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Radiological and Toxicity Hazards Estimate of Drinking Water in Al-Diwaniyah, Iraq

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ABSTRACT

In this work, analyses of ^{222}Rn concentration and effective ^{226}Ra content in all available types of drinking water in Al-Diwaniyah city, Iraq, were achieved by using CR-39 detectors technique. The annual effective dose from ^{222}Rn and ^{226}Ra distribution by three age groups were calculated. Radiological and chemical hazards were also calculated in drinking water samples. Drinking water samples were taken from tap water, water treatment plants, reverse osmosis water, and bottled drinking water in Al-Diwaniyah city. Effective ^{226}Ra content level in some tap water samples were bigger than recommended value WHO for drinking water (1 Bq/L), but far below maximum acceptable limit of 370 Bq/L according to IAEA. All other values of ^{222}Rn concentration and effective ^{226}Ra content, annual effective dose, cancer morbidity and mortality hazards, and the lifetime average daily dose caused by consumption ^{226}Ra in drinking water were less than recommended limits. Therefore, ^{222}Rn concentration and effective ^{226}Ra content in drinking water obtained in this work cannot give rise to radiological and chemical threats to population. However, for greater safety, we advise not to use tap water directly as drinking water. This work will provide important new data on the possible health effects of drinking water in Al-Diwaniya city.

INTRODUCTION

We live in an environment where radiation is a natural part of our lives; humans are exposed to natural radioactivity from soil, air, food, and water [1,2]. Radon gas (^{222}Rn) may be moved from the ground depths to the surface without reacting with other atoms in the environment [3]. Half of this natural radiation exposure came from ^{222}Rn source [4,5], with half-life of 3.82 days. ^{222}Rn is a direct decay product of radium (^{226}Ra) in natural uranium (^{238}U) decay chain [6,7]. So, the existence of ^{226}Ra can contribute to the concentration of ^{222}Rn and its decay products [8]. ^{226}Ra and ^{222}Rn exist in all types of rocks and soils. When ^{226}Ra atom decays, alpha particle is released, and ^{222}Rn atom made an emission. Alpha recoil is considered most essential element controlling ^{222}Rn emission from soil. 80 % of ^{222}Rn first few meters of the earth leak into the air [9]. The radioactive composition of the rocks creates a concentration of natural radionuclides in water, the level of fissuring of the rocks, the chemical properties of the water, and the contact time of the water with the rocks [10], which makes ^{222}Rn and ^{226}Ra among the radionuclides that are studied the most.

Natural radioactivity has been related to various cancer occurrences, including lung and blood cancers, and can induce genetic damage in livers. Therefore, it is necessary to determine exposure dose of various materials around the general public [11]. Drinking water is essentially an indispensable portion of human life, so all people may receive natural radioactivity from drinking water [12]. ^{222}Rn, ^{238}U [13], and ^{226}Ra in drinking water may cause harmful health effects in human when they dissolve in drinking water.

According to Environmental Protection Agency (EPA), any exposure to ^{222}Rn constitutes a

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hazard of lung cancer [14]. According to EPA, about 168 deaths per year are caused by cancer due to the presence of ^{222}Rn in drinking water. Of these deaths, 89 % are caused by breathing in ^{222}Rn that is released from the water into indoor air, resulting in lung cancer. The remaining 11 % of deaths are caused by drinking water that contains ^{222}Rn, leading to stomach cancer [15,16].

^{226}Ra has two main effects on the human body: radiological hazard from its radiation and chemical risk as a result of it is considered as heavy metal. The main way of absorption of ^{226}Ra in the human body is by the digestive system, about 15-21 % of the ingested amount [17].

The methods used to measure ^{222}Rn and its progeny in studies are generally based on detection of α-particles [18]. Measurement of ^{222}Rn concentration can be divided into two main categories, namely active techniques and passive techniques. In active techniques, quick and instant radon measurements can be estimated. These techniques have high costs, and radon concentration can be notably affected by factors such as temperature, pressure, and humidity, which lead to remarkable changes in short-periods. On the contrary, long-term radon concentration measurement can be made using passive techniques; these techniques have low cost, and mean value for radon concentration can be obtained from measurement periods of up to some months [19].

