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# Estimation of environmental radioactivity and radiation dose from exposure to radon in groundwater for inhabitants in Qassim Area, Saudi Arabia

E.E. Massoud[a,b], Atef El-Taher[c,*], Abd Elmoniem A. Elzain[d]

[a]*Faculty of Sciences and Arts in Dahran Aljanoub, King Khalid University, Dahran Aljanoub, Saudi Arabia, Tel. (00966) 536955743; email: ehabheca@gmail.com (E.E. Massoud)*
[b]*Agriculture Research Center, Soil, Water and Environment Research Institute, Giza, Egypt*
[c]*Department of Physics, Faculty of Science, Al-Azhar University, Assuit 71452, Egypt, Tel. (002) 01025604646; Fax: (002) 088 214809; email: atef.eltaher@gmail.com (A. El-Taher)*
[d]*Department of Physics, College of Science and Arts Uglat Asugour, Qassim University, Buraidah, Saudi Arabia, email: abdelmoniem1@yahoo.com (A.E.A. Elzain)*

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**ABSTRACT**

Studies of radon isotope $^{222}$Rn activity concentration in underground water used for irrigation and consumption in Al-Asyah city-Saudi Arabia were performed using RAD7 electronic radon identifier associated with RAD-$H_2O$ extra (Durridge Co., USA). Waters samples chosen for investigations were gathered from 18 various wells in and around the town. The activity concentration of $^{222}$Rn varied from 1.2 ± 0.3 to 12.6 ± 1.6 Bq $L^{-1}$, with an average of 5.1 ± 1.1 Bq $L^{-1}$. The annual effective dose per liter was calculated for inhabitants to be in the range 6.0 ± 1.4 to 62.9 ± 8.2 nSv $L^{-1}$ with a mean value of 25.4 ± 5.4 nSv $L^{-1}$. The annual effective doses rate for ingestion and inhalation due to the consumption of $^{222}$Rn with water ranged from 4.4 ± 1.1 to 45.9 ± 5.9 μSv $y^{-1}$, with an average of 18.5 ± 3.9 μSv $y^{-1}$ and from 3.0 ± 0.7 to 31.7 ± 4.1 μSv $y^{-1}$, with an average of 12.8 ± 2.7 μSv $y^{-1}$, respectively. The total annual effective dose ranged from 7.4 ± 1.7 to 77.6 ± 10.1 μSv $y^{-1}$, with an average of 31.3 ± 6.6 μSv $y^{-1}$. Moreover, roughly 11% of our samples were above the maximum contamination level, while 89% from the samples are below the maximum contaminant level as quoted by US Environmental Protection Agency. The results showed that radon from water would be expected to contribute by (5.1 ± 1.1) × $10^{-4}$ Bq $L^{-1}$ to the indoor air radon concentration. The results were compared with other results.

*Keywords:* Aeration; Effective dose rate; Radon; RAD7; Underground water; Well water

## 1. Introduction

Radon is a naturally occurring radioactive and synthetically inactive gas. This vapid, boring, and scentless gas is delivered by natural radioactive decay of uranium, radium, and thorium found in follow sums wherever in the stones and soils of the Earth's crust. It is essential to examine the levels of radionuclides in water. Natural radioactive elements, for example, uranium, radium, and radon are disintegrated in exceptionally low concentrations during typical response among water and rock or soil. The fundamental worry of ecological observation is the estimation of the natural radiation emerging from naturally radioactive elements and their progenies which exist in air and water [1]. Radon and its progenies cause lung cancer [2–5]. Radon concentrations in groundwater may differ with time in light of variables, for example, weakening by reviving and changes in energizing zone due to siphoning and so on.

* Corresponding author.

The seasonal changes might be low or high depending upon the variables, liable for the enhancement of radon in groundwater. Consideration has been focused around radon in drinking water by the European Commission Recommendation [6–8].

