

^{222}Rn , ^{226}Ra and ^{238}U concentration in water samples for some marshes in Dhi-Qar governorate, Iraq

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ABSTRACT

Radon (^{222}Rn), radium (^{226}Ra) and uranium (^{238}U) concentration in the samples of marshes' water have been measured. The samples were collected from various places at the marshes, in Dhi-Qar governorate. The method that used in the present study is the can technique by Solid State Nuclear Track Detectors (SSNTDs) with CR-39 detectors. Also, it was determined the average internal effective dose risk (AED), with lifetime cancer risk due to ingestion of ^{222}Rn and ^{226}Ra in drinking water. The average values of ^{222}Rn , ^{226}Ra and uranium ^{238}U concentration in water samples were found to be $288.02 \pm 31.21 \text{ Bq/m}^3$, $0.45 \pm 0.04 \text{ Bq/L}$, and $0.60 \pm 0.06 \text{ ppm}$, respectively. The average values of AED (in mSv/y unit) caused by ingestion of ^{222}Rn and ^{226}Ra in the samples of the study were found to be 0.019 ± 0.002 and 0.093 ± 0.01 , respectively. The average values of total AED and lifetime cancer risk values were calculated to be $0.11 \pm 0.01 \text{ mSv/y}$ and $(4.34 \pm 0.47) \times 10^{-4}$, respectively. The average concentration values of ^{222}Rn and ^{226}Ra were found to be within the global average limitations (0.4 Bq/L), and (1 Bq/L) that are recommended by World Health Organization (WHO) in 1993 and 2011, while the average of ^{238}U concentrations were higher than that of the global average limitation (0.566 ppm) that was recommended by Environmental Protection Agency (EPA). When some results of AED due to ^{222}Rn and ^{226}Ra concentrations, in the samples under study, were compared with the worldwide median value it was found that the lifetime cancer risk in all samples of the present study were higher than the safety limit for the healthy drinking water. Therefore, consuming the water of marshes in the Dhi-Qar Governorate, Iraq, for cooking and drinking (which is contaminated with alpha emitters like ^{222}Rn , ^{226}Ra , and ^{238}U) may lead to a considerable variation in the internal effective dose.

Key words: alpha emitters, SSNTD, water and marshes in Dhi-Qar

HIGHLIGHT

- In this manuscript, I have been affording in a truly innovative way the issue to put the basis towards the realization for the first time of a baseline for assessment of the exposure of Iraq's people to lifetime cancer risk and annual effective dose assessment due to alpha emitters concentrations in water of marshes in Dhi-Qar Governorate, Iraq. The results show that the cancer risk in samples is higher than the world.

1. INTRODUCTION

It has been reported that naturally originated radiation is among the biggest contributors to the accumulative radiation dose that the world population receives. A persistent population exposure to radiation at a specific location, and for some period of time, may be one cause of the hazards of radiation to the exposed population (L'annunzia 2016; Mirdoraghi *et al.* 2020). The most common forms of ionization radiation are alpha particles such as ^{222}Rn , ^{226}Ra , and ^{238}U . These three elements occur naturally in the environment and are found in very trace amounts in rocks, soil, water and plants (L'annunzia 2012). Water is indispensable for life; therefore, it is supposed to be radioactive contamination free. The water has two important closely related measures, they are: quantity and quality. Naturally, the water is known to have certain impurities: water quality is a matter of the utmost priority when the environment is considered. The resources of water, in any country, would impact food production process, public health, development of industries, and consequently its economy (Murray 1981). The water people drink can also contain amount radionuclides: the common radionuclides are ^{40}K , ^{226}Ra and ^{238}U and their

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associated progeny (Charles *et al.* 2010). Examples of the radioactive nuclides include uranium, radium, and radon can be existed in the air, soil, food, and water. Inhaling and/or ingesting of these radionuclides in larger amounts than that of the safe levels, can be turned into health hazards (Attix 2008). The levels of radon concentrations in groundwater is 11 kBq/m³ (11Bq/L) set by United States Environmental Protection Agency (USEPA) (Raymond *et al.* 2007), while in drinking water is 400 Bq/m³(0.4 Bq/L) that are the recommended levels by WHO Guidelines for drinking water quality (WHO 1993, 2011). In this regard, the priority of the health system in any developing country is a profound supply of clean water. Geographic information system (GIS) technology has been widely used in various fields, such as agriculture, business, geography, ecology, electricity and gas, emergency management and public safety, environmental management, forestry, health care, education, mining and geosciences, real estate, remote sensing, telecommunications, and transportation as well as water distribution and resources (Abojassim & Rasheed 2019; Saleh *et al.* 2019; Kiani *et al.* 2021). The study of natural radioactivity (alpha emitters) was carried out by many investigators in different countries around Iraq and others throughout the world (Abbasi & Bashiry 2016; Abojassim & Mohammed 2017; Abojassim *et al.* 2017a, 2017b, 2019; El-TaHER *et al.* 2020). Many regions in the Dhi-Qar governorate have been bombarded in the recent wars that Iraq was exposed to in the previous period. Water marshes and their direct impact on the lives of people, animals, and agricultural crops are important. As well, there is no comprehensive study of alpha emitters like ²²²Rn, ²²⁶Ra, and ²³⁸U, lifetime cancer risk water, and radiation mapping marshes in the Dhi-Qar Governorate. Indeed, the present study is the first attempt to evaluate the risk related to radon presence in water samples of marshes (Ahwar) at Dhi-Qar Governorate. Therefore, the aim of this work was to estimate the concentrations of radon, radium, and uranium in water samples from marshes in Dhi-Qar Governorate, Iraq, using CR-39 detector. Also, evaluation of the AED and lifetime cancer risk due to consumption of ²²²Rn and ²²⁶Ra in the drinking water is estimated. GIS techniques were used to draw a map that depicts all alpha emitters found in the present study.