CR-39 detectors are a passive technique widely used to record α-track activity [20] because they withstand various environmental factors without affecting their sensitivity to α-particles emitted by ^{222}Rn. Where low-energy α-particles can be recorded depending on the sensitivity of CR-39. So, this technique may give an actual assessment of ^{222}Rn concentration [21].

Given that monitoring ^{222}Rn concentration in water is a global phenomenon due to its health risks and to address the lack of published data on the concentrations of radioactive elements in drinking water in Al-Diwaniyah city, the purpose of our study was to estimate ^{222}Rn concentration and effective ^{226}Ra content in the different types of water widely used as drinking water in Al-Diwaniyah city, Iraq, namely tap water, water treatment plants, reverse osmosis water in some houses, and bottled drinking water in local markets. The annual effective dose of ^{222}Rn and ^{226}Ra distribution by three age groups (infants, children, and adults) are determined. Radiological and toxicity hazards are also investigated in these drinking water samples.

METHODOLOGY

Twenty samples of water were collected from different types of water that may be consumed as drinking water in Al-Diwaniyah (located between latitude 31.17 and 32.24˚N and longitude 44.24 and 45.49˚E), five samples for each type. These types are tap water (TW), water treatment plants (WTP), reverse osmosis water (ROW) in some houses, and bottled drinking water (BDW) in markets. The first three types are shown in Fig. 1, while the fourth type has not been located because it is found in various markets.

20 mL of each sample was prepared and placed in cylindrical chambers (length of 10 cm) with one of CR-39 detectors used. The chambers were sealed and stored for 132 days. At this time of exposure, the detector registers the tracks of alpha particles. After exposure time was completed, the detectors were collected from these chambers; then, they undergo chemical etching using NaOH in 6.25 normality at 70 ± 1 °C for 8 h [22]. Number of tracks were calculated using an optical-microscope with a magnification of 400X. This method is widely used in such studies [23-25].

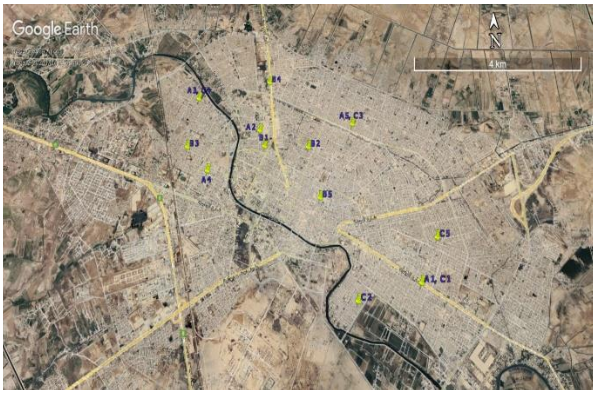

Fig. 1. Location of the samples in Al-Diwaniyah city.

CALCULATION

Calculation of ^{222}Rn concentration and effective ^{226}Ra content

The concentration of ^{222}Rn (C_{Rn}) released from the sample inside the chamber is given by Eq. (1) [26]:

$$C_{Rn} = \frac{\rho}{KT} \quad (1)$$

where $\rho\left(\frac{tracks}{cm^2}\right)$ is the track density, $T(day)$ is exposure time and $K(0.053\ tracks.cm^{-2}.day^{-1}/\ Bq.m^{-3})$

is the calibration factor. It depends on the geometrical dimension of chamber [27]. It was calculated by Eq. (2) [21]:

$$K = 0.25 \times r\left(2cos\theta_c - \frac{r}{R}\right) \quad (2)$$

where $r(2.4cm)$ is the radius of cylindrical chambers. $\theta_c(35°)$ is the critical angle for detector used [27], and $R(3.9\,cm)$ is the range of alpha particle of ^{222}Rn in air [23,28].