The investigation of radon concentration in tube wells indicated that the de-ionization of water reduces the radon concentration [9]. Radon in water supplies displays a potential hazard to the population in two pathways: ingestion of water and inward breath of radon (and its offspring) discharged from water [7]. A few national and universal associations have decided adequate activity levels for radon and radium concentrations. The US Environmental Protection Agency (USEPA) characterized an estimation of 11 Bq $L^{-1}$ for radon concentration in water in its report in 2000 [6]. USEPA guidelines set the drinking water standard at an average annual concentration of gross alpha particle radiation in drinking water to 15 pCi $L^{-1}$ [10–14]. Radon can be breathed in from the air or ingested from water. Inward breath of radon expands the odds of lung malignancy, representing a greater danger than that of stomach disease from gulping water with a high radon fixation. For the most part, ingested waterborne radon is the definitely an insignificant reason for concern. The degree of the impacts and the hazard gauges included are cannot be decided. As indicated by the EPA's 2003 assessment of risks from radon in homes [15], radon is evaluated to cause around 21,000 lungs malignant growth passing's every year. The National Research Council's report concerning, risk assessment of radon in drinking water, appraises that radon in drinking water causes around 160 diseases passings every year because of inward breath and 20 stomach malignancies passings because of ingestion [15]. The present paper estimates the radiation dose from exposure to radon in groundwater for inhabitants in Al-Qassim, Saudi Arabia.

## 2. Study area

Asyah is a city in Al-Qassim region, situated at 26.7750031°N 44.2146506°E in a territory of 200 km² and a height of 700 m, and the number of its inhabitants is around 40,000. It is right around 330 km north of Riyadh. It is flanked by the Ha'il Region toward the north. Moreover, it shares a place with Al-Qassim region which consolidates the sands of the Nafud desert and the encompassing greenery of the field with a wealth of water and transcending Palm trees. The standard moreover, it shares involve farming, touching, and old industry, where the civic chairman and branch water (Fig. 1).

## 3. Experimental procedure

### *3.1. Sampling preparation*

A total of 18 samples from Al-Asyah in Al-Qassim area were selected for investigation. The wells were purged through pumping for 10 min to ensure sample quality. All the water samples were collected in special glass bottles 250 mL capacity designed for radon in water activity measurement ensuring minimum radon loss by degassing and without any air contact.

### *3.2. Radon measurements in groundwater using RAD7*

$^{222}$Rn measurement of groundwater samples was carried out using a radon-in-air monitor RAD-7 (Durridge Co., Ltd.) employing RAD $H_2O$ technique. The radon activity was measured using a radon-in-air monitor (RAD7) coupled with a specially fabricated closed loop of aeration system that strip/free radon from water. The sample bottles of 250 mL were connected to the RAD-7 and the internal

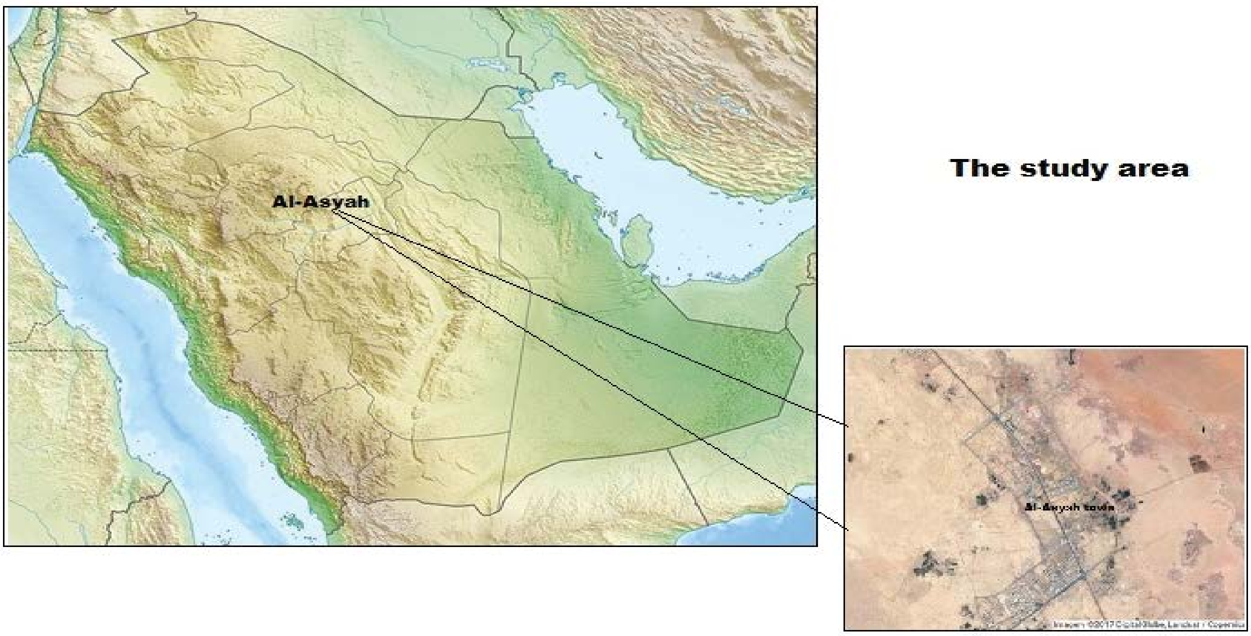


Fig. 1. Study area of Al-Asyah town, Al-Qassim region, Saudi Arabia.