2. MATERIALS AND METHODS

2.1. Study area and collection samples

Dhi-Qar is one of the Iraqi governorates; it has the greatest history in the world: it is the place where the first writing letters were invented, so one can proudly say that what you see of human prosperity and development, in fact is owed to that great city and its marshes. It lies on the banks of the Euphrates River, 370 km southeast of Baghdad, capital of Iraq. It is located 31°05'388.8"N latitudes, 46°26'66.7"E 32.05 longitudes. It rises about 9 m above the sea level (Jassim & Goff 2006). The marshes of the south of Iraq are known to include areas suitable for the growth and reproduction of algae. Furthermore, they are famous in their biodiversity and cultural richness. The two rivers of Iraq (i.e. Tigris and Euphrates) have created about 15,000 km² of wetlands known as Mesopotamian marshes in Iraq. These wetlands include complicated inter-connected shallow freshwater lakes and marshlands. These lakes and marshlands are considered as the most extensive wetland of the ecosystem of the middle east (Brasington 2002). Twenty water samples were collected from different marshes at Dhi-Qar Governorate for the study: the period of collection from 1/1/2020 to 1/3/2020 to measure the ²²²Rn, ²²⁶Ra, and ²³⁸U levels. Sample locations were determined by coordinates using the Global Positioning System (GPS) which is a satellite navigation system used to determine the ground position of any object. The locations of the samples and name of marshes (Ahwar) at the Dhi-Qar governorate are shown in Figure 1 drawn using GIS technique by ArcGIS 10.7.1. Water samples were measured directly without any preparation. The collected samples were stored for about one month prior to counting. The storage is done in order that the secular equilibrium is reached between ²²²Rn and its parent ²²⁶Ra within the uranium chain (Alaboodi *et al.* 2020).

2.2. Samples measurement

0.25 L samples were collected in plastic cups with radius of 3.5 cm and length of 18 cm. Solid state nuclear track detector was used in this study as shown in Figure 2. The detector name CR-39 (C₁₂H₁₈O₇) and it was purchased from TASTRAK Analysis System Ltd, UK: TASTRAK. A sheet of CR-39 detector was cut into pieces which of 2 cm × 2 cm dimensions, thickness 1 mm, and density of 1.3 gm/cm³. A piece of the CR-39 detector was positioned at the bottom of each cover of the cylinders. The samples were set at the bottom of the cylinders, then the cylinders were sealed, and stored at room temperature for 90 days (exposure time). At the end of the exposure time, the CR-39 detectors were etched of sodium hydroxide (NaOH) solution at 70 °C temperature for 5 h, with 6.25 normality solution (Abojassim & Mohammed 2017; Abojassim *et al.* 2017a, 2017b). Following this step, the detectors were washed using distilled water. Then, a microscopic treatment was performed to calculate the concentrations of radon using the optical microscope (Novel, China). The magnifying power of the microscope used to count tracks of 400X, where the object piece is 40X. The detector surface dividing into 10 areas of view to count the

