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Radon in harvested rainwater at the household level, Palestine

Issam A. Al-Khatib [a,*], Hamzeh Al Zabadi [b], Ghassan Saffarini [c]

[a] Institute of Environmental and Water Studies, Birzeit University, P.O. Box 14, Birzeit, West Bank, Palestine
[b] Public Health Department, Faculty of Medicine and Health Sciences, An-Najah National University, Nablus, Palestine
[c] Radiation Physics Laboratory, An-Najah National University, Nablus, Palestine

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ABSTRACT

The main objective of this study was to assess Radon concentration in the harvested rainwater (HRW) at the household level in Yatta area, Palestine. HRW is mainly used for drinking as it is the major source of water for domestic uses due to water scarcity. Ninety HRW samples from the household cisterns were collected from six localities (a town and five villages) and Radon concentrations were measured. The samples were randomly collected from different households to represent the Yatta area. Fifteen samples were collected from each locality at the same day. RAD7 device was used for analysis and each sample was measured in duplicate. Radon concentrations ranged from 0.037 to 0.26 Bq/L with a mean ± standard deviation of 0.14 ± 0.06 Bq/L. The estimated annual effective radiation doses for babies, children and adults were all far below the maximum limit of 5 mSvy^{-1} set by the National Council on Radiation Protection and Measurements.

1. Introduction

Many localities in Palestine suffer from water shortage due to regular failures of the water supply systems and insufficient supplied water, mainly during the summer season, further restricted by the Israeli control on the main water sources. Therefore, the use of rainwater harvesting (RWH), water tankers and water from supply networks are commonly practiced in the West Bank of Palestine, mainly in Hebron district in the southern part (Lange et al., 2012). Almost all of households of Hebron district have their own reinforced concrete cisterns to collect rainwater from the roofs of their houses during the rainy season to use it during the dry seasons (Al-Salaymeh et al., 2011).

Yatta has been connected to a water network since 1974, serving nearly 85% of the households. The water network is old and inadequate to meet current population needs. Despite the annual maintenance of the water network, the major problems are water losses due to deficiencies in the network, reduction of pumped water from the source, and the uneven distribution within the network which does not satisfy the population's needs. About 25–30% of the town's neighborhoods are not connected to the municipal water network, which creates a large demand on water distribution tankers. The tankers provide water with a lower quality than that of municipal water while costs reach up to 400% of the price of municipal water. As a result, people tend to depend on rainwater harvesting (RWH) cisterns, and almost all households in Yatta area have between 1 and 4 RWH cisterns as water quantities from the network is estimated to be around 20 L per capita per day (Al-Batsh, 2016). It is worth mentioning that the harvested rainwater in Yatta area is used mainly for drinking, in addition to other domestic uses.

The decay of ^{238}U results in the production of gaseous radon (^{222}Rn) which is soluble in water. Water supply behaves as a vector for the entrance of radon to homes. This helps to increase the concentration of radon, especially in enclosed places, especially during the cold seasons. So radon emitted from the water to indoor air constitutes an important and effective source of exposure to internal radiation (Nevinsky et al., 2015). Typically radon enters the human body through inhalation of air from the closed areas or drinking water (Mittal et al., 2016). This accounts for around 50% of all radiation of exposure (ICRP , 1993). The radon gas itself does not constitute a health concern, but its decay products include short-lived daughter α emitters (Cross et al., 1985). A large amount of energy is discharged in connection with α-particle emission. This energy and α- particles have propensity to destroy tissue and has a long term effect on the DNA, becoming a significant role in the end in the incidence of gastric cancer and lung cancer (USEPA, 1991; Ravikumar and Somashekar, 2014; Todorovic et al., 2012;

* Corresponding author.
E-mail address: ikhatib@birzeit.edu (I.A. Al-Khatib).