air pump of the radon-monitor was used for re-circulating a closed air-loop through the water sample, purging radon from the water into the air-loop. The air was recirculated through the water continuously to extract the radon until RAD-$H_2O$ system reaches a state of equilibrium. After reaching equilibrium between water, air, and radon progeny attached to the PIPS detector, the radon activity concentration measured in the air loop was used for calculating the initial radon-in-water concentration of the respective sample. The RAD-7 allows determination of radon-in-air activity concentrations through detecting the alpha-decaying radon progeny $^{218}$Po and $^{214}$Po using a passivated implanted planar silicon detector (PIPS). The radon monitor (RAD-7) uses a high electric field above a silicon semi-conductor detected at ground potential to attract the positively charged polonium daughters, $^{218+}$Po ($t_{1/2}$ = 3.1 min; alpha energy = 6.00 MeV) and $^{214+}$Po ($t_{1/2}$ = 164 μs; alpha energy = 7.67 MeV), which are counted as a measure of $^{222}$Rn concentration in air [10–11].

### 3.3. Calculation of the annual effective dose

Radon gas is the largest contributor to all types of natural radiation to the population in the world [15–18]. The inhalation of its short decay products is estimated at an average of about 50% of the effective equivalent dose to the population [19]. The annual effective doses of water samples to an individual consumer due to ingestion are evaluated using the following equation [20]:

$$E_{W-\text{Ig}}\left(\mu\text{Svy}^{-1}\right) = C_{\text{Rn}-W} \times C_W \times D_{\text{CW}} \tag{1}$$

where $E_{W\text{–Ig}}$ is the annual effective dose (mSvy$^{-1}$) due to ingestion of radionuclides from the consumption of water, $C_{\text{Rn–}W}$ concentration of $^{222}$Rn in the ingested drinking water (Bq L$^{-1}$), $C_W$ is the estimated annual intake of water consumption (L y$^{-1}$), $D_{\text{CW}}$ is the ingested dose conversion factor for $^{222}$Rn (Sv Bq$^{-1}$) [20–22]. For the calculation of effective dose, a dose conversion factor of 5 × 10$^{-3}$ mSv Bq$^{-1}$ suggested by the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) report has been used [23]. Annual effective dose due to intake of $^{222}$Rn from drinking water has been calculated considering that an adult (assuming that his/her age is greater than 18 y), on average, takes 730 L of water annually [9]. Following the ingestion of $^{222}$Rn dissolved in drinking water, annual effective doses (μSvy$^{-1}$) and effective doses per liter (nSvL$^{-1}$) were calculated. The annual mean effective doses of drinking water samples due to inhalation were calculated using the parameters established in UNSCEAR [23]:

$$E_{W-\text{Ih}}\left(\mu\text{Svy}^{-1}\right) = C_{\text{Rn}-W} \times R_{a-w} \times F \times O \times D_{\text{CF}} \tag{2}$$

where $E_{W\text{–Ih}}$ is the effective dose for inhalation, $C_{\text{Rn–}W}$ is the radon concentration in water (Bq L$^{-1}$), $R_{a–W}$ is the ratio of radon in air to radon in tap water (10$^{-4}$), $F$ is the equilibrium factor between radon and its decay products (0.4), $O$ is the average indoor occupancy time per person (7,000 h y$^{-1}$), and $D_{\text{CF}}$ is the dose conversion factor for radon exposure 9 × 10$^{-6}$ Sv h$^{-1}$ per Bq L$^{-1}$.

## 4. Results and discussion

Table 1 and Figs. 2–6 present the radon concentration from the selected groundwater. The radon concentration values range from 1.2 ± 0.4 to 12.6 ± 1.6 Bq L$^{-1}$, with an average of 5.1 ± 1.1 Bq L$^{-1}$. These concentrations are consistently found to be within the recommended safe range of 4–40 Bq L$^{-1}$ as quoted by the UNSCEAR report [23]. All of the resulted concentration values from water samples were far below the recommended action level of 100 Bq L$^{-1}$ set by the (EC) European Commission for drinking purposes [3]. The US EPA has recommended that the permitted maximum contamination level (MCL) for radon concentration in water is 11 Bq L$^{-1}$ in which about 11% of our samples were above the maximum contamination level, while 89% of the examples were lower than the most maximum contaminant level (MCL) [15]. The spatial varieties in radon concentration could be an element of the geographical structure of the territory, profundity of the water source, and contrasts in the atmosphere of the region. The higher estimation of radon concentration can be ascribed to the nature of basement rock in the study locations and also could be linked to the deserty nature of the area, this may contribute to increasing the amount of radium element in the bedrocks [21].