The effective ^{226}Ra content (C_{Ra}) in drinking water was calculated in Eq. (3) [6]:

$$C_{Ra} = \frac{\rho\, h\, A}{K\, T_e\, M} \quad (3)$$

where $h\,(9\,cm)$ is the distance between drinking water and detector, $M\,(L)$ is the mass of sample, and $T_e(day)$ is the effective exposure time, which may be calculated in Eq. (4).

$$T_e = T - \frac{1}{\lambda}\left(1 - e^{-\lambda T}\right) \quad (4)$$

where λ is ^{222}Rn decay constant.

Age-dependent dose assessment

The annual effective dose (AED) depends on age groups from ingestion of radionuclides in drinking water was evaluated as Eq. (5).

$$AED = C_i \times DWI \times DCF \times 365 \quad (5)$$

where $C_i\,(Bq/L)$ is the concentration of the radionuclides, $DWI\,(L/day)$ is age-dependent daily water intake, which is (0.6), (0.8), and (1.3) *L* for infants, children, and adults, respectively. $DCF\,(Sv/Bq)$ is the dose conversion factor which, depends on radionuclides and age groups, given for ^{222}Rn [2], ^{226}Ra [29].

Radiological hazard assessment

Excess-lifetime cancer risk (ECR) can be calculated based on annual effective dose by the Eq. (6) [30]:

$$ECR = AED \times ED \times RF \quad (6)$$

where *AED* of ^{222}Rn for adults, *ED* is the exposure duration, which is about 70 years [6], and *RF* is the risk factor per Sievert, where ICRP-60 uses the value of 0.05.

Assessment of radiological risk was also calculated to obtain ECR with the corresponding ^{226}Ra intake in drinking water samples as given in the Eq. (7) [31,32]:

$$ECR = C_{Ra} \times RC \times DWI \times TED \quad (7)$$

where *RC* is the risk coefficient, which is calculated for ^{226}Ra for mortality and morbidity, taken from EPA [33]. *DWI* was taken for adults, and TED (day) is the total exposure duration.

Toxicity hazard assessment

The chemical toxicity determines the relation between carcinogenic risks and chemical toxicity of ^{226}Ra in drinking water samples chosen for this work. The carcinogenic risk was assessed using the lifetime average daily dose (LADD) of this radionuclide through the intake, defined by Eq. (8) [34,35].

$$LADD = \frac{EPC \times DWI \times EF \times ED}{AT \times BW} \quad (8)$$

where *EPC (μg/L)* is the exposure point-concentration, *EF (350 days/y)* is the exposure frequency, *AT (25,550 days)* is the average time, and *BW (70 kg)* is the body weight.

RESULTS AND DISCUSSION

Concentration of ^{222}Rn and its AED

Table 1 displays the measurements obtained of ^{222}Rn concentration and its AED for three age groups from different types of drinking water available in Al-Diwaniyah city. Concentration of ^{222}Rn in TW varied between 98.89 ± 3.25 - 224.75 ± 3.84 mBq/L, with average value of 163.62 ± 9.27 mBq/L. Average value of AED in TW from ^{222}Rn was 2.51, 0.96 and 0.78 μSv/year for infants, children and adults, respectively.

Concentration range of ^{222}Rn in investigated WTP samples were 8.99 ± 0.95 - 89.9 ± 3.6 mBq/L, its average value of 43.15 ± 4.24 mBq/L. While average value of AED in WTP was 0.66 μSv/year for infants, 0.25 μSv/year for children, and 0.21 μSv/year for adults.

The measured concentrations of ^{222}Rn in ROW is in ranges of 17.98 ± 1.66 - 89.9 ± 4.52 mBq/L, with average value of 59.33 ± 4.41 mBq/L. Average value of AED in ROW from ^{222}Rn was 0.91, 0.35, and 0.28 μSv/year for infants, children, and adults, respectively.

Table 1. ^{222}Rn concentration and its AED for three age groups, from drinking water in Al-Diwaniyah city.

