] and 100 Bq\ l^{-1} recommended by WHO and the EU on the protection of the public against exposure to radon in drinking water supplies.

### 3.2. Evaluation of annual effective dose

The annual effective dose due to ingestion in the various age groups had a range and mean of 6.79E-01-1.90E-01 μSv\ yr^{-1} and 4.66E-01 ± 3.77E-02 μSv\ yr^{-1} for adults, 3.80E-01-1.36 E-01 μSv\ yr^{-1} and 9.33E-01 ± 7.55E-02 μSv\ yr^{-1} for children and 1.33-4.75 μSv\ yr^{-1} and 3.26 μSv\ yr^{-1} ± 2.64E-01 for infants. From figure 5, the order of the effective dose due to ingestion received by the age groups is infants > children > Adults. The effective dose due to ingestion received from the bottled water in infants and children were 1.43 and 0.50 times bigger than adults respectively. On the average, the effective dose received in both age groups were much lower than the recommended maximum value of 0.1 mSv\ yr^{-1}. [30].

#### Table 2. Radon concentration in various drinking waters from other studies as compared to the present study.

| Water source        | $^{222}$Rn (Bq/l) | Country       | References |
|---------------------|-------------------|---------------|------------|
| Drinking water      | 0.27–5.4          | India         | [31]       |
| Drinking water      | 0.20–1.23         | Palestine     | [29]       |
| Tap water           | 0.91–12.58        | Turkey        | [32]       |
| Bottled water       | 0.91–1.463        | Serbia        | [29]       |
| Tap water           | 3.7               | Iran (Teheran)| [33]       |
| Tap water           | 17.99             | Iran (Neyshabour)| [33]     |
| Tap water           | 16.23             | Iran ( Mashhad)| [33]     |
| Drinking Groundwater| 1.02–7.26        | Libya         | [34]       |
| Tap water           | 3.4               | Iran ( Ramsar)| [33]       |
| Drinking water      | 0.333–0.903       | Pakistan      | [35]       |
| Drinking water      | 0.39–0.47         | Brazil        | [36]       |
| Tap water           | 0.025–0.128       | Iran (Kastamonu)| [37]     |
| Bottled water       | 0.04–0.25         | Iraq          | [38]       |
| Bottled water       | 0.026–0.093       | Ghana         | This study |

![Figure 5. A graph showing the annual effective dose in the different age groups versus Samples.](image-url)
The average radon concentration obtained in the present study is compared with studies from other countries from the literature findings as listed in table 2.

4. Conclusion

The present study showed that the radon concentration in bottled drinking water in the greater Accra region are well within the maximum contaminant level (MCL) value of 11 Bq L⁻¹. The radon concentration measured does not have serious health risks to the public. The annual effective dose varied with respect to the increase in radon concentration and were significantly lower than the UNSCEAR and WHO recommended limit for members of the public of 0.1 mSv y⁻¹. These data must be regarded as preliminary and further extensive studies should be done on large scale by initiating further detailed investigation into other drinking water on the Ghanaian market to increase awareness and mitigate possible hazards. It can be concluded that the radiation dose from radon in the bottled water analysed is low and pose no risk to the public.

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