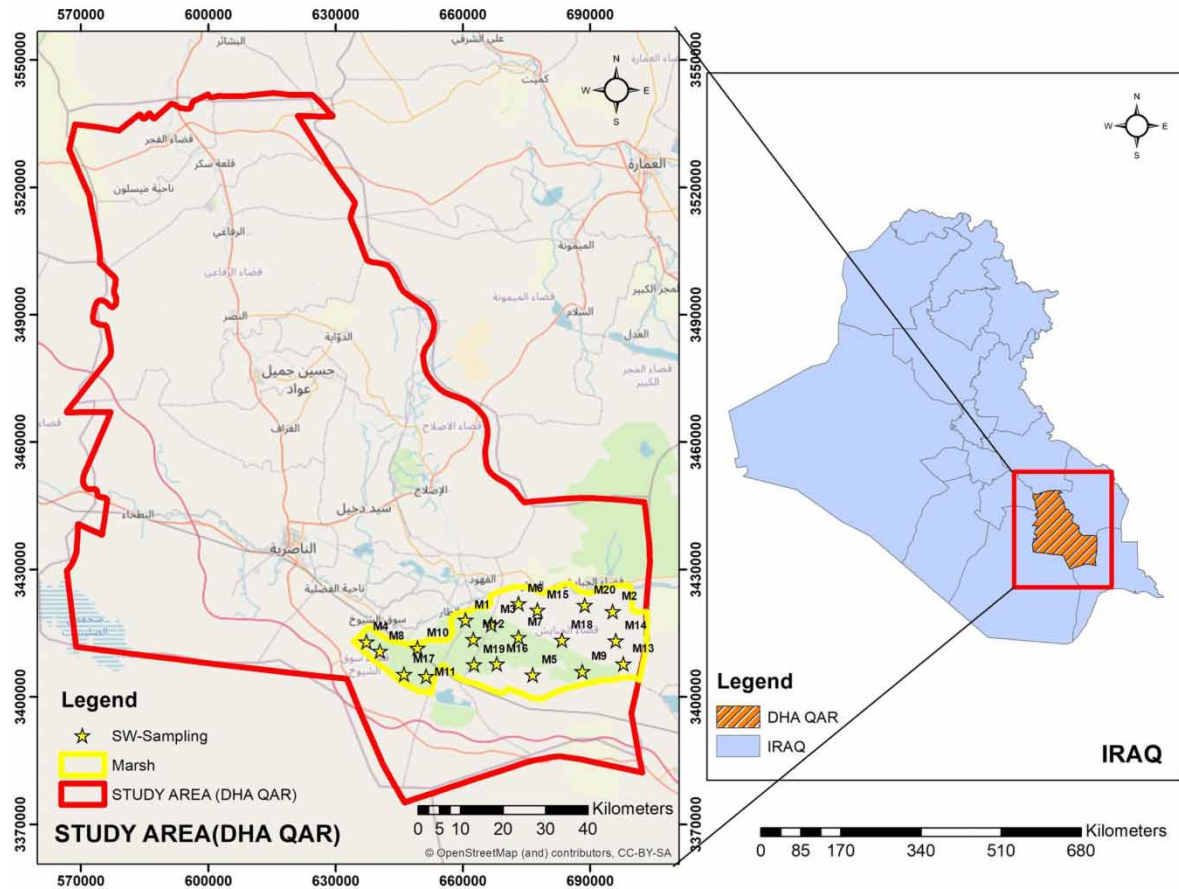


Figure 1 | Study area and sampling places.

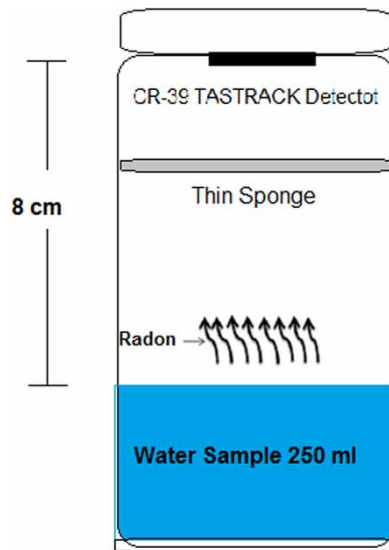


Figure 2 | Diagram of for radon measurements.

alpha particles and taking multiple pictures of each region by using a digital camera connecting with computer via cable USB after installing the camera program on the computer to measure a number of tracks. The background correction was done via the subtraction of the background level from the counted alpha track density.

2.3. The calculations

^{222}Rn concentrations in the air of the tube (C_{Rn}^a) was calculated using the following formula (Mayya *et al.* 1998):

$$C_{\text{Rn}}^a \left(\frac{\text{Bq}}{\text{m}^3} \right) = \frac{\rho}{K t} \quad (1)$$

where ρ is the track density on the detector (Tr/cm^2), t is the exposure time (90 days), and K is the calibration factor. The calibration factor for the detector had a range of 0.5–3 days for the Radium-226 (Radon source) whose activity of 3.3 kBq was calculated to be (0.2217 ± 0.033) (track/cm^2)/($\text{Bq}\cdot\text{day}/\text{m}^3$). These values agreed well with the reported values in many works (Abojassim 2013; Subber *et al.* 2015; Mohammed 2016; Alkhafaji *et al.* 2019).

The concentration of the radon in the sample (C_{Rn}^s), can be calculated using the following Equation (2) (Elzain 2014):

$$C_{\text{Rn}}^s \left(\frac{\text{Bq}}{\text{m}^3} \right) = \frac{C_{\text{Rn}}^a \lambda_{\text{Rn}} h t}{l} \quad (2)$$

where λ_{Rn} is the decay constant of ^{222}Rn (0.1814 d^{-1}), h is the distance from the surface of the sample to the detector, t is the exposure time, and l is the thickness of the sample in the tube.

The activity concentration of radon inside sample ($C_{\text{Rn}}^{s,ac}$) was determined using the relation (3) (Abojassim 2018; Abojassim & Lawi 2018; Mohsen & Abojassim 2019):

$$C_{\text{Rn}}^{s,ac} \left(\frac{\text{Bq}}{\text{L}} \right) = \frac{C_{\text{Rn}}^s l A^s}{M^s} \quad (3)$$

where A^s is the surface area of the sample and M^s is the mass of the investigated sample.

Radium activity concentration (^{226}Ra) within the sample ($C_{\text{Ra}}^{s,ac}$) was determined using the relationship (4) (Azam *et al.* 1995):

$$C_{\text{Ra}}^{s,ac} \left(\frac{\text{Bq}}{\text{L}} \right) = \frac{C_{\text{Rn}}^a h A^s}{M^s} \quad (4)$$

The concentration of uranium (C_U^s) in ppm is given by Equation (5) (Sajo *et al.* 1997; Abojassim 2018; Abojassim & Lawi 2018):

$$C_U^s (\text{ppm}) = \frac{M_U^s}{M^s} \quad (5)$$

where M_U^s is the mass of uranium in the sample.

The annual effective dose (AED) due to the ingestion of ^{222}Rn and ^{226}Ra through drinking water for adults was calculated using Equation (6) (Sajo *et al.* 1997):

$$AED \left(\frac{\text{Sv}}{\text{y}} \right) = C \left(\frac{\text{Bq}}{\text{L}} \right) \times WC \left(\frac{\text{L}}{\text{y}} \right) \times DCF \left(\frac{\text{Sv}}{\text{Bq}} \right) \quad (6)$$

where C is the radionuclide activity concentration (^{222}Rn and ^{226}Ra), WC is the annual water consumption for a person (2 L/d) (El-Taher *et al.* 2020) and DCF is the ingestion dose conversion factor for the corresponding radionuclide, which it is equal for radon-222, and radium-226 ingestion by people as $0.0035 \mu\text{Sv}/\text{Bq}$ and $0.28 \mu\text{Sv}/\text{Bq}$ (ICRP 1995; Eckerman *et al.* 1988; UNSCEAR 2001).

The lifetime cancer risk due to ingestion of ^{222}Rn and ^{226}Ra from samples has been calculated according to the Equation (7) (Abojassim & Mohammed 2017; Abojassim *et al.* 2017a, 2017b):

$$\text{Lifetime cancer risk} = AED \times DL \times RF \quad (7)$$

where DL is the duration of life (70 yr) and RF is the risk factor (0.055 Sv^{-1}) recommended by the International Commission on Radiological Protection (ICRP) (Clarke & Bines 2011).