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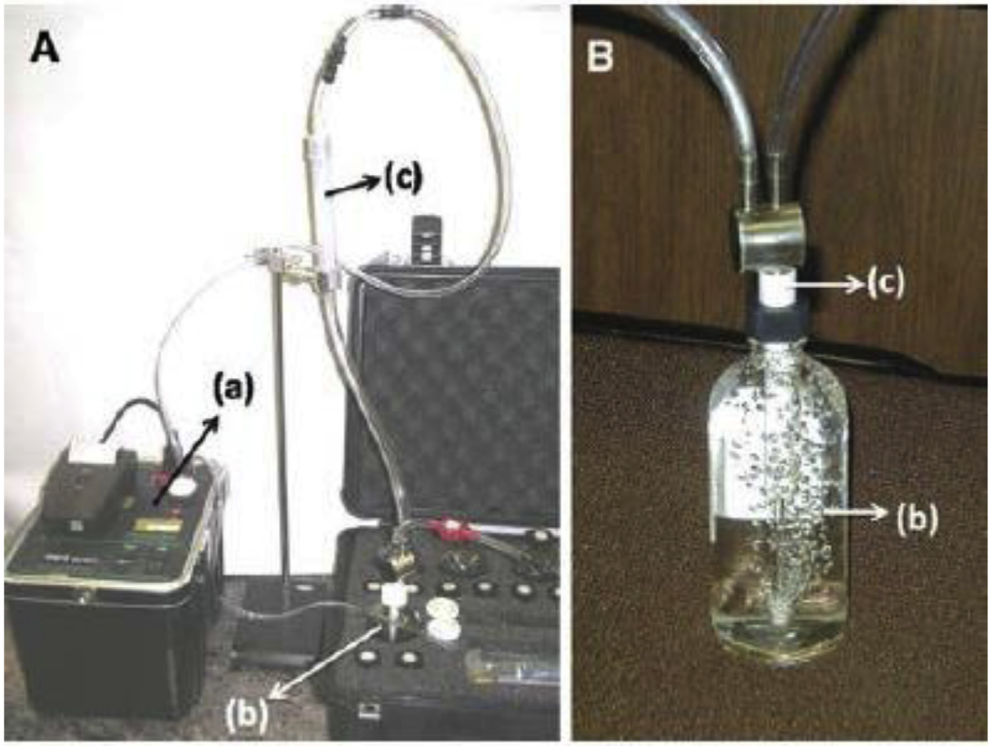

Fig. 1. Radon-in-air monitor RAD-7. Adapted from reference (DURRIDGE Company Inc., 2015) with permission.

Fonollosa et al., 2016).

In a study conducted in Calcutta, India, it was noted that the maximum radon activity could be associated with scant and isolated rainfalls. The radon activity rapidly diminished with the amount of rainfall. It was also noted that for equivalent rainfalls the radon activity of nocturnal rain was usually less than that of diurnal rains, confirming the diurnal variation of the radon content in the atmosphere (Banerji and Chatterjee, 1964).

Rainwater can be intensely radioactive due to high levels of radon and its decay progenies ^{214}Bi and ^{214}Pb. The highest levels of radon in rainwater occurs during thunderstorms, and it is hypothesized that radon is concentrated in thunderstorms on account of the atom's positive electrical charge (Yamazawa et al., 2008; Greenfield et al., 2008).

At the level of the world, it is estimated that the average annual effective dose is 1.2 mSv due to inhalation of thoron, radon and their decay products (Ahmad et al., 2014, 2015; UN, 2000).

Measurements of radon in HRW are seldom performed or presented in the literature, as most of developed countries do not use HRW for drinking, while researchers in underdeveloped countries may not have access to active radon measurements (RAD7). This paper presents the results of a survey on the concentrations of radon in harvested drinking water in rainfed cisterns at the household level in Yatta area, southern West Bank of Palestine. The primary objective of the survey was to determine the range of radon levels in the harvested rainwater and thereby establish whether or not there is an increased exposure to radon in Yatta area compared to the permissible exposure limits.

2. Materials and methods

2.1. Study area

The Yatta area includes Yatta town and many villages surrounding it. Yatta town is located in the Hebron governorate, 9 km south of Hebron city in the southern part of the West Bank of Palestine. The town is located on a mountainous area at an elevation of 793 m above sea level, with a mean rainfall of 303 mm, an average annual temperature of 18 °C, and average annual humidity of 61% (ARIJ, 2009). The 270,000,000 m^2 (270,000 dunums) are the total estimated area of Yatta town, of which 14,000,000 m^2 are classified as 'built up' area; whilst 115,000,000 m^2 are agricultural,

Table 1
Activity concentrations of ^{222}Rn in harvested rainwater in cisterns in Yatta area, Palestine.

