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Measurement of Radon Concentrations and Surface Exhalation Rates using CR-39 detector in Soil Samples of Al-Diwaniyah Governorate, Iraq

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ABSTRACT

Introduction: Natural radioactivity in the soil is considered a major indicator of radiological contamination. Primordial radionuclides are the main source of natural radioactivity. Natural radioactivity transfers radionuclides into the environment and poses radiation hazards to people's health. Therefore, the present study aimed to determine the radon concentration and surface exhalation rate in soil samples collected from different locations of industrial, agricultural, and residential of Al-Diwaniyah governorate, southern Iraq.
Material and Methods: In the present study, five different depths of 0, 10, 20, 30, and 40 cm were taken from each location. The radon concentration and exhalation rate were measured using CR-39 detectors (Pershore Moulding Ltd, UK). The CR-39 detectors were left inside plastic cans with soil samples. The tracks of nuclear particles were recorded using an optical microscope.
Results: Results of the present study showed that the radon concentrations in soil samples ranged from 163.58 to 689.89 Bq/m^3 with a mean value of 350.64 Bq/m^3, while surface exhalation rate was found to be ranged from 0.015 Bq/m^2.h to 0.063 Bq/m^2.h with an average value of 0.031 Bq/m^2.h. The obtained results demonstrated that the radon concentration and exhalation rate decreased with increased depth of soil.
Conclusion: Based on the current findings, it was found that radon concentrations in all the examined soil samples were within the acceptable value of 600 Bq/m^3, according to the International Commission on Radiological Protection and International Atomic Energy Agency. However, the sample S13 from AL-Hamad village with a mean value of 642.51±22.95 Bq/m^3 was an exception.

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Introduction

Natural radioactivity in the soil is considered a major indicator of radiological contamination. Primordial radionuclides are the main source of natural radioactivity. In addition, natural radioactivity transfers radionuclides into the environment and poses radiation hazards to people's health. Uranium, thorium, and their progeny are the main source of ionizing radiation in the earth crust. Recent studies indicate that more than 50% of the total annual radioactive dose received by people is due to inhalation and ingestion of natural radioactive radon gas and its decay products. Radon is a chemically inert gas and is produced as part of the natural radioactive decay series of radium (^{226}Ra) which is also a product of uranium (^{238}U) decay series [1-4]. Radon is found in three radioactive isotopes ^{219}Rn, ^{220}Rn, and ^{222}Rn with a half-life of 3.96 s, 56.65 s, and 3.82 d, respectively.

In the last few decades, researchers were concerned with the effect of natural radiation on organisms, especially on humans [5]. Radon is a carcinogen and the second leading cause of lung cancer in the United States, According to the US Environmental Protection Agency [6]. Many studies have indicated an association between uranium exposure and increased cancer risks due to inhalation of radon as it was the case with uranium miners during the thirties. The risk of radon gas lies in its quick disintegration which results in release of high energy alpha particles. The α-particles travel into lung tissue and their high energy causes an intestinal local ionization, damaging the tissue with a consequent risk for cancer development [7]. Other radiations may be also released by some of the decay products (e.g., beta and gamma); however, these decay products release much lower energy content, compared to α-particles. Inhaling these radioactive elements can damage the cells that line the lungs. Therefore, indicating that long-exposure to radon can lead to lung cancer [8]. Many researchers measured radon concentrations in the soil of different parts of the world because of the importance of the subject and its impact on the environment and people's health [1, 4]. The aim of the present study was to determine the radon concentration and surface exhalation rate in soil

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samples collected from different locations (industrial, agricultural, and residential) of Al-Diwaniyah governorate southern Iraq, using simple and effective technique of CR-39 nuclear track detectors to detect the alpha particles emitted from radon gas [9, 10]. Al-Diwaniyah governorate has extended over an area of 8,153 km^2 and is located in Euphrates River between latitudes 31.17-32.24ºN longitudes 44.24-45.49ºE as shown in (Figure 1). The soil type of Al-Diwaniyah is clay [11].