Sample type	Sample name	$C_{Rn}(mBq/L)$	The annual effective dose (µSv/year)		
			Infants	Children	Adults
Tap water (TW)	A1	224.75 ± 3.84	3.45	1.31	1.07
	A2	98.89 ± 3.25	1.52	0.58	0.47
	A3	179.8 ± 12.69	2.76	1.05	0.85
	A4	107.88 ± 15.08	1.65	0.63	0.51
	A5	206.77 ± 11.5	3.17	1.21	0.98
	Average	163.62 ± 9.27	2.51	0.96	0.78
Water treatment plants (WTP)	B1	89.9 ± 3.6	1.38	0.53	0.43
	B2	8.99 ± 0.95	0.14	0.05	0.04
	B3	35.96 ± 3.6	0.55	0.21	0.17
	B4	17.98 ± 1.66	0.28	0.11	0.09
	B5	62.93 ± 11.4	0.96	0.37	0.3
	Average	43.15 ± 4.24	0.66	0.25	0.21
Reverse osmosis water (ROW)	C1	71.92 ± 3.98	1.1	0.42	0.34
	C2	62.93 ± 4.02	0.96	0.37	0.3
	C3	17.98 ± 1.66	0.28	0.11	0.09
	C4	53.94 ± 7.85	0.83	0.32	0.26
	C5	89.9 ± 4.52	1.38	0.53	0.43
	Average	59.33 ± 4.41	0.91	0.35	0.28
Bottled drinking water (BDW)	D1	53.94 ± 4.87	0.83	0.32	0.26
	D2	17.98 ± 5.53	0.28	0.11	0.09
	D3	8.99 ± 2.19	0.14	0.05	0.04
	D4	26.97 ± 3.25	0.41	0.16	0.13
	D5	26.97 ± 4.21	0.41	0.16	0.13
	Average	26.97 ± 4.01	0.41	0.16	0.13

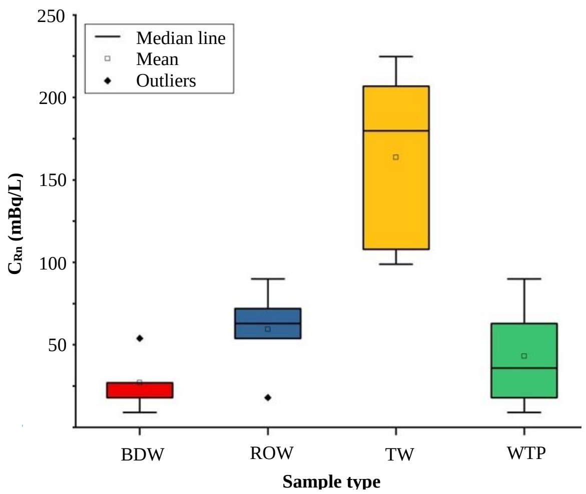

Fig. 2. Box plot presented distribution and variability of ^{222}Rn concentration in each type of water.

For BDW, ^{222}Rn concentration is in ranges of 8.99 ± 2.19 - 53.94 ± 4.87 mBq/L, its average value of 26.97 ± 4.01 mBq/L. Average value of AED in BDW was 0.41 µSv/year for infants, 0.16 µSv/year for children, and 0.13 µSv/year for adults.

As shown in Fig. 2, ^{222}Rn concentration in TW is greater than that in WTP, ROW, and BDW, because there are additional filters in WTP, ROW, and BDW compared to TW. These additional filters may reduce concentrations of radionuclide.

Several health organizations have limited acceptable action levels for radionuclide concentration. It has existed that all ^{222}Rn concentrations in drinking water samples from Al-Diwaniyah city are much lower than 100 Bq/L [36], 40 Bq/L [37], and 11 Bq/L [38] according to WHO, UNSCEAR, and EPA, respectively.

Annual effective dose of ^{222}Rn of all results in drinking water is much lower than 2.4 mSv/year global average for a natural radiation as recommended by UNSCEAR [39], 1 mSv/year to the population for long time exposure according to ICRP [40], and 0.5 mSv/year for Jordanian level [41].