3. RESULTS AND DISCUSSION

To achieve the aim of this study, alpha emitters (^{222}Rn , ^{226}Ra , and ^{238}U) concentrations in water samples from marshes in Dhi-Qar Governorate were studied using SSNTDs with CR-39. The results of ^{222}Rn (C_{Rn}^a , C_{Rn}^s , and $C_{Rn}^{s,ac}$), ^{226}Ra , and ^{238}U concentrations in water samples for selected marshes in Dhi-Qar Governorate are shown in Table 1. The values of C_{Rn}^a ranged between $106.41 \pm 5.32 \text{ Bq/m}^3$ in sample M15 to $645.58 \pm 32.82 \text{ Bq/m}^3$ in the sample M6 with an average value of $288.02 \pm 31.21 \text{ Bq/m}^3$, while the values of C_{Rn}^s and $C_{Rn}^{s,ac}$ in Bq/L units were ranged from 5.21 ± 0.26 to 31.61 ± 1.85 with an average value of 14.10 ± 1.52 and from 2.77 ± 0.14 to 16.78 ± 0.84 with an average value of 7.48 ± 0.81 , respectively. Also, from Table 1, it has been found that $C_{Ra}^{s,ac}$ ranged from 0.17 ± 0.01 to $1.03 \pm 0.05 \text{ Bq/L}$, with an average value of $0.45 \pm 0.04 \text{ Bq/L}$. The results of $C_U^{s,ac}$, in ppm units, as shown in Table 1, ranged from 0.22 ± 0.01 to 1.35 ± 0.02 with an average value of 0.60 ± 0.06 . The results of ^{222}Rn concentration in water samples were turn out to be lower than the maximum acceptable limit reported by WHO in 1993 (WHO 1993; Pfister 2000): 0.4 Bq/L (400 Bq/m^3), except samples M6, M9, M10 and M11. Variations in concentration values of radon in the water samples, in the present study, were given. These variations were resulted from several factors such as the geological nature of the area where the samples were collected, their geochemistry and their components (that may vary from one area to another). It should be noted that the pollution that resulted from the radiation may be directly caused by the absorption of radionuclides of the atmosphere. When we compared the values of

Table 1 | Results of radon, radium and uranium in samples under study

No.	Location name	Sample code	^{222}Rn						^{226}Ra		^{238}U	
			C_{Rn}^a (Bq/m^3)		C_{Rn}^s (KBq/m^3)		$C_{Rn}^{s,ac}$ (Bq/L)		$C_{Ra}^{s,ac}$ (Bq/L)		$C_U^{s,ac}$ (ppm)	
			Average	\pm S.E	Average	\pm S.E	Average	\pm S.E	Average	\pm S.E	Average	\pm S.E
1	Al Hammar (1)	M1	290.86	14.54	14.25	0.71	7.56	0.38	0.46	0.02	0.61	0.03
2	Al Chebaish	M2	127.70	6.39	6.25	0.31	3.32	0.17	0.20	0.01	0.27	0.01
3	Al Hammar (2)	M3	248.30	12.42	12.16	0.61	6.45	0.32	0.40	0.02	0.52	0.03
4	Khamisiyah	M4	138.34	6.92	6.78	0.34	3.60	0.18	0.22	0.01	0.29	0.01
5	Umm Nakhleh (1)	M5	170.26	8.51	8.34	0.42	4.43	0.22	0.27	0.01	0.36	0.02
6	AZ 24 (1)	M6	645.58	32.28	31.62	1.58	16.78	0.84	1.03	0.05	1.35	0.07
7	AZ 24 (2)	M7	230.56	11.53	11.29	0.56	5.99	0.30	0.37	0.02	0.48	0.02
8	M2 (1)	M8	156.07	7.80	7.64	0.38	4.06	0.20	0.25	0.01	0.33	0.02
9	M2 (2)	M9	464.67	23.23	22.76	1.14	12.08	0.60	0.74	0.04	0.97	0.05
10	M2 (3)	M10	532.07	26.60	26.06	1.30	13.83	0.69	0.85	0.04	1.12	0.06
11	M5 (1)	M11	415.01	20.75	20.33	1.02	10.79	0.54	0.66	0.03	0.87	0.04
12	M5 (2)	M12	390.18	19.51	19.11	0.96	10.14	0.51	0.62	0.03	0.82	0.04
13	BC3 (1)	M13	319.24	15.96	15.64	0.78	8.30	0.42	0.51	0.03	0.67	0.03
14	BC3 (2)	M14	198.64	9.93	9.73	0.49	5.16	0.26	0.32	0.02	0.42	0.02
15	BC4	M15	106.41	5.32	5.21	0.26	2.77	0.14	0.17	0.01	0.22	0.01
16	Umm Nakhleh (2)	M16	312.15	15.61	15.29	0.76	8.11	0.41	0.50	0.03	0.65	0.03
17	Public Estuary	M17	212.83	10.64	10.42	0.52	5.53	0.28	0.34	0.02	0.45	0.02
18	AlHafar	M18	351.17	17.56	17.20	0.86	9.13	0.46	0.56	0.03	0.74	0.04
19	M4	M19	212.83	10.64	10.42	0.52	5.53	0.28	0.34	0.02	0.45	0.02
20	Abu Subat	M20	237.66	11.88	11.64	0.58	6.18	0.31	0.38	0.02	0.50	0.03
Minimum			106.41 ± 5.32		5.21 ± 0.26		2.77 ± 0.14		0.17 ± 0.01		0.22 ± 0.01	
Maximum			645.58 ± 32.82		31.61 ± 1.85		16.78 ± 0.84		1.03 ± 0.05		1.35 ± 0.02	
Average \pm S.E			288.02 ± 31.21		14.10 ± 1.52		7.48 ± 0.81		0.45 ± 0.04		0.60 ± 0.06	