Materials and Methods

Sample collection

A total of 100 soil samples were collected from 20 different sites of Al-Diwaniyah, Iraq. The samples were taken from different depths of the soil, including 0, 10, 20, 30, and 40cm.

Samples were collected from various sites (e.g., industrial, agricultural, and residential) and five samples with different depths were taken from each site (Table 1). The clean soil samples were weighed at 0.5kg and their stones, root parts, and gravels were removed. After that, the samples were stocked in plastic containers and were labeled with codes.

Experimental method

The radon concentrations and surface radon exhalation rates in soil samples were determined using solid nuclear track detectors of CR-39 (Pershore Moulding Ltd, UK). Soil samples were heated at 100˚C for 2h using an electric oven. After that, the soil samples were grinded to form a fine powder. About 10g of soil powder was weighed and then placed in plastic cans, where the height and inner diameter of the used plastic cans were 10cm and 5cm, respectively. The track detectors were cut into small pieces with an area of $1.5\times1.5cm^2$. The detectors were fixed on the inside cover and the lid of the plastic can was tightly closed to prevent any radon leakage. The detectors were left inside plastic cans with soil samples for 30 days (Figure 2). After irradiation, the CR-39 detectors were etched in (N=6.25) NaOH solution at a temperature of 60°C for 5 h, as already reported in previous studies [12, 13].

The density tracks were recorded using an optical microscope with magnification 400x according to the following equation [13, 14].

$$Density\ Tracks\ (\rho) = \frac{Average\ number\ of\ total\ tracks}{Area\ of\ field\ view} \quad (1)$$

