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Measurement of ^{222}Rn concentration levels in drinking water samples from Qena city (Egypt) and evaluation of the annual effective doses

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ABSTRACT

Background: *Radon is one of the most important radionuclides, formed from the decay of the element radium and more soluble in water. As* drinking water is a vital source of life, control of its quality is critical. Drinking water containing high radon levels presents a serious risk to human health. Thus awareness of radon levels in drinking water is extremely significant to protect against radiation exposure. We measured *^{222}Rn concentrations in different types of drinking water from Qena city, Egypt.* **Materials and Methods:** *111 water samples were collected from various sources in Qena city (77 samples of household tap water, 14 samples of bottled water and 20 samples from municipal public water supply locations). The ^{222}Rn concentrations were determined using an AlphaGUARD radon gas analyzer. We calculated annual effective dose due to ingestion and inhalation of ^{222}Rn present in these waters.* **Results:** *^{222}Rn concentration ranges were as follow: 22.0±0.7 to 118±3 mBq l^{-1}, from tap water 14±3 to 237±5 mBq l^{-1} from bottled water and 6.0±0.5 to 30.0±0.9 mBq l^{-1} from municipal public supplies.* The annual effective dose due to inhalation and ingestion of ^{222}Rn in all types of drinking water measures less than the recommended reference level of 100 µSv y^{-1}. **Conclusion:** *Based on the obtained results, ^{222}Rn concentrations in the studied water samples were less than the permitted concentrations of USEPA and WHO guidelines.*

Keywords: *^{222}Rn, AlphaGUARD, , Annual effective doses, Bottled water, tap water.*

INTRODUCTION

Radon originates from the radioactive decay of naturally-occurring uranium and radium deposits found in trace amounts in soil and rocks. Radon decays through the emission of energetic alpha particles, thus it was classified as a human carcinogen [1]. Radon gas can escape from soil, rocks and dissolve into ground water, which can carry it away from its point of origin. ^{222}Rn is a member of the ^{238}U series as a decay product of ^{226}Ra and is in a gaseous state. ^{222}Rn is colorless, odorless, tasteless, and is a noble gas. Due to these properties, radon is difficult to detect.

Drinking water is one of the most vital sources of life. Thus, its accessibility, purity and control are timely and important issues. Because of this, it is necessary to have rules governing the level of radioactivity in drinking water. The World Health Organization (WHO) and the US Environmental Protection Agency (EPA) have issued regulations applying to drinking water. The standard limit set by World Health Organization for ^{222}Rn in drinking water is 100 Bq l^{-1} [2]. Whereas the standard limit set by the United States Environmental Protection Agency is 11 Bq l^{-1} [3].