(C_{Rn}^a) and (C_{Rn}^s) of the investigated metrics (Table 1), it was clear that the radon concentration of the samples itself was much higher than that of the airspace of the tube. This clear difference between the two values can be attributed to the known fact that most the radon atoms of the sample were disintegrated before entering the space of the tube as they had a short decay time of 3.82 d (Sajo *et al.* 1997). In addition to this, the existence of the radium (i.e. radon parent) inside the sample is not in the airspace of the tube. It can be concluded from Table 2 that the activities of alpha due to radium in water samples were found to be lower than those caused by radon. These observations can be clarified by the fact that radon has the shorter half-life (3.82 d) than that of radium (1,600 y) (Elzain 2014; Abojassim & Mohammed 2017; Abojassim *et al.* 2017a, 2017b). The results of $C_{Ra}^{s,ac}$ for samples of water in the present study were found to be within the global average limitations (1 Bq/L) that are recommended by WHO (2011), except sample M6 was larger than global average limitations.

The values of $C_U^{s,ac}$ for most water specimens of Marshes in Dhi-Qar Governorate are higher than the global average limitations (0.566 ppm) in the drinking water according to EPA organization (Raymond *et al.* 2007).

Figures 3–5 show the maps of C_{Rn}^a , $C_{Ra}^{s,ac}$, and $C_U^{s,ac}$ respectively in the water samples of marshes (Ahwar) at Dhi-Qar Governorate that was drawn by GIS technique with ArcGIS 10.7.1. Where different colors were used to distinguish between high, medium, and low quantities.

AED due to activity of ^{222}Rn , ^{226}Ra , and the total of AED in water samples in the present study are shown in Table 2. It was found that the AED in mSv/y for ^{222}Rn , ^{226}Ra , and total of AED were ranged from 0.007 to 0.043, with an average value of 0.019 ± 0.002 , from 0.035 to 0.210, with an average value of 0.093 ± 0.01 respectively. While the values of the total AED ranged from 0.04 mSv/y to 0.25 mSv/y, with an average value of 0.11 ± 0.01 mSv/y. Ingestion of radioactive contaminated food or drinks (contaminated water, juices, tea, coffee, etc.) contribute to around 0.3 mSv/y of the average human exposure to

Table 2 | Results of AED and lifetime cancer risk in samples under study

No.	Sample code	AED (mSv/y)		Total AED (mSv/y)	Lifetime cancer risk $\times 10^{-4}$
		^{222}Rn	^{226}Ra		
1	M1	0.019	0.095	0.11	4.39
2	M2	0.008	0.042	0.05	1.93
3	M3	0.016	0.081	0.10	3.75
4	M4	0.009	0.045	0.05	2.09
5	M5	0.011	0.055	0.07	2.57
6	M6	0.043	0.210	0.25	9.74
7	M7	0.015	0.075	0.09	3.48
8	M8	0.010	0.051	0.06	2.35
9	M9	0.031	0.151	0.18	7.01
10	M10	0.035	0.173	0.21	8.03
11	M11	0.028	0.135	0.16	6.26
12	M12	0.026	0.127	0.15	5.89
13	M13	0.021	0.104	0.13	4.82
14	M14	0.013	0.065	0.08	3.00
15	M15	0.007	0.035	0.04	1.61
16	M16	0.021	0.102	0.12	4.71
17	M17	0.014	0.069	0.08	3.21
18	M18	0.023	0.114	0.14	5.30
19	M19	0.014	0.069	0.08	3.21
20	M20	0.016	0.077	0.09	3.58
Minimum		0.007	0.035	0.04	1.61
Maximum		0.043	0.210	0.25	9.74
Average \pm S.E		0.019 ± 0.002	0.093 ± 0.01	0.11 ± 0.01	4.34 ± 0.47