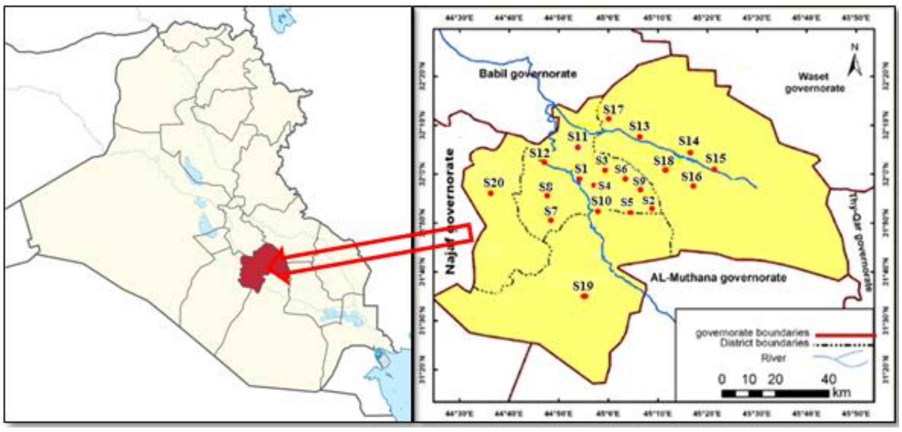

Figure 1. Map of the studied area of Al-Diwaniyah governorate

Table1. Coordinates and natures of the studied areas

Name of area	Sample code	Coordinates	Area classification
Al-Forat district	S1	$32^{O}.03^{/}$ N, $44^{O}.89^{/}$ E	Industrial – Electrical power plant
Al-Thaqlin district	S2	$31^{O}.96^{/}$ N, $44^{O}.95^{/}$ E	Industrial – Factory of plastic and fabric
Al-Askari district	S3	$31^{O}.99^{/}$ N, $44^{O}.94^{/}$ E	Residential
Al-Wahda district	S4	$31^{O}.99^{/}$ N, $44^{O}.95^{/}$ E	Residential – Main road and traffic jam
Al-Jameih district	S5	$31^{O}.97^{/}$ N, $44^{O}.95^{/}$ E	Agricultural
Al-Nahda district	S6	$31^{O}.98^{/}$ N, $44^{O}.95^{/}$ E	Residential
Al-Sinaeiu district	S7	$31^{O}.98^{/}$ N, $44^{O}.89^{/}$ E	Industrial – Car repair garage
Al-jamieih district	S8	$31^{O}.99^{/}$ N, $44^{O}.87^{/}$ E	Residential
Al-Taamim district	S9	$31^{O}.98^{/}$ N, $44^{O}.93^{/}$ E	Residential – Main road and traffic jam
Al- Adharayuh district	S10	$31^{O}.98^{/}$ N, $44^{O}.91^{/}$ E	Agricultural
Al-Dagharah	S11	$32^{O}.06^{/}$ N, $44^{O}.77^{/}$ E	Agricultural
Al-Saniya	S12	$32^{O}.07^{/}$ N, $44^{O}.77^{/}$ E	Agricultural
Al-Hamad village	S13	$31^{O}.99^{/}$ N, $44^{O}.97^{/}$ E	Industrial – Electrical power plant
Afak (Al-Rasul district)	S14	$32^{O}.03^{/}$ N, $45^{O}.14^{/}$ E	Industrial – Car repair garage
Afak (Or district)	S15	$32^{O}.04^{/}$ N, $45^{O}.18^{/}$ E	Residential
Afak (Al-Shirtah district)	S16	$32^{O}.06^{/}$ N, $45^{O}.24^{/}$ E	Residential
Sumer	S17	$32^{O}.14^{/}$ N, $44^{O}.99^{/}$ E	Agricultural
Niffur	S18	$32^{O}.12^{/}$ N, $45^{O}.23^{/}$ E	Residential
Al-Hamza	S19	$31^{O}.73^{/}$ N, $45^{O}.00^{/}$ E	Residential
Al-Sahmiya	S20	$31^{O}.97^{/}$ N, $44^{O}.69^{/}$ E	Industrial – Electrical power plant

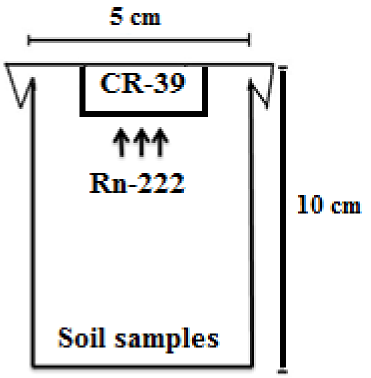

Figure 2. Diagram of the cup technique in soil

Calculation

Radon concentration in the soil samples was measured by comparing the density of the tracks registered by CR-39 detectors and that of the standard samples, according to the relation [15]:

$$C_{\mathrm{Rn}} = \rho_n \left(\frac{C_{Rs}}{\rho_s}\right) = \frac{\rho_n}{slope} \quad (2)$$

Where ρ_n and ρ_s are the tracks density of the unknown sample and standard sample in (track/mm^2), respectively. C_{Rn} and C_{Rs} are the radon concentrations of the unknown sample and standard samples in (Bq/m^3), respectively. The slope is equal to 12.23 (track/mm^2)/(Bq/m^3).

The surface exhalation rate in units (Bq.m^{-2}.h^{-1}) can be calculated by the following equation [15].

$$E_A = \frac{CV\lambda}{A[T+\lambda^{-1}(e^{-\lambda T}-1)]} \quad (3)$$

Where C is radon exposure (Bq.h.m^{-3}), V is the volume of air in cup (m^3), A is the surface area of the sample (m^2), T is exposure time, (T) =30 day, and λ is decay constant for ^{222}Rn =0.00755 h^{-1}.

Results

Radon concentrations and exhalation rates in soil samples collected from the Al-Diwaniyah governorate are presented in (Table 2). As seen in this table, the max values of radon concentrations Rn-222 and surface radon exhalation rates E_A at depth of 0cm were 689.89 Bq/m^3 and 0.063Bq/m^2.h, respectively. These values found in Al-Hamad village (S13), the min values of Rn-222 levels and exhalation rates were 163.58 Bq/m^3 and 0.015 Bq/m^2.h, respectively. These values found in Niffur (S18), the average values of Rn-222 levels and exhalation rates in the surface soil samples at depth of 0cm were 350.64 Bq/m^3 and 0.031 Bq/m^2.h, respectively.