The study of the level of ^{222}Rn in drinking water is a higher priority and is given more attention in environmental studies. Many researchers have measured radon in drinking water around the world. Asikainen and Kahlos [4] analyzed concentrations of ^{222}Rn in tap water in Finland and the average concentration was 25 Bq l^{-1}. Duenas *et al.* (5) measured radon in bottled water in Spain and found ^{222}Rn values ranging between 0.22 and 52 Bq l^{-1}. Amrani and Cherouati (6) studied radon levels in the drinking water in Algiers, discovering ^{222}Rn concentrations ranging from 0.26 to 2.28 Bq l^{-1}. Sarrou and Pashalidis (7) measured radon concentrations in tap water in Cyprus, where ^{222}Rn concentrations were in the range 0.1 to 2 Bq l^{-1}. Kralik *et al.* (8) analyzed levels of ^{222}Rn in bottled water in Austria, measuring concentrations ranging from 0.12 Bq l^{-1} to 18 Bq l^{-1}. Marques *et al.* (9) had measurements in the range of 0.34 to 0.47 Bq l^{-1} for ^{222}Rn in tap water in Brazil. Binesh *et al.* (10) studied radon in 50 drinking water samples from different regions of Mashhad, Iran, finding radon concentrations low, below the proposed concentration limit. Malakootian *et al.* (11) analyzed ^{222}Rn concentrations in the drinking water of Taft villages and the Shirkooh area of Iran. The results indicated that 82% of samples from Taft city have radon concentrations below EPA recommended levels. Samples with radon concentrations exceeding the permissible limit were from the Shirkooh area, due to the higher concentration of granite in this area. Ahmad *et al.* (12) surveyed ^{222}Rn concentrations as well as heavy metals in drinking water and irrigated water samples from Kulim, Malaysia. They found that radon concentrations in wells, streams and lakes are higher than recommended levels set by EPA but lower than reference levels set by WHO. Kurnaz and Atlf Çetiner (13) measured radon concentrations in tap water from Kastamoun, Turkey. The results ranged from 0.025±0.006 Bq l^{-1} to 0.128±0.025 Bq l^{-1}, relatively low and less than the international reference level. Rafat Amin (14) recorded values of radon concentrations in drinking water of Murzuq and Sabha districts, southwest Libya. The ^{222}Rn concentrations varied from 1.02 Bq l^{-1} to 7.26 Bq l^{-1}, with an average value of 3.46±1.76 Bq l^{-1}. The variation in radon concentrations was attributed to numerous factors, such as the nature of the rocks in the study area, depths of wells and lengths of storage times of water from wells. Hussein (15) presented radon concentrations in tap water from the western desert, Egypt, and found concentrations in the range 0.04 to 0.48 Bq l^{-1}. The obtained values of radon concentration reflect a very low background radiation locality. Thabayneh Khalil (16) measured ^{222}Rn concentration levels in potable water in the southern area of the West Bank, Palestine and the obtained average ranged from 0.44 Bq l^{-1} to 1.14 Bq l^{-1}. Fakhri *et al.* (17) analyzed ^{222}Rn in bottled water samples in Bandar Abbas City, Iran, and the average value was 0.641±0.009 Bq l^{-1}, less than the standard limits set by WHO and EPA. Malakootian and Nejhad (18) measured radon in drinking water of Bam Village, Iran, and the radon concentrations ranged from 1.2 Bq l^{-1} to 9.88 Bq l^{-1}. High concentrations of radon in water resources of Bam Village were attributed to granitic rocks in the studied area.

In Qena city, the main source of drinking water is tap water (surface water) and due to its hot climate, people widely use bottled water (well water) as a source of drinking water. Therefore, the present research aims to measure ^{222}Rn concentrations in different drinking water sources consumed in Qena City and evaluate the doses in populations due to levels of consumption.

MATERIALS AND METHODS

Water sampling

A total of 111 water samples were collected from various sources of drinking water for radon measurement in Qena City (figure 1), the main city of Qena governorate located in Upper Egypt, approximately 600 km south of Cairo. 77 samples of tap water from Campus University and surrounding areas, 14 famous brands and widely used bottled water and 20 samples from public municipal water supplies (ten samples before the water entered any treatment process and ten samples after treatment) were used for radon measurements in this research. In radon measurement, the sampling technique is the major source of error, so sampling from water sources was done with minimal contact with ambient air and the containers were filled with

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no empty spaces. Due to the short half-life of radon gas, the time difference between the time of collection of samples and the time that measurements were done are taken into consideration.

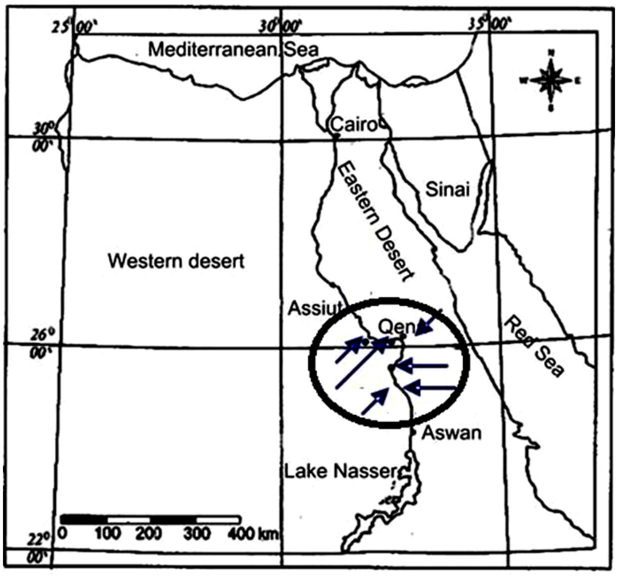

Figure 1. Location of study area.