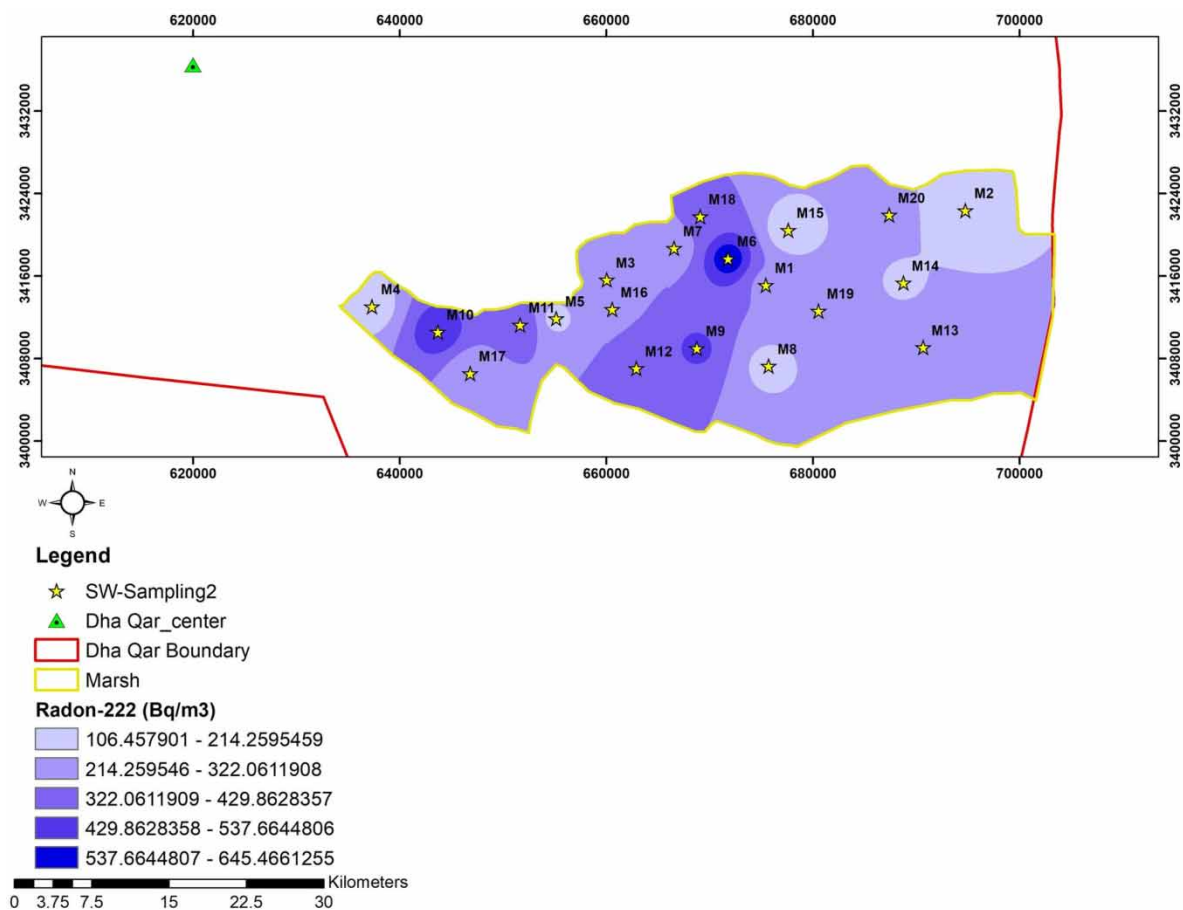


Figure 3 | The map of C_{Rn}^a in the present study.

radiation from natural sources. The total suggestive radiation dose is restricted to about 0.1 mSv/y through the intake of radionuclides via drinking of the water (WHO 2011). If these radionuclides have resulted in more than 0.1 mSv/y dose limit, then the resulting AED will be the summation of AED equivalents from each of the radioelements present in the food or drink. The mean of the total AED in the present study was 0.11 mSv/y for two radionuclides (^{222}Rn and ^{226}Ra), which is lower than an action limit of 1.0 mSv/y (excluding ^{222}Rn). The average AED from ingested ^{222}Rn in drinking water was calculated to be as low as 0.002 mSv/y (UNSCEAR 2001; Somlai *et al.* 2007). The lifetime cancer risk due to water intake was also evaluated. The biggest lifetime risk resulted from water intake, seen in the sample M6, while the lowest lifetime risk was found in the sample M15. The lifetime risk from ingestion of ^{222}Rn and ^{226}Ra in water samples for the inhabitants of some marshes in Dhi-Qar Governorate, Iraq, was found ranging from 1.61×10^{-4} to 9.74×10^{-4} with an average value of $(4.34 \pm 0.47) \times 10^{-4}$, which exceeds the admissible limit of 10^{-4} (Alomari *et al.* 2019). Figures 6 and 7 show the maps of total AED and lifetime cancer risk respectively in the water samples of marshes (Ahwar) at Dhi-Qar Governorate, that were drawn by GIS technique, with ArcGIS 10.7.1, where different colors were used to distinguish between high, medium, and low quantities of these radioactive elements in drinking water. These findings of alpha emissions were varied across all water samples that were studied, due to the radioactivity in origin, or natural materials that compose the contents of the samples such as chemical material, and from one another important factor which is the geology. Indeed, the present study is the first attempt to evaluate the risk related to radon presence in water samples of marshes (Ahwar) at Dhi-Qar Governorate. The results of the current study were compared with the results of other local and international studies, which were conducted to measure the concentration of radon gas in water, as shown in Table 3. Through these studies, it is of note that the average of ^{222}Rn concentration in the waters of the present study were within the other studies in Table 3. The total number of locations measured should be increased in future studies. It was found that the radon concentration in most of the samples under study was not high