Radon in water usually originates from wells that are penetrated bedrock containing radon gas. Radon for the most part does not happen in critical focuses in surface waters instead of groundwater [20]. Dissolved radon in groundwater will escape into indoor air during showering, washing, and dishwashing. Evaluations are that indoor air fixations increase by roughly 0.0370 Bq L$^{-1}$ (1 pCi L$^{-1}$) for every 370 Bq L$^{-1}$ (10,000 pCi L$^{-1}$) in water. The results reveal that the average value of water well containing (5.08 ± 1.08 Bq L$^{-1}$) of radon would be expected to contribute by (5.08 ± 1.08) × 10$^{-4}$ Bq L$^{-1}$ (0.01372972972973 pCi L$^{-1}$) to the indoor air radon concentration. In light of the potential for disease, the EPA proposes that indoor air ought not to surpass (4 pCi L$^{-1}$). EPA and different states have suggested drinking water principles for radon in the water extending from 11.1 Bq L$^{-1}$ (300) to 370 Bq L$^{-1}$ (10,000 pCi L$^{-1}$) however no standard exists at the present. One investigation of radon in more than 900 Pennsylvania water wells found that 78% surpassed 300 pCi L$^{-1}$, 52% exceeded 1,000 pCi L$^{-1}$, and 10% exceeded 5,000 pCi L$^{-1}$ [21]. Comparing the result of this study, we can see that our results are lower than these recorded values. For further comparison, our results could be shown with the other findings from various parts of the world as in Table 2. It is noticed that the radon concentration taken for the wells of Al-Asyah town is well compared with the radon concentrations from the water samples of various locations in Saudi Arabia and other places in the world.

Table 1 and Figs. 2–6 represents the annual effective dose rate (ingestion and inhalation) for the selected wells. The annual effective dose per liter was calculated for inhabitants who were in the range 6.0 ± 1.4 to 62.9 ± 8.2 nSv L$^{-1}$ with a mean value of 25.4 ± 5.4 nSv L$^{-1}$. It can be seen that the annual effective doses rate due to the consumption of radon gas from water through the usual uses was calculated for both ingestion and inhalation to be ranging from 4.4 ± 1.0 to 45.9 ± 5.9 μSv y$^{-1}$, with an average of 18.5 ± 3.93 μSv y$^{-1}$ and from 3.0 ± 0.7 to 31.7 ± 4.1 μSv y$^{-1}$, with an average of

Table 1
Radon concentration and their annual effective dose exposure in groundwater from Al Asyah, Qassim area, Saudi Arabia