Locality	Number of samples	^{222}Rn Concentration (Bq/L)	
		Mean ± SD	Range
Kheroshewesh Wal Hadedeyah	15	0.14 ± 0.06	0.04–0.22
Al Heila	15	0.17 ± 0.06	0.04–0.25
Om Ashoqhan	15	0.12 ± 0.04	0.04–0.21
Yatta	15	0.10 ± 0.04	0.04–0.19
Khallet Salih	15	0.15 ± 0.06	0.04–0.26
Om Al Amad (Sahel Wadi Elma)	15	0.16 ± 0.05	0.05–0.22
Total	90	0.14 ± 0.06	0.04–0.26

and 141,000000 m^2 are forests, uncultivated, or public land (ARIJ, 2009; Al-Batsh, 2016). The population of Yatta town in 2016 is estimated to be 64,277 people (PCBS, 2016). The agricultural and forest areas are actually part of the town and are outside the area inhibited by the population.

2.2. Selection of sampling sites

Ninety houses (each having a rainfed cistern) were carefully selected for the current drinking water radon survey. The choice of the houses was based on geographical spread, convenience, and willingness of the dwellers of the surveyed area. Water samples were collected from cisterns in 6 localities in Yatta area with 15 samples from each locality. The localities are: Kheroshewesh Wal Hadedeyah, Al Heila, Om Ashoqhan, Yatta, Khallet Salih, and Om Al Amad (Sahel Wadi Elma). Samples were collected in glass bottles (250 mL each). The water in the cistern was stirred before sampling. Samples were collected from the cisterns at about 0.5 m below water surface level through the lid of the cistern. Water samples were collected in glass bottles, tightly sealed, and put in dark to avoid interaction with sunlight. The samples were refrigerated in a chilled-cold box at 4 °C. Water samples were collected as described above (immediately after raining) and measured within 48 h.

2.3. Experimental setup and measurement procedure

Research project was approved by the research committee at Birzeit University and the experimental procedures were approved and permitted by An-Najah National University administration. The researcher then received training in using the DURRIDGE RAD7 H_2O device following the manual instructions (DURRIDGE Company Inc., 2015). Therefore, we used RAD water device, an accessory to the RAD7 device manufactured by DURRIDGE Company (DURRIDGE Company Inc., 2015).

The device used and the experimental procedures were previously described (Al Zabadi et al., 2012). Briefly, the schematic diagram of this device is presented in Fig. 1. Using RAD H_2O technique employs closed loop concept, consisting of three components: (a) the RAD7 or radon monitor, on the left, (b) the water vial with aerator, in the case near the front, and (c) the tube of desiccant, supported by the retort stand above as marked in Fig. 1. For the protocol of Wat-250 that we used, the extraction efficiency was usually very high; typically 95% for a 250 mL sample vial (DURRIDGE Company Inc., 2015).

After reaching equilibrium between water and air, the radon progeny were assumed to be attached to the passivity implanted planar silicon detector, the radon activity concentration measured in the air loop was used for calculating the initial radon-in-water concentration of the respective sample. Radon-222 activities were then expressed with uncertainty down to under ±5%. At the end of the run (30 min after the start), the RAD7 prints out a summary, showing the average radon readings from the four cycles.

The RAD H20 enables the measurement of radon in water over a concentration range between 1.11 Bq/L and 0.037 Bq/L. The lower limit of detection was less than 0.037Bq/L (DURRIDGE Company Inc., 2015). The exact value of the extraction efficiency depends somewhat on ambient temperature, but it is almost always well above 90%. Furthermore, the temperature effect on accuracy is usually noticeable with the 250 mL vial at only very low or high temperatures. The RAD-H_2O system has been calibrated for a sample analysis temperature of 20 C°. In our study, the mean ± standard deviation (M ± SD) temperature value for the rainfed cisterns samples was 21.4 ± 0.54. At this temperature of measurements and with the good desiccant in the air sample path, the humidity in the measurement chamber is brought well below 10% RH. Under this condition the collection has maximum efficiency and no correction for humidity is required.