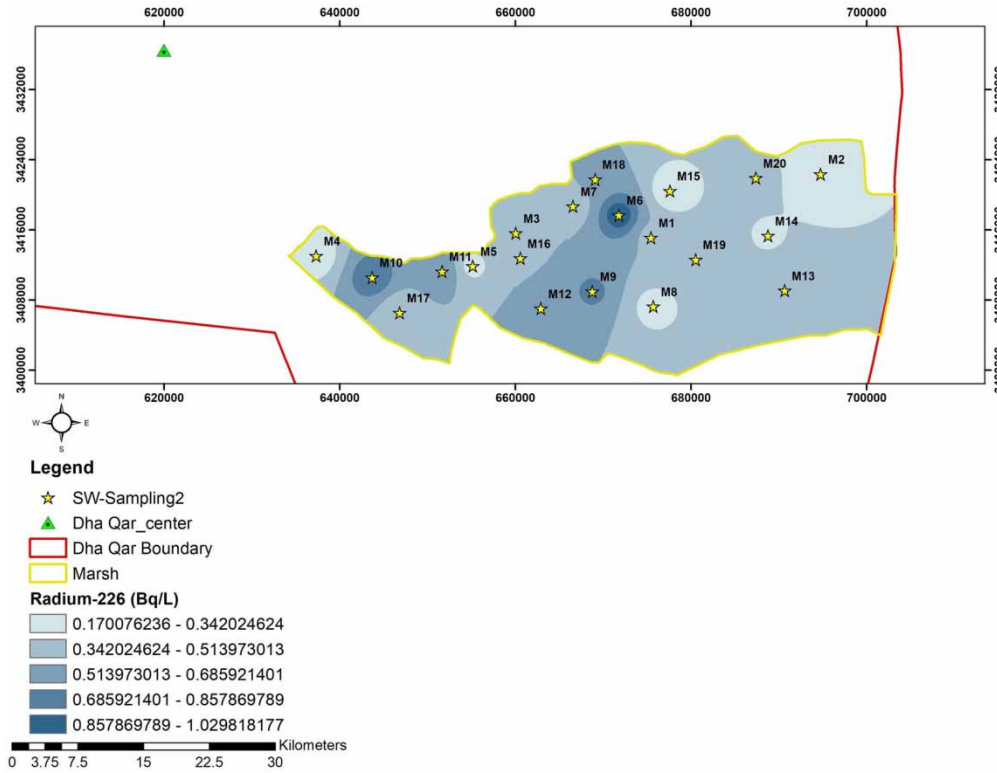


Figure 4 | The map of $C_{Ra}^{s,ac}$ in the present study.

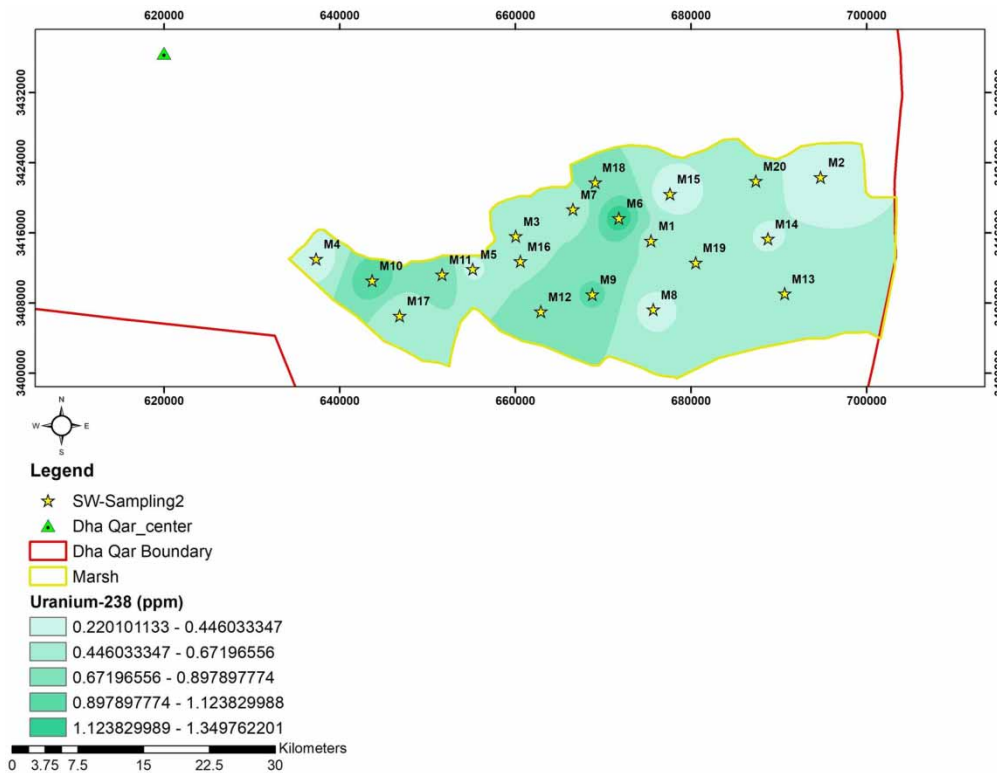


Figure 5 | The map of $C_U^{s,ac}$ in the present study.

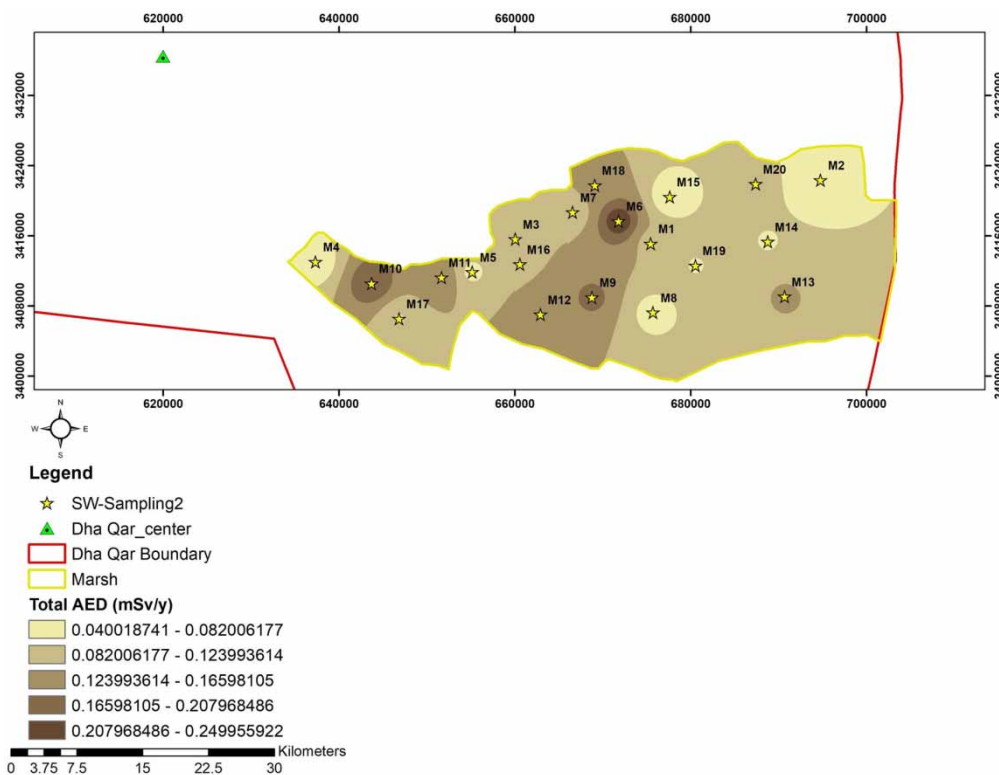


Figure 6 | The map of total AED in the present study.