Based on these values, the average value of Rn-222 concentrations in the soil samples of Al-Diwaniyah governorate was less than the acceptable level of radon 600 Bq/m^3 as reported in the related literature [15]. At depth of 10cm of soil samples, the values of Rn-222 levels and exhalation rates E_A ranged from 139.04 Bq/m^3 and 0.012 Bq/m^2.h in sample (S18), to 664.98 Bq/m^3 and 0.061 Bq/m^2.h in sample (S13), with average values of 317.38 Bq/m^3 and 0.028 Bq/m^2.h for radon levels and exhalation rates, respectively. The min, max, and average concentrations of radon at depth of 20cm were 126.95 Bq/m^3 in the sample (S18), 652.44 Bq/m^3 in the sample (S13), and 279.59 Bq/m^3, respectively. On the other hand, the min, max, and average concentrations of E_A at 20cm depth were 0.011 Bq/m^2.h in sample (S18), 0.060 Bq/m^2.h in sample (S13), 0.026 Bq/m^2.h, respectively. At 30cm depth of the soil samples, the highest, lowest, and average levels of radon were 610.82 Bq/m^3 in sample (S13), 120.90 Bq/m^3 in sample (S18), and 261.86 Bq/m^3, respectively. However, the corresponding values of exhalation rates were 0.056 Bq/m^2.h, 0.011 Bq/m^2.h, and 0.024 Bq/m^2.h, respectively. Furthermore, the levels of Rn-222 and exhalation rates E_A at depth of 40cm varied from 108.86 Bq/m^3 and 0.010 Bq/m^2.h in sample (S18), to 594.44 Bq/m^3 and 0.054 Bq/m^2.h in sample (S13), with the average values were 248.51 Bq/m^3 and 0.021 Bq/m^2.h, respectively.

Figure 3 shows the average values of radon concentrations in soil samples of the Al-Diwaniyah governorate as a function of location. From this figure, the highest recorded radon concentrations values were observed in AL-Hamad village with a mean value of 642.51 Bq/m^3, while the lowest recorded radon levels values were observed in Niffur with a mean value of 131.86 Bq/m^3.

Table 3. Radon concentrations (Bq/m^3) in soil samples

Area classification	No. of samples	Mean±SD.dev
Industrial	6	570.46±20.4
Agricultural	5	302.21±18. 34
Residential	9	230.32±17.68

Table 3 presents the average values of radon concentrations in surface soil samples collected from Al-Diwaniyah governorate's industrial, agricultural, and residential soil. The highest value of radon concentration was found in industrial regions and measured at 570.46±20.4 Bq/m^3.

Table 2. Radon concentrations and exhalation rates in soil samples of the studied area

Depth (cm)	No. of samples	Radon Concentrations Bq/m^3			E_A Bq/m^2.h	
		Min±SD	Max±SD	Mean±SD	Ranges	Mean
0	20	163.58±19.36	689.89±20.10	350.64±21.29	0.015-0.063	0.031
10	20	139.04±18.33	664.98±24.83	317.38±22.31	0.012-0.061	0.028
20	20	126.95±20.97	652.44±26.17	279.59±20.78	0.011-0.060	0.026
30	20	120.90±23.41	610.82±21.69	261.86±20.68	0.011-0.056	0.024
40	20	108.86±21.51	594.44±22.00	248.51±20.32	0.010-0.054	0.021