Effective ^{226}Ra content and its AED

Effective ^{226}Ra content in investigated TW samples were ranged 836.42 ± 27.52 - 1900.94 ± 32.46 mBq/L, with average value of 1383.89 ± 78.42 mBq/L. Average value of AED in TW from ^{226}Ra for three age groups were 290.95 µSv/year for infants, 323.28 µSv/year for children, and 183.86 µSv/year for adults.

Effective ^{226}Ra content in WTP varied between 76.04 ± 8.02 - 760.38 ± 30.44 mBq/L, its average value of 364.98 ± 35.86 mBq/L. Average value of AED in WTP from ^{226}Ra was 76.73, 85.26 and 48.49 µSv/year for infants, children, and adults, respectively.

For ROW, effective ^{226}Ra content is in ranges of 152.08 ± 13.99 - 760.38 ± 38.24 mBq/L, with average value of 501.85 ± 37.26 mBq/L. Average value of AED in ROW was 105.51 µSv/year for infants, 117.23 µSv/year for children, and 66.67 µSv/year for adults.

The measured effective ^{226}Ra content in BDW is in ranges of 76.04 ± 18.49 - 456.23 ± 41.16 mBq/L, its average value of 228.11 ± 33.9 mBq/L. Average value of AED in BDW from ^{226}Ra was 47.96, 53.29, and 30.31 µSv/year for infants, children and adults, respectively.

As shown in Fig. 3. Effective ^{226}Ra content in TW is larger than that in WTP, ROW, and BDW, where additional filters in WTP, ROW, and BDW contribute to reducing radionuclide concentrations.

All previous results in this section are shown in Table 2. Three of TW samples and average of TW are higher than recommended WHO ^{226}Ra concentration of about 1 Bq/L [42]; all other effective ^{226}Ra content in drinking water samples are lower than 1 Bq/L. However, all results of effective ^{226}Ra content in water samples are much below the maximum acceptable limit of 370 Bq/L according to IAEA [43,44].

AED of ^{226}Ra of water samples are also less than 2.4 mSv/year, 1 mSv/year, and 0.5 mSv/year.

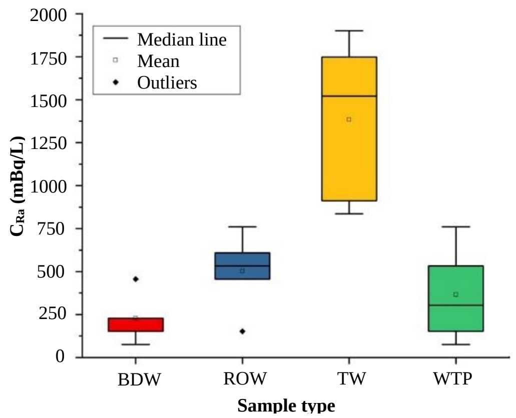

Fig. 3. Box plot presented distribution and variability of effective ^{226}Ra content in each type of water.

Table 2. Effective ^{226}Ra content and its AED for three age groups, from drinking water in Al-Diwaniyah city.

Sample type	Sample name	$C_{Ra}(mBq/L)$	The annual effective dose (µSv/year)		
			Infants	Children	Adults
Tap water (TW)	A1	1900.94 ± 32.46	399.65	444.06	252.56
	A2	836.42 ± 27.52	175.85	195.39	111.13
	A3	1520.76 ± 107.33	319.72	355.25	202.05
	A4	912.45 ± 127.51	191.83	213.15	121.23
	A5	1748.87 ± 97.29	367.68	408.54	232.35
	Average	1383.89 ± 78.42	290.95	323.28	183.86
Water treatment plants (WTP)	B1	760.38 ± 30.44	159.86	177.62	101.02
	B2	76.04 ± 8.02	15.99	17.76	10.1
	B3	304.15 ± 30.44	63.94	71.05	40.41
	B4	152.08 ± 13.99	31.97	35.52	20.2
	B5	532.26 ± 96.4	111.9	124.34	70.72
	Average	364.98 ± 35.86	76.73	85.26	48.49
Reverse osmosis water (ROW)	C1	608.3 ± 33.65	127.89	142.1	80.82
	C2	532.26 ± 34.04	111.9	124.33	70.72
	C3	152.08 ± 13.99	31.97	35.52	20.2
	C4	456.23 ± 66.39	95.92	106.57	60.61
	C5	760.38 ± 38.24	159.86	177.62	101.02
	Average	501.85 ± 37.26	105.51	117.23	66.67
Bottled drinking water (BDW)	D1	456.23 ± 41.16	95.92	106.57	60.61
	D2	152.08 ± 46.75	31.97	35.52	20.2
	D3	76.04 ± 18.49	15.99	17.76	10.1
	D4	228.11 ± 27.52	47.96	53.29	30.31
	D5	228.11 ± 35.59	47.96	53.29	30.31
	Average	228.11 ± 33.9	47.96	53.29	30.31