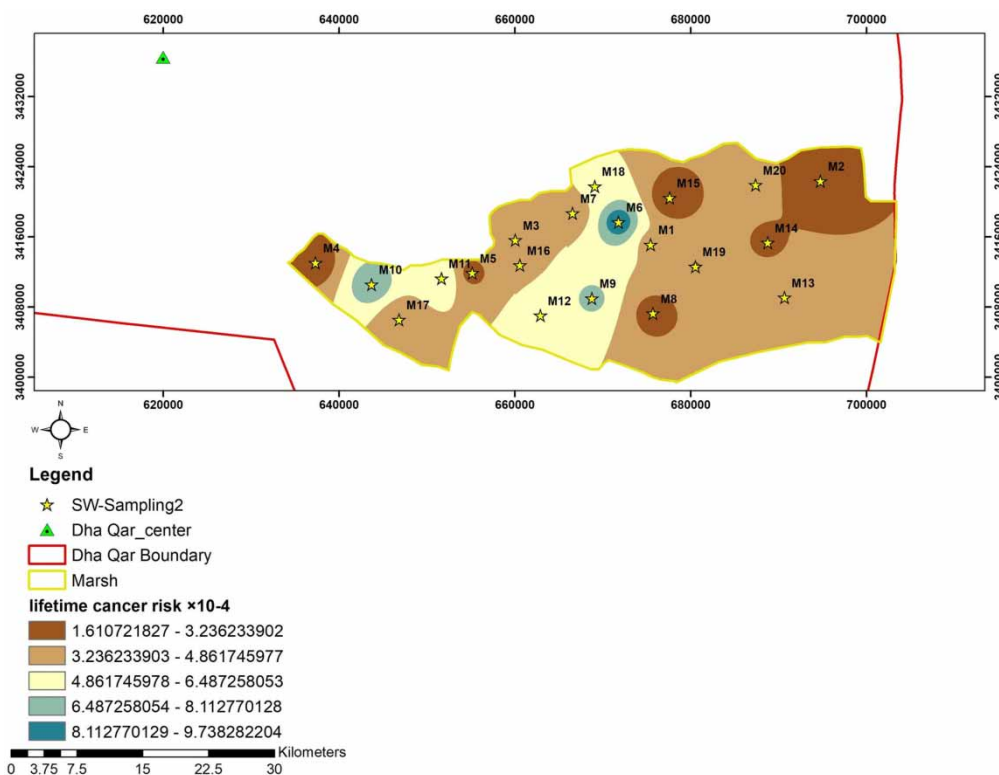


Figure 7 | The map of lifetime cancer risk in the present study.

Table 3 | Comparing the results of ^{222}Rn concentration in the current study with other local and international studies

No.	Country	Average of ^{222}Rn concentrations (Bq/m ³)	References
1	Saudi Arabia	5,180	El-Taher <i>et al.</i> (2020)
2	Iraq (Najaf)	335	Alaboodi <i>et al.</i> (2020)
3	Sudan	6,930	Elzain (2014)
4	Iraq (Babylon)	290	Mohammed (2014)
5	Iran	3,400	Mowlavi <i>et al.</i> (2009)
6	India	1,280	Shilpa <i>et al.</i> (2017)
	Turkey	680	Oner <i>et al.</i> (2009)
7	Present study	288.02 ± 31.21	—

and not significant to represent a health hazard from the point of view of this study. Certainly, this study was conducted to provide a health-oriented radon assessment of marshes in the Dhi-Qar Governorate, address long-term management goals, especially from the environmental point of view. The results provide a framework for future studies that should include a large and broader survey of radon concentration of water as well as other natural radioactivity in Iraq.

4. CONCLUSIONS

The concentrations of radon-222, radium-226, and uranium-238 in water samples of marshes (Ahwar) at Dhi-Qar Governorate were studied. Most results of radon concentrations in the present samples are within that recommended WHO (400 Bq/m³). Also, it was found that the values of ^{226}Ra in all samples were lower than that of the global average limits (1Bq/L) recommended by WHO, except sample M6, where the ^{238}U concentrations were higher than global average limitations (0.566 ppm) which is recommended by the EPA in healthy drinking water. The average value of total AED from radon-222 and radium-226 in water for drinking for all samples under study were lower than an effective limit of 1.0 mSv/y, and were very close to the radiation dose limit of 0.1 mSv/y acceptable level of radionuclides to be ingested via drinking water, as recommended by WHO. It is also found that the lifetime cancer risk in most samples exceeds the allowed maximum level of (10^{-4}). Consequently, measurement of alpha emitters and radiological risks due to radon-222 and radium-226 of water samples collected from some marshes (Ahwar) at Dhi-Qar Governorate, revealed that some water samples do not comply with the global average limitation standards. Therefore, the water of the study area is not suitable for human drinking but suitable for other activities.

5. RECOMMENDATIONS

Through the present study and according to the obtained results and the conclusions, many ideas for the suggestion concerning the works and important recommendations can be outlined.

1. The need to routinely monitor the concentration of alpha emitters in all types of water for Dhi-Qar Governorate.
2. Provide science and academic institutions that are modern enough to conduct their own environmental tests of radioactivity programs.

CONFLICT OF INTEREST

There was no conflict of interest in this study.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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