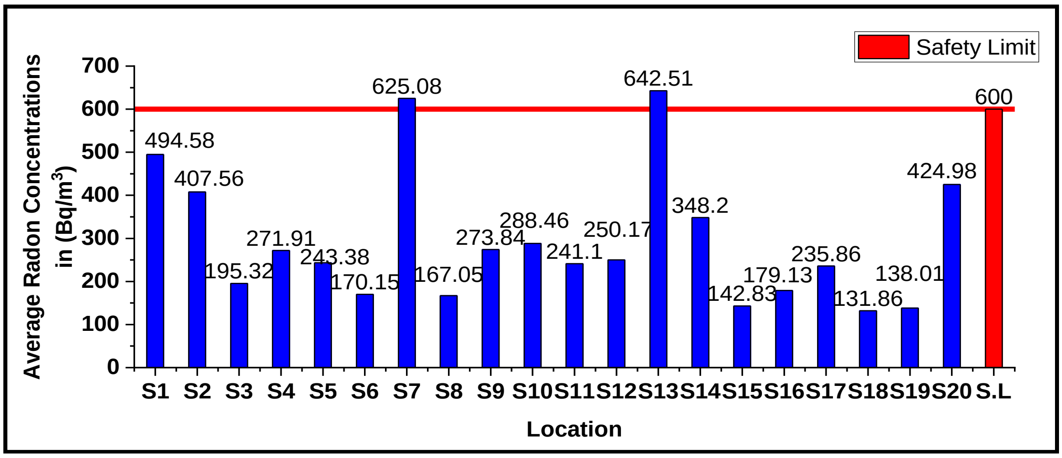

Figure 3. Average values of radon concentrations in the soil samples of the studied sites

Discussion

According to the obtained results, the levels of Rn-222 and EA varied depending on the depth of the soil, where the average levels of Rn-222 and EA at a depth of 0cm were 350.64 Bq/m^3 and 0.031 Bq/m^2.h, respectively. In addition, these values were higher than those of the other depths of the soil. From these results, it is concluded that there is an increasing factor between the average values of radon concentrations at 0cm depth with those of the other depths of soil (10, 20, 30, and 40cm), where the increase factor is as follows 110%, 125%, 133%, and 141%, respectively.

Based on the findings of the current study, with an increase in the depth of soil, the concentrations of Rn-222 and E_A decreases. In addition, these findings were in agreement with the results of other studies [15]. This may be due to the fact that the radon concentrations in soil samples depend on several factors, such as moisture, permeability, porosity, erosion, and other factors, where the severity and the degree of these factors vary according to the nature of the studied soil [16].

The highest value of radon concentration was measured at 570.46±20.4 Bq/m^3 and was detected in the industrial regions (Table 3). Accordingly, the mean value of radon concentrations in the industrial regions was significantly higher than those of the agricultural and residential regions with 1.88 and 2.47 factors of increase, respectively. This result indicated that the industrial regions were exposed to high levels of radon, compared to other regions as a result of human activities. The reason for the presence of the radioactive materials in agricultural soil can be due to the widespread use of fertilizers; therefore, the proportion of radon in the soil samples was in the following order: industrial>agricultural>residential.

The concentrations of radon in soil samples are compared with other reports from different countries as summarized in Table 4. The concentrations of radon in surface soil samples of all regions in the present investigation varied from 163.58 to 689.89 Bq/m^3 with an average value of 350.64 Bq/m^3. As seen in this table, the highest recorded radon concentration values were observed in Baghdad (Iraq); whereas the lowest average radon content was observed in Brazil. In the present study, the measured average values of radon concentration were lower than that of Pakistan and Iraq (Baghdad) and higher than Brazil, Malaysia, Saudi Arabia, and India. Since the current research was the first study conducted on radon gas levels and exhalation rates in soil samples of different sites in Al-Diwaniyah southern Iraq, the obtained results now serve as a database for future studies.

Table 4. Comparison of radon levels (Bq/m^3) of present research with different countries

Country	Radon Concentrations		
	Mean	Ranges	References
Brazil	69	4–404	[17]
Malaysia	198.44	67.21–295.06	[18]
Saudi Arabia	75.41	…….	[19]
Pakistan	376	…….	[20]
India	330.5	117.5–583.4	[21]
Iraq (Baghdad)	994.4	…….	[22]
Iraq (Al-Diwaniyah)	350.64	163.58–689.89	Present study

Conclusion

Radon gas level and surface exhalation rates in soil samples of Al-Diwaniyah governorate southern Iraq were measured using CR-39 detectors. The obtained results of the present research which were compared to the previous ones indicated that in general are within the safety limits 600 Bq/m^3.

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