Experimental techniques

An ionization chamber, the AlphaGUARD PQ2000PRO (GENITRON, Germany) along with additional equipment, AquaKIT, were used for measurement of radon concentrations in water samples. The experimental setup used in the study is shown in figure 2. The measuring system consisted of two vessels (degassing and security vessel), the Alpha Pump, AlphaGUARD, and the progeny filter. The measurement was based on expelled radon from a water sample placed in a degassing vessel by a pump and transferred to the AlphaGUARD radon monitor through a closed gas cycle. The security vessel was connected to the degassing vessel. All droplets would be deposited in the security vessel if they entered the gas cycle during the degassing process. Prior to each measurement, the background of the empty setup was measured for several minutes. About 500 ml of water was slowly injected into the degassing vessel, and the AlphaGUARD and Alpha Pump were switched on with a flow rate of 0.3 l/minute with 10 minutes of flow, so radon concentration was be recorded every minute. The pump was turned off after ten minutes, whereas the AlphaGUARD was kept on for twenty minutes. For heightened accuracy, this round was repeated three times per measurement. The experimental technique was described in detail by Kochowska et al. [19].

Radon concentration in water samples was estimated based on the value recorded by the AlphaGUARD. The value recorded by the AlphaGUARD did not represent the radon concentration in water samples because the radon driven out was diluted in air within measurement setup. Moreover, a small residual amount of the radon remained diluted in the watery phase. Radon concentration in the measured water sample was calculated by the following equation 1 [19].

$$C_{water} = \frac{Cair \times \left(\frac{V_{system} - V_{sample}}{V_{sample}} + K \right) - C_0}{1000} \qquad (1)$$

Where; C_{water} is radon concentration in water sample (Bq l^{-1}), C_{air} the radon concentration in the set-up after expelling radon from water sample (Bq m^{-3}), C_0 the background (Bq m^{-3}), V_{system} the interior volume of the measurement set-up (ml), V_{sample} the volume of the water sample (ml) and K the radon distribution coefficient. The statistical uncertainties were given by 1σ counting. The total uncertainties of the radon determination were calculated as the standard deviation of the equation 1 using Excel software.

Assessment of effective dose

The occurrence of radon in drinking water represents an important issue of dosimetry due to human exposure through inhalation, as radon is released from water to indoor air and through ingestion of radon from direct consumption of drinking water. Therefore, radon in water is a source of radiation exposure to the lungs and the stomach. The annual effective doses to the individual result from inhalation and ingestion were calculated according to parameters presented in WHO [2] and UNSCEAR reports [20, 21] using the following equations 2 and 3.

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$$E^{Rn}_{inh} = C^{Rn}_{W} \times R_W \times F \times T \times D_f \quad (2)$$

Where E^{Rn}_{inh} is the annual effective dose from inhalation of radon released from water into air, C^{Rn}_{W} is the radon concentration in water Bq m^{-3}, R_W is the air/water concentration ratio (equal 10^{-4}), F is the equilibrium factor between indoor radon and its progeny (equal 0.4), T is the exposure time in hours (7000 h y^{-1}) and D_f is the dose conversion factor 9 nSv (Bqhm^{-3})$^{-1}$.

$$E^{Rn}_{ing} = C^{Rn}_{W} \times I_a \times D_f \quad (2)$$

Where; E^{Rn}_{ing} is the annual effective dose from ingestion of radon in drinking water, C^{Rn}_{W} is the radon concentration in water Bq l^{-1}, I_a is the water consumption rate ly^{-1} and D_f is the ingestion dose conversion factor Sv Bq^{-1}. Doses were estimated by considering a daily water consumption rate by an adult as 2 l (730 l y^{-1}) [2], and the dose conversion factor as 10^{-8}, 2×10^{-8} and 7×10^{-8} (Sv/Bq) for adults, children and infants, respectively [20]. According to the UNSCEAR (2000) report [21], doses to children and infants for similar consumption rates could be a factor of 2 and 7 higher, respectively.