Radiological and toxicity hazards

ECR associated with ingestion of ^{222}Rn and ^{226}Ra in the drinking water in Al-Diwaniyah city was assessed in terms of mortality and morbidity risks, as shown in Table 3. ECR due to ingestion of ^{222}Rn in all water samples in Al-Diwaniyah city varied from 0.14×10^{-6} to 3.75×10^{-6}, with average value of 2.72×10^{-6} in TW, 0.72×10^{-6} in WTP, 1.00×10^{-6} in ROW, and 0.46×10^{-6} in BDW.

The calculated cancer-mortality risk caused by ingestion of ^{226}Ra in all drinking water samples in Al-Diwaniyah city varied from 0.18×10^{-4} to 4.52×10^{-4}, with average value of 3.29×10^{-4} in TW, 0.87×10^{-4} in WTP, 1.19×10^{-4} in ROW, and 0.54×10^{-4} in BDW. Whereas cancer-morbidity risk in all drinking water samples in Al-Diwaniyah city varied from 0.26×10^{-4} to 6.56×10^{-4}, with average value of 4.77×10^{-4} in TW, 1.26×10^{-4} in WTP, 1.73×10^{-4} in ROW, and 0.79×10^{-4} in BDW.

The calculated LADD caused by ingestion of ^{226}Ra in the drinking water is also shown in Table 3. ranging from 0.91×10^{-6} to 0.04×10^{-6} µg/kg.day, with average value of 0.67×10^{-6} µg/kg.day in TW, 0.18×10^{-6} µg/kg.day in WTP, (0.24×10^{-6}) µg/kg.day in ROW, and (0.11×10^{-6}) µg/kg.day in BDW.

All values of both Radiological hazards caused by ingestion of ^{222}Ra and ^{226}Ra in the drinking water samples were below acceptable limit of 10^{-3} according to EPA [35,45]. So, cancer-mortality risk for drinking water samples was considered to be negligible. However, it is preferable to avoid using TW as drinking water directly.

The values of LADD obtained in our work are much lower than the maximum permissible value of 0.6 µg/kg.day recommended for drinking water by EPA [45,35].

Table 3. Radiological and chemical hazards in drinking water in Al-Diwaniyah city.

Sample type	Sample name	Radiological hazard of ^{222}Rn and ^{226}Ra			Chemical risk of ^{226}Ra
		ECR of ^{222}Rn $\times 10^{-6}$	Cancer-mortality risk of ^{226}Ra $\times 10^{-4}$	Cancer-morbidity risk of ^{226}Ra $\times 10^{-4}$	LADD $\mu g/kg.day$ $\times 10^{-6}$
Tap water (TW)	A1	3.75	4.52	6.56	0.91
	A2	1.65	1.99	2.89	0.40
	A3	2.98	3.62	5.25	0.73
	A4	1.79	2.17	3.15	0.44
	A5	3.43	4.16	6.03	0.84
	Average	2.72	3.29	4.77	0.67
Water treatment plants (WTP)	B1	1.51	1.81	2.62	0.37
	B2	0.14	0.18	0.26	0.04
	B3	0.60	0.72	1.05	0.15
	B4	0.32	0.36	0.52	0.07
	B5	1.05	1.27	1.84	0.26
	Average	0.72	0.87	1.26	0.18
Reverse osmosis water (ROW)	C1	1.19	1.45	2.10	0.29
	C2	1.05	1.27	1.84	0.26
	C3	0.32	0.36	0.52	0.07
	C4	0.91	1.09	1.58	0.22
	C5	1.51	1.81	2.62	0.37
	Average	1.00	1.19	1.73	0.24
Bottled drinking water (BDW)	D1	0.91	1.09	1.57	0.22
	D2	0.32	0.36	0.52	0.07
	D3	0.14	0.18	0.26	0.04
	D4	0.46	0.54	0.79	0.11
	D5	0.46	0.54	0.79	0.11
	Average	0.46	0.54	0.79	0.11