| Sample no. | Well no. | $^{222}$Rn (Bq L$^{-1}$) | Annual effective doses per liter (nSv L$^{-1}$) | Annual mean effective dose (μSv y$^{-1}$) | | |
|---|---|---|---|---|---|---|
| | | | | Ingestion | Inhalation | Total |
| 1 | *W*1 | 5.7 ± 1.0 | 28.5 ± 5.1 | 20.8 ± 3.7 | 14.3 ± 2.6 | 35.1 ± 6.3 |
| 2 | *W*2 | 1.2 ± 0.4 | 6.1 ± 1.9 | 4. 5 ± 1.4 | 3.1 ± 0.9 | 7.5 ± 2.3 |
| 3 | *W*3 | 2.1 ± 0.8 | 10.3 ± 4.2 | 7.5 ± 3.1 | 5.2 ± 2.1 | 12.7 ± 5.2 |
| 4 | *W*4 | 2.2 ± 0.9 | 10.8 ± 4.3 | 7.9 ± 3.2 | 5.4 ± 2.2 | 13.3 ± 5.3 |
| 5 | *W*5 | 5.4 ± 1.3 | 27.2 ± 6.7 | 19.9 ± 4. 9 | 13.7 ± 3.4 | 336 ± 8.3 |
| 6 | *W*6 | 1.2 ± 0.3 | 6.0 ± 1.4 | 4.4 ± 1.02 | 3.0 ± 0.7 | 7.4 ± 1.7 |
| 7 | *W*7 | 4.5 ± 1.0 | 22.6 ± 5.1 | 16.5 ± 3.7 | 11.4 ± 2.6 | 27.9 ± 6.3 |
| 8 | *W*8 | 5.2 ± 1.4 | 26.2 ± 6.8 | 19.1 ± 4.9 | 13.2 ± 3.4 | 32.3 ± 8.3 |
| 9 | *W*9 | 4.2 ± 1.2 | 21.2 ± 6.2 | 15.5 ± 4.5 | 10.7 ± 3.1 | 26.2 ± 7.7 |
| 10 | *W*10 | 4.8 ± 0.9 | 23.8 ± 4.9 | 17.4 ± 3.6 | 12.0 ± 2.5 | 29.4 ± 6.1 |
| 11 | *W*11 | 5.2 ± 1.4 | 26.0 ± 6.8 | 18.9 ± 4.9 | 13.1 ± 3.4 | 32.1 ± 8.31 |
| 12 | *W*12 | 2.1 ± 1.2 | 10.3 ± 6.2 | 7.5 ± 4.5 | 5.2 ± 3.1 | 12.7 ± 7.7 |
| 13 | *W*13 | 5.4 ± 0.9 | 27.1 ± 4.7 | 19.8 ± 3.4 | 13.7 ± 2.4 | 33.4 ± 5.8 |
| 14 | *W*14 | 12.6 ± 1.6 | 62.9 ± 8.2 | 45.9 ± 5.9 | 31.7 ± 4.1 | 77.6 ± 10.1 |
| 15 | *W*15 | 5.5 ± 0.9 | 27.6 ± 4.3 | 20.2 ± 3.1 | 13.9 ± 2.2 | 34.1 ± 5.3 |
| 16 | *W*16 | 2.9 ± 0.7 | 14.3 ± 3.5 | 10.4 ± 2.5 | 7.2 ± 1.7 | 17.6 ± 4.3 |
| 17 | *W*17 | 11.1 ± 1.9 | 55.6 ± 9.4 | 40.6 ± 6.8 | 28.0 ± 4.7 | 68.6 ± 11.5 |
| 18 | *W*18 | 10.2 ± 1.5 | 50.9 ± 7.3 | 37.1 ± 5.3 | 25.6 ± 3.7 | 62.8 ± 8.9 |
| Minimum | | 1.2 ± 0.3 | 6 ± 1.4 | 4.4 ± 1.0 | 3.0 ± 0.7 | 7.4 ± 1.7 |
| Maximum | | 12.6 ± 1.6 | 62 ± 8.2 | 45.9 ± 5.9 | 31.7 ± 4.1 | 77.6 ± 10.1 |
| Average | | 5.1 ± 1.1 | 25.4 ± 5.4 | 18.5 ± 3.9 | 12.8 ± 2.7 | 31.3 ± 6.6 |

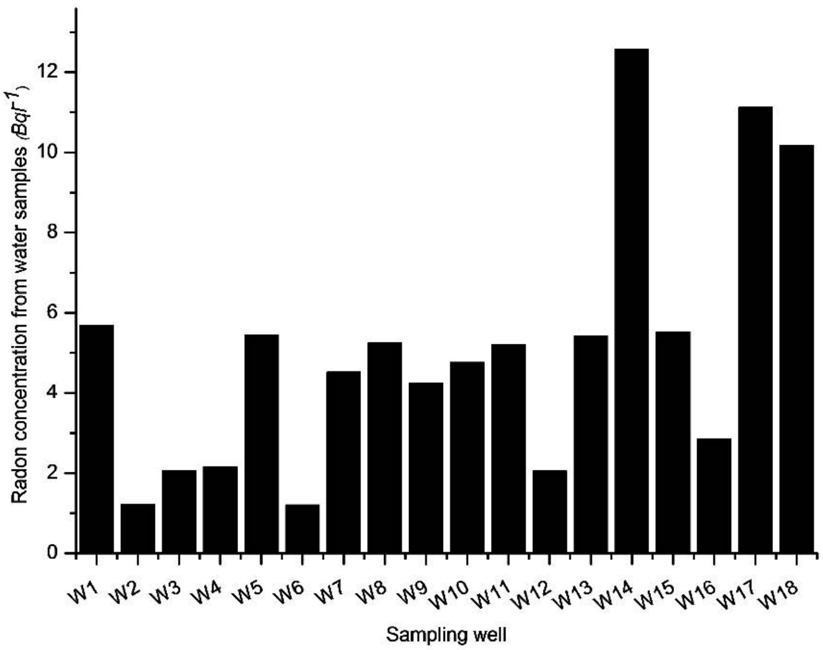


Fig. 2. Radon concentration with respect to the sampling well.