The collection of the samples and their analysis were done between 13th of April, 2016 and 24th of May 2016. To ensure the quality control and reliability of the sampling and measurement methods, each sample was analyzed in 4 cycles. The mean for these 4 cycles was then calculated in regard to the rainfed cisterns. Analysis was conducted at the radon research laboratory at An-Najah National University. All samples were analyzed within 3 days of collection (Polpong and Bovornkitti, 1998). The relative standard deviations of all the 4 cycles analyzed were within the 10% for their corresponding mean. The SPSS (statistical package for social sciences) software 20 was used for analysis (SPSS Institute Inc, 2015).

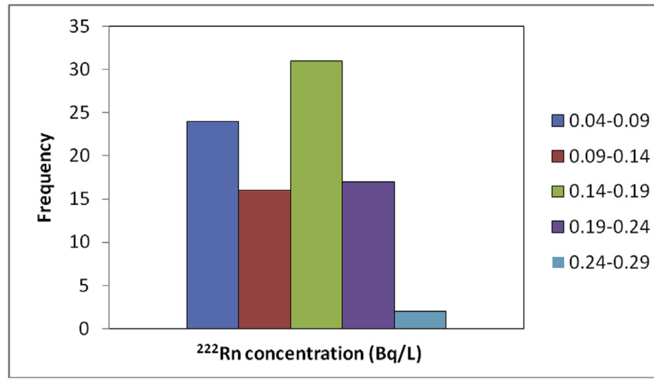

Fig. 2. Frequency of activity concentrations of ^{222}Rn in harvested rainwater in Yatta area.

2.4. Ingestion doses

In this study, the annual effective per capita annual radiation dose (E_D) due to the harvested rainwater water intake was calculated by the use of Eq. (1) (Ajayi and Achuka, 2009):

$$E_D = A_C \cdot I_A \cdot C_F \quad (1)$$

where A_C is the activity concentration from ^{222}Rn ingested water in terms of Bq l^{-1}, I_A describes the annual intake of drinking water estimated as 730, 330, and 230 L/y for adult, children and babies respectively (WHO , 1988; Fonollosa et al., 2016) and C_F is the dose conversion factors for ^{222}Rn (3.5, 5.9 and 23 nSv Bq^{-1}) for adults, children and babies, respectively) (UN, 2008; Fonollosa et al., 2016).

3. Results and discussion

3.1. Activity concentrations of ^{222}Rn in water

The results are presented in Table 1. Radon concentration varied from 0.04 to 0.26 Bq/L with a mean ± SD of 0.14 ± 0.06 Bq/L, which are much lower than the assumed world average (10 Bq/L) (UNSCEAR, 1993; WHO , 1996), or the US Environmental Protection Agency maximum permissible value (11.1 Bq/L) (USEPA, 1991). These data (radon concentrations) are very close to being normally distributed but slightly skewed to the right as can be shown in Fig. 2.

As can be seen from Fig. 2, all of the values are below 0.26 Bq/L. The highest frequency of ^{222}Rn concentration (27 out of 90 samples) was from 0.10 to 0.15 Bq/L. Part of the results are similar to those reported in Venezuela (0–2 Bq/L) (Horvath et al., 2000).

The radon concentrations in rainfed cisterns were lower than

Fig. 3. Representative pictures of the cistern tops.

those recommended by WHO (1996), which may be due to aeration of radon gas to the atmosphere and also due to the lack of major contact with radon emanating mineral material (Chandrashekara et al., 2012; Shivakumara et al., 2014; Ahmad et al., 2015). Fig. 3 shows pictures of representative rainfed cistern tops.

The ingestion radiation doses for adults, children and babies of the Yatta area ranged from 66.2 to 1349 $nSvy^{-1}$. As expected these values are far below the maximum limit of 5 $mSvy^{-1}$ set by the National Council on Radiation Protection and Measurements (NCRP, 2004) or 0.1 $mSvy^{-1}$ set by the WHO (2011).

4. Conclusions

The measured radon concentration in all the drinking HRW samples at the household level is well below the safe limit recommended by the WHO (2011). This confirmed the expectation for HRW. The estimated annual effective dose from ingestion of HRW for inhabitants of Yatta area is very much lower than the accordable limit as given by WHO (2011) and NCRP (2004).

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