When calculating the percentage of radiological and toxicity hazards associated with ingestion of ^{222}Rn and ^{226}Ra in drinking water in Al-Diwaniyah city, it was found that TW contributes 56 % of it, while other types of drinking water (WTP with 15 %, ROW with 20 % and BDW with 9 %) contribute 44 % of it, as presented in Fig. 4. Radiological and toxicity risks of BDW are the smallest, as a result of the low concentrations of ^{222}Rn and ^{226}Ra in that water). The reason for this can be attributed to the fact that BDW is produced in large factories whose equipment may be subject to periodic maintenance, in addition to government health oversight. While the radiation and toxicity risks in the local WTP were slightly higher than in BDW, the decrease in these risks can be attributed to the same reasons we mentioned for BDW. Still, the local WTP has limited capabilities, which could be the reason for the minimal increase in risks to health status of water from local WTP compared to BDW produced by large factories. Radiological and toxicity risks associated with ROW were larger than those of BDW and WTP. This could be because ROW devices do not have specific mandatory periodic maintenance and are not subject to government oversight; rather, their maintenance depends on the residents of the house themselves. TW lacks the additional filters contained in BDW, WTP, and ROW, so it has significantly greater radiation and toxicity risks than other sources.

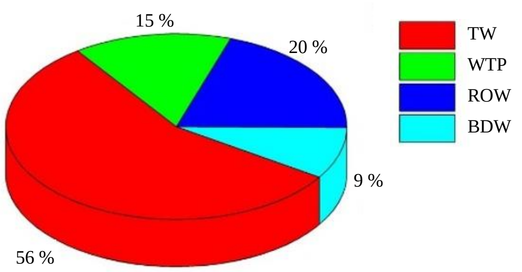

Fig. 4. Percentage of radiological and toxicity hazards for each type of water.

Comparison of ^{222}Rn and ^{226}Ra concentrations with other studies

The studied radionuclide concentrations were compared with worldwide works in Table 4. ^{222}Rn concentration in water samples from other regions in Iraq are comparable with our work, whereas ^{222}Rn concentration is higher in water samples of Saudi Arabia, Iran, Jordan, Turkey, Kuwait, and India.

^{226}Ra concentration in water samples from other regions in Iraq (Thi-Qar, Baghdad, Erbil, and Al-Hurrah) is also comparable with this work. However, ^{226}Ra concentration is higher in water samples of Iraq (Kurdistan region), Saudi Arabia, Egypt and Romania. Our results of ^{226}Ra concentration is also less than maximum values of ^{226}Ra concentration in Italy, Finland, Spain, Germany, and Switzerland.

Table 4. Comparison concentration of ^{222}Rn and ^{226}Ra in water worldwide.