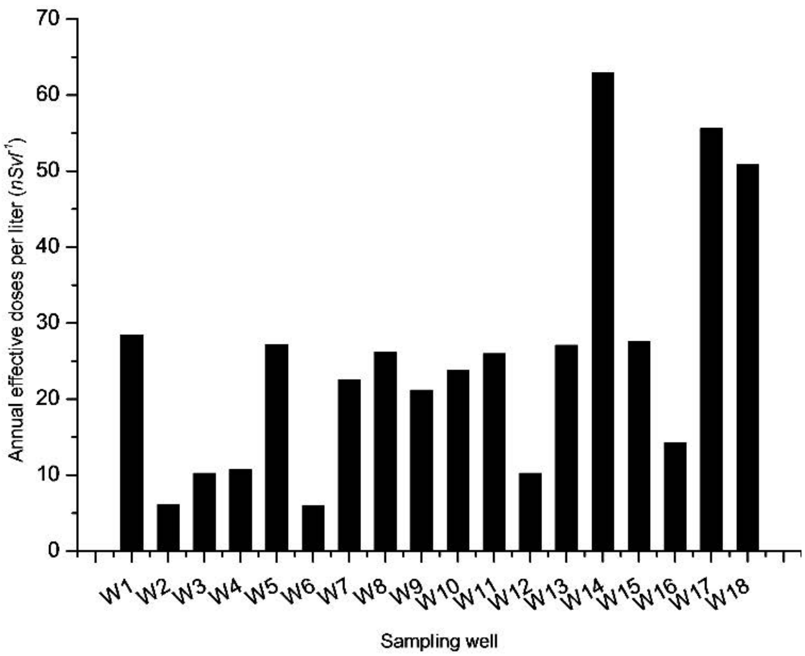


Fig. 3. Annual effective dose per liter against the sampling well.

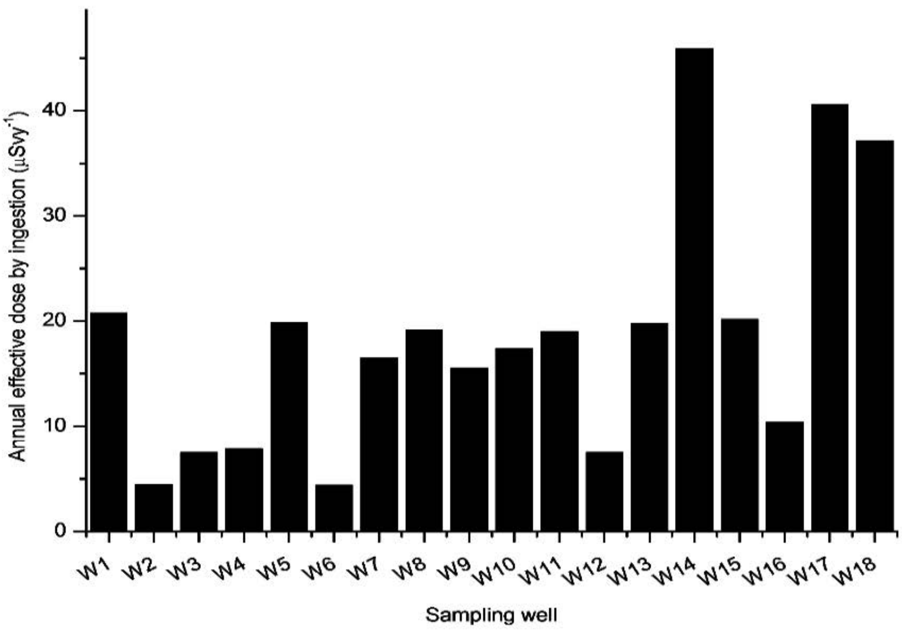


Fig. 4. Annual effective dose by ingestion against the sampling well.

12.8 ± 2.7 μSv y$^{-1}$, respectively. The total annual effective dose rate was calculated to be from 7.4 ± 1.7 to 77.6 ± 10.1 μSv y$^{-1}$ with an average of 31.3 ± 6.6 μSv y$^{-1}$.

The ingested water quality is a matter of concern for the World Health Organization [24]. Radiological factors are important for the evaluation of water. Although these present a lower risk compared to chemical and microbiological aspects, various radioactive compounds found in the environment may be also present in drinking water. In some circumstances, this increases health risk. The contribution of drinking water to total exposure is typically small but its major portion is related to the radionuclides present in decay chains of uranium and thorium [24].