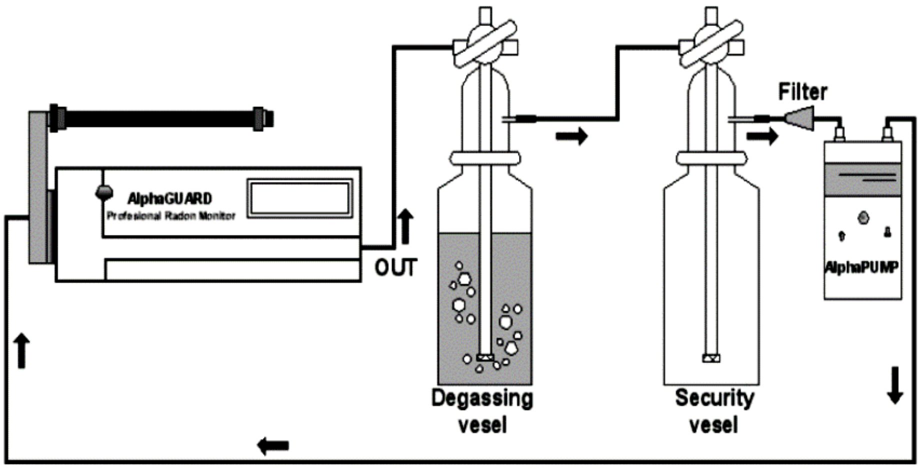

Figure 2. measurement system.

RESULTS

^{222}Rn activity concentrations in investigated drinking water samples and the annual effective doses due to inhalation and ingestion are presented in table 1. The values of ^{222}Rn concentration in tap water ranged from 22.0±0.7 to 118±3 mBql^{-1} with an average value of 49.0±2.5 mBql^{-1}. In bottled water samples, ^{222}Rn concentration varied from 14±3 mBql^{-1} in Dasani to 237±5 mBql^{-1} in Nestle with an average value of 77±2 mBql^{-1}. ^{222}Rn concentrations in water samples collected from municipal public water supplies before any treatment process was in the range from 14.0±0.6 mBql^{-1} to 30.0±0.9 mBql^{-1} with an average value of 22.0±0.7 mBql^{-1}. The concentration after the treatment process was from 6.0±0.5 to 18.0±0.7 mBql^{-1} with an average value of 11.0±0.6 mBql^{-1}. The annual effective dose due to ingestion of ^{222}Rn in tap water was in the range of 0.16 to 0.86 μSv y^{-1}, 0.32 to 1.72 μSv y^{-1}and 1.12 to 6.03 μSv y^{-1} for adults, children and infants, respectively. Whereas the resulting dose from inhalation ranged from 0.06 to 0.3 μSv y^{-1}. In bottled water, the annual dose due to ingestion ranged from 0.10 to1.73 μSv y^{-1}, 0.20 to 3.46 μSv y^{-1} and from 0.72 to 12.11 μSv y^{-1} for adults, children and infants, respectively. The inhalation dose was from 0.04 to 0.60 μSv y^{-1}.

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Table 1. ^{222}Rn (mBq l^{-1}) concentration and annual effective dose due to ingestion and inhalation of radon in different types of drinking water from Qena city (Egypt).

Water type	No. of samples	^{222}Rn mBql^{-1}		E^{Rn}_{ing} µSvy^{-1}			E^{Rn}_{inh} µSvy^{-1}	
		Min	Max	Adult	Children	Infants	Min	Max
Tap water	77	22.0±0.7	118.0±3.0	0.16-0.86	0.32-1.72	1.12-6.03	0.06	0.30
Bottled water	14	14.0±3.0	237.0±5.0	0.10-1.73	0.20-3.46	0.72-12.11	0.04	0.60
public supply municipality^{b}	10	14.0±0.6	30.0±0.9	0.10-0.22	0.20-0.44	0.72-1.53	0.04	0.08
public supply municipality^{a}	10	6.0±0.5	18.0±0.7	0.04-0.13	0.09-0.26	0.31-0.92	0.02	0.05

a,b (after and before water enters any treatment process in the public supply municipality)