Region	Range	Average	Type of water	Reference
		^{222}Rn		
Al-Diwaniyah, Iraq	98.89- 224.75 mBq /L	163.62 mBq /L	Tap water	Present study
	8.99-89.9 mBq /L	43.15 mBq/L	Water treatment plants	Present study
	17.98 - 89.9 mBq/L	59.33 mBq/L	Reverse osmosis water	Present study
	8.99 - 53.94 mBq/L	26.97 mBq/L	Bottled drinking water	Present study
Thi-Qar, Iraq	0.108 - 0.223 Bq /L	0.175 Bq /L	Tap water	[46]
Wassit, Iraq	0.325- 0.820 Bq /L	0.563 Bq /L	Tap water	[47]
Kirkuk, Iraq	0.07 -5.01 Bq /L	0.97 Bq/L	drinking water	[48]
Babylon, Iraq	0.072- 0.325 Bq /L	0.183 Bq /L	drinking water	[49]
Samawa, Iraq	0.015- 1.01 Bq /L	0.174 Bq /L	drinking water	[50]
Dammam, Saudi Arabia	0.11- 9.2 Bq/L		drinking water	[51]
Mashhad, Iran		2.15 Bq /L	Surface water	[52]
		11.44 Bq /L	Tap water	[52]
Amman, Jordan		3.9 Bq/L	Tap water	[53]
Sakarya, Turkey	0.75 - 22.8 Bq/L	5.41 Bq/L	bottled water	[54]
Kuwait	1.02 - 6.05 Bq/L	2.97 Bq/L	Bottled Mineral drinking water	[55]
Haryana, India	16.06 - 57.35 Bq/L	32.98 Bq/L	drinking water	[56]
		226Ra		
Al-Diwaniyah, Iraq	836.42 - 1900.94 mBq /L	1383.89 mBq /L	Tap water	Present study
	76.04 - 760.38 mBq /L	364.98 mBq/L	Water treatment plants	Present study
	152.08 - 760.38mBq/L	501.85 mBq/L	Reverse osmosis water	Present study
	76.04 - 456.23 mBq/L	228.11 mBq/L	Bottled drinking water	Present study
Thi-Qar, Iraq	0.633 - 5.273 Bq/L	3.41 Bq/L	Tap water	[57]
Baghdad, Iraq	0.12 - 0.35 Bq/L	0.29 Bq/L	Water treatment plants	[58]
Erbil, Iraq	0.01-0.65		drinking water	[2]
Al-Hurrah, Iraq	ND* - 2.92 Bq/L	1.84 Bq/L	drinking water	[59]
Kurdistan region, Iraq	42.335 - 102.209 Bq/L	75.675 Bq/L	drinking water	[44]
Saudi Arabia	11.31 - 27.50 Bq/L		drinking water	[60]
Fayoum depression, Egypt	1.70 - 5.70 Bq/kg	2.88 Bq/kg	Tap water	[61]
Romania	0.6 - 3.0 Bq/L		drinking water	[62]
Italy	0.0002-1.2 Bq/L		drinking water	[63]
Finland	0.010-49 Bq/L		drinking water	[63]
Spain	<0.02-4 Bq/L		drinking water	[63]
Germany	0.001-1.8 Bq/L		drinking water	[63]
Switzerland	0-1.5 Bq/L		drinking water	[63]

CONCLUSION

The measured ^{222}Rn concentration in all water samples from Al-Diwaniyah city was much lower than limits recommended by WHO, UNSCEAR, and EPA. The measured effective ^{226}Ra content in three tap water samples from Al-Diwaniyah city is higher than that recommended by WHO, but these values and all other values of effective ^{226}Ra content in water samples were much below maximum acceptable limit recommended by IAEA.

Values of ^{222}Rn concentration and effective ^{226}Ra content obtained in TW are greater than those in WTP, ROW, and BDW. This variation is natural because additional filters in WTP, ROW, and BDW reduce concentrations of radionuclides in them.

AED determined in all water samples are found to be lower than limits reported by UNSCEAR, ICRP, and Jordanian level. ECR associated with ingestion of ^{222}Rn and ^{226}Ra, and LADD associated with ingestion of ^{226}Ra in drinking water samples are found to be lower than acceptable limits reported by EPA.

We believe, according to our results, there are no radiological and chemical threats to population due to ^{222}Rn concentration and effective ^{226}Ra content revealed in water samples. However, we advise, for more safety, to avoid using tap water directly as drinking water.

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AUTHOR CONTRIBUTION

The authors collectively participated in shaping the final manuscript. The experiment was conducted by First author. Second author proposed the study idea and written the manuscript. Third author contributed to the calculation of some results. All authors thoroughly reviewed and endorsed the ultimate version of the paper.

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