In general, radon can be removed or decreased from water using one of the two following methods:

- *Aeration process* – spraying or mixing water with air which should be vented from the water before use, or

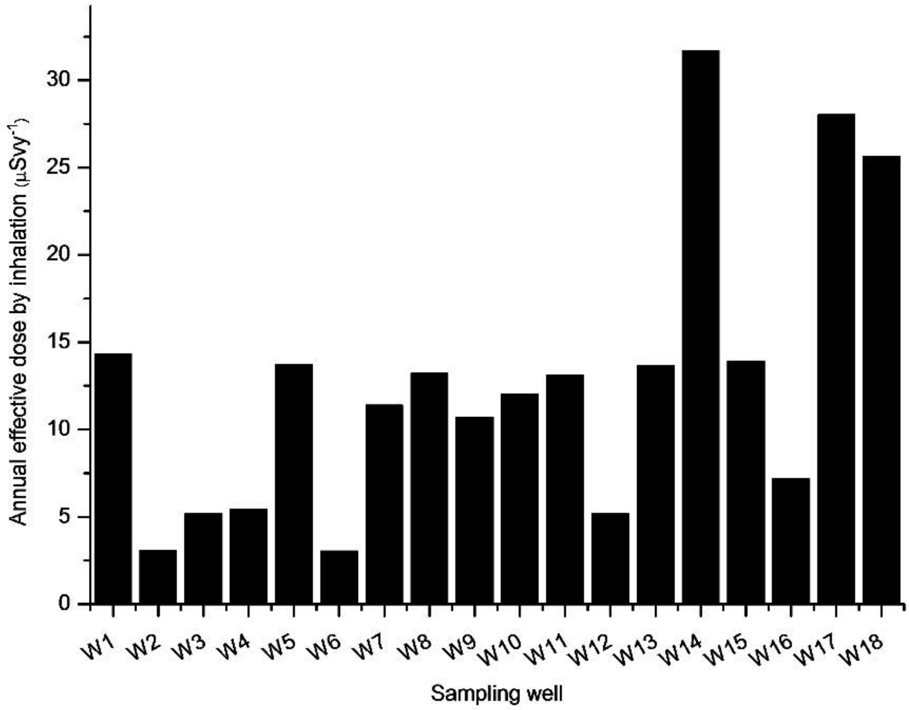


Fig. 5. Annual effective dose by inhalation against the sampling well.

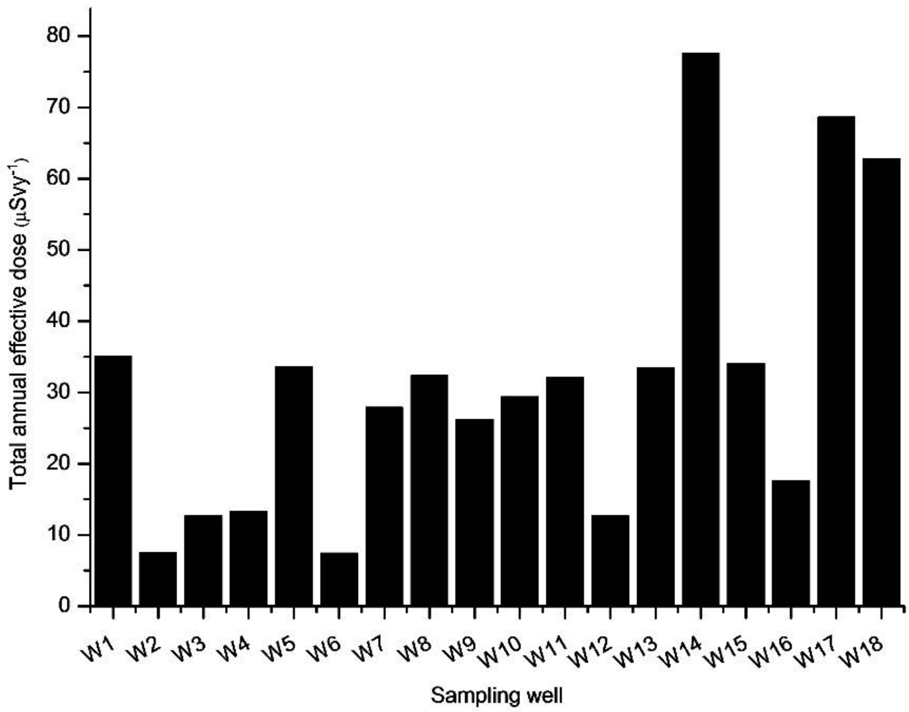


Fig. 6. Total annual effective dose against the sampling well.