DISCUSSION

In general, the range of ^{222}Rn concentration was low, with highest values related to bottled water samples and minimum values related to samples from municipal public water supplies. This is attributed to the source of drinking water; the source for bottled water was groundwater wells and surface water for tap water and water from municipal public water supplies (Nile water). It was found that 29.9% of tap water samples had ^{222}Rn activity concentrations in the range of 22 to <50 mBql^{-1}, whereas 67.5% was in the range of 50 to 100 mBql^{-1}, and 2.6% more than 100 mBql^{-1}. Low level of radon in tap water is due to the source of tap water in Qena City being surface water (Nile River), so most radon in the water has been released into the air.

As shown in figure 3, radon concentration in bottled water had a wide range. This divergence in concentration of ^{222}Rn in bottled water samples may be due to different origins of bottled water from groundwater wells or natural springs in different locations in Egypt. Also, the difference in production processes from brand to another may also contribute to this divergence.

Based on the results of radon concentrations for samples from municipal public water supplies before and after treatment, we can conclude that the treatment process used in municipal public water supplies resulted in 50% of radon removal.

Achieved values of ^{222}Rn in all studied drinking water samples were less than the standards set by WHO and USEPA (100 Bq l^{-1} and 11 Bq l^{-1}, respectively) [2,3]. A comparison with measurements of ^{222}Rn concentrations in drinking water from different countries is given in table 2. It is evident that the range of concentrations of ^{222}Rn in the studied drinking water samples from Qena City is lower than other countries.

From dose calculations, it's evident that the annual effective dose is less than the recommended reference level of 100 µSv y^{-1} [2]. Therefore, the contributions to dose levels from ^{222}Rn due to the intake of drinking water in Qena City can be considered negligible.

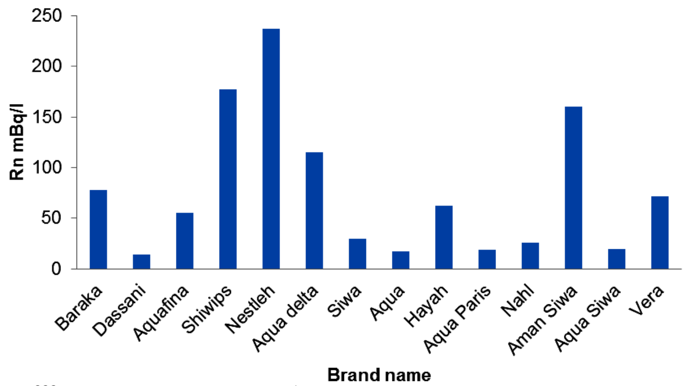

Figure 3. ^{222}Rn concentration mBq l^{-1} in famous brands of bottled water in Qena city.

Table 2. Comparison of ^{222}Rn (Bq l^{-1}) concentrations in our study with pervious measurements from different countries.

Water type	^{222}Rn (mBq l^{-1})	Country Reference
Tap water	260-2280	Algeria[6]
	100-2000	Cyprus[7]
	390-470	Brazil[9]
	25-128	Kastamoun (Turkey) [13]
	40-480	Western desert (Egypt)[15]
	600	Palestine([16]
	22.0±0.7-118.0±3.0	Qena[This study]
Bottled water	5560- 14870	(Saudi Arabia) Jeddah[22]
	2600- 14000	Algeria[23]
	120- 18000	Austria[8]
	30- 430	Turkey (Marmara)[24]
	35-248	Iraq[25]
	440-1140	Palestine[16]
	0-900	Iran (Bandar Abbs) [17]
	14.0±3.0-237.0±5.0	Qena city (Egypt) [This study]

CONCLUSION

111 drinking water samples from different sources (tap water, bottled water and municipal public water supplies) at Qena City, Egypt, were measured for ^{222}Rn concentration. The range of ^{222}Rn concentration in all samples was low with the highest in bottled water and lowest in water from municipal public water supplies. The obtained results well indicate that ^{222}Rn concentrations in all measured samples are low and below the proposed concentration limit. From a radiological point of view, dose calculations show that the analyzed water poses no health hazards to the affected populations.

***Conflicts of interest**: Declared none.*

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