- *GAC process* – separating water through utilizing granular initiated carbon. Instantly, gas joins carbon and takes water to be free of radon. Special handling is required for disposing of the carbon at the high radon concentration.

In either treatment, it is critical to treat water when enters your dwelling with the goal that all water may be dealt with. Point-of-use devices that should only treat a small portion of water (those installed on a tap or under the sink)

Table 2
Radon concentration values from different kinds of water around the world

| Water type | Country | Radon concentration (Bq $L^{-1}$) | Reference |
|---|---|---|---|
| Well water | Saudi Arabia | 1.45–9.15 | [14] |
| Groundwater | Saudi Arabia | 0.76–9.15 | [17] |
| Well water | Sudan | 19.76 ± 4.54 | [20] |
| Drinking water | Bangladesh | 4.46 | [25] |
| Drinking water | India | 0.87–32.10 | [26] |
| Drinking water | Iran | 146–316 | [27] |
| Drinking water | Poland | 0.42–10.52 | [28] |
| Well water | Turkey | 0.70–31.70 | [29] |
| Well water | Jordan | 3.1–5.7 | [30] |
| Groundwater | Brazil | 0.95–36.00 | [31] |
| Groundwater | India | 0.50–85.7 | [32] |
| Groundwater | Saudi Arabia | 10–100 | [33] |
| Groundwater | Saudi Arabia | 0.76–4.69 | [34] |
| Drinking water | Saudi Arabia | 0.89–35.44 | [35] |
| Groundwater | Saudi Arabia | 5.08 ± 1.08 | Present work |

are ineffective in minimizing radon levels in your water. It is essential to consider the procedures of home water treatment units to avoid other water contamination issues. A few tenants utilize a help contract from the installer to obtain carbon substitution and general framework support. Thus, it is suitable to mention that to decrease the concentration values of radon from water samples we can use both of these methods for their effectiveness and simplicity.

A comparison of radon concentration in the groundwater samples of the investigated area and other aquatic environments is presented in Table 2. The present concentrations of $^{222}$Rn are lower than those in some locations, such as Saudi Arabia, Iran, and Sudan, but they are higher than the activities in India, Brazil, Turkey, Poland, and Bangladesh. When the measured radon concentration values are compared with the allowed maximum contamination level for radon concentration in water (which is 11 Bq $L^{-1}$), proposed by the USEPA, it can be seen that present values are below this recommended value. Furthermore, when the measured values for radon concentration are compared with the European Commission recommendations on the protection of the public against exposure to radon in drinking water supplies, which recommends action levels of 100 Bq $L^{-1}$ for public water supplies, it can be seen that the levels we measured were below these limits.

The global average dose from the inhalation of radon and its decay products from all sources is approximately 1 mSv $y^{-1}$ [8] which is slightly less than half the total natural radiation exposure of 2.4 mSv $y^{-1}$ [24]. In comparison, the average global dose from ingestion of radon in drinking water is relatively as low as 0.025 mSv $y^{-1}$ via inhalation and 0.002 mSv $y^{-1}$ from ingestion [8]. Hence, the present attempt is to estimate the total annual effective dose resulting from radon in the sampled groundwater. It was noticed that annual effective dose (EDE) and effective dose per liter (EDL) were varying with an increase in radon concentration. The calculated EDL, the total EDE, and EDL ranged from 6 to 62 nSv $L^{-1}$ and 7.4 to 77.6 μSv $y^{-1}$, respectively (Table 1). Table 1 exhibits that the total annual effective dose resulting from radon in groundwater of Al-Asyah area was significantly lower than the recommended limit 1 mSv $y^{-1}$ for the public.

## 5. Conclusion

The $^{222}$Rn activity concentration in all well water tests from Al-Asyah was very much recorded to be involved in the recommendations of UNSCEAR. The annual effective dose per liter was calculated for inhabitants. The annual effective dose rate due to the consumption of $^{222}$Rn with water was defined for both ingestion and inhalation and the total annual effective dose rate was determined. It was discovered that our concentrated region is not exactly the prescribed safe farthest point given by WHO and EU board. It was found that about 11% of our samples were above the maximum contamination level, while 89% from the samples were below the MCL as quoted by USEPA. Finally, our results were compared with other results.

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