**Iraqi National Journal of Earth Science**
www.earth.mosuljournals.com

# Evaluation of Radon Concentrations in The Soil of Kirkuk City

**Genan Nassir Hawas [1*] , Ahmed Abed Ibrahim [2], Omer Sabah Al-Tamimi [3]**

[1,2] *Department of Physics, College of Science, University of Kirkuk, Kirkuk, Iraq.*
[3] *Department of Applied Geology, College of Science, University of Kirkuk, Kirkuk, Iraq.*

**Article information**

**Received:** 07- -June -2023

**Revised:** 04- Oct -2023

**Accepted:** 18- Oct -2023

**Available online:** 01- Jan – 2024

**Keywords**:
Radon gas
Rad7 detector
geological formation
Alpha decay
soil
Kirkuk

**Correspondence**:
**Name:** Genan Nassir Hawas

Email:scph20m020@uokirkuk.edu.iq

## ABSTRACT

In the current study , the radon activity concentration in soil gas was measured at 22 different locations in Kirkuk City ,NE Iraq using electric radon meter (Rad-7) for three different depths (20,40, and 60 cm ) .The results show that the emanation rate of radon gas varied from location to another ,depending on the geological formation .It was found that the highest concentration of radon is 146 Bq/m3 in location (sample S16) and the lowest is 0 Bq/m3 in location (sample S20 & S22 ) for a depth of 20 cm . For a depth of 40cm, the highest concentration is 3330 Bq/m3 in location (sample S5) and the lowest is 16.8 Bq/m3 in location (sample S20) and for a depth of 60 cm the highest concentration is 12005 Bq/m3 in location (sample S8) and the lowest is 42.3Bq/m3 in location (sample S12). Annual effective dose (AED) due to inhalation was estimated from the measured radon concentration is found to range from (0) to (0.1140 mSv.y-1) with an average value of (0.01586 mSv.y-1) for all depths. The AED due to inhalation was found to be within the safe limit recommended by WHO of 0.1 mSv.y-1 and so far below from the reference levels proposed by ICRP of 1mSv.y-1, which revealed that the radon concentration and the associated annual effective dose does not pose any kind of health hazard to the population and tourists in the study area.

DOI: 10.33899/earth.2023.140762.1092, ©Authors, 2024, College of Science, University of Mosul.

# تقييم تركيزات الرادون في تربة مدينة كركوك

جنان ناصر هواس [1*] ، احمد عبد ابراهيم [2] ، عمر صباح التميمي [3]

[2،1] قسم علوم الفيزياء، كلية العلوم، جامعة كركوك، كركوك، العراق.

[3] قسم علوم الارض، كلية العلوم، جامعة كركوك، كركوك، العراق.

معلومات الارشفة

**تاريخ الاستلام:** 07- يونيو -2023

**تاريخ المراجعة:** 04- اكتوبر -2023

**تاريخ القبـول:** 18- اكتوبر -2023

**تاريخ النشر الالكتروني:** 01- يناير -2024

**الكلمات المفتاحية:**

غاز الرادون

كاشف Rad7

التكوين الجيولوجي

انحلال الفا

التربة

كركوك

**المراسلة:**

**الاسم:** جنان ناصر هواس

Email:scph20m020@uokirkuk.edu.iq

**الملخص**

في الدراسة الحالية، تم قياس تركيز نشاط الرادون في غاز التربة في 22 موقعا مختلفا في مدينة كركوك، العراق باستخدام مقياس الرادون الكهربائي (Rad-7) لثلاثة أعماق مختلفة (20 و40 و60 سم). تظهر النتائج أن معدل انبعاث غاز الرادون يختلف من موقع إلى آخر، اعتمادا على التكوين الجيولوجي. وجد أن أعلى تركيز للرادون هو 146 $Bq/m^3$ في الموقع (عينة S16) وأقلها هو 0 $Bq/m^3$ في الموقع (عينة S20 & S22) لعمق 20 سم. لعمق 40 سم، أعلى تركيز هو 3330 $Bq/m^3$ في الموقع (عينة S5) وأقل هو 16.8 $Bq/m^3$ في الموقع (عينة S20) ولعمق 60 سم أعلى تركيز هو 12005 $Bq/m^3$ في الموقع (عينة S8) وأقل تركيز هو 42.3$Bq/m^3$ في الموقع (عينة S12). تم تقدير الجرعة الفعالة السنوية (AED) بسبب الاستنشاق من تركيز الرادون المقاس الذي وجد أنه يتراوح من (0) إلى (0.1140 $mSv.y^{-1}$) بمتوسط قيمة (0.01586 $mSv.y^{-1}$) لجميع الأعماق. تم العثور على أن AED بسبب الاستنشاق يقع ضمن الحد الآمن الذي أوصت به منظمة الصحة العالمية البالغ 0.1 $mSv.y^{-1}$ وأقل بكثير من المستويات المرجعية التي اقترحها ICRP من mSv.y-1(1)، والتي كشفت أن تركيز الرادون والجرعة الفعالة السنوية المرتبطة به لا يشكل أي نوع من المخاطر الصحية على السكان والسياح في منطقة الدراسة.

DOI: 10.33899/earth.2023.140762.1092, 

## Introduction

Radon is a noble gas, occurs naturally as a product of the uranium-238 decay series, it has no odor or taste, with no color, radioactive gas decays by emitting alpha particles with characteristic amount of energies to give a set of short-lived radionuclide (such as polonium -218 and polonium-214). radon has a half-life of (3.82 days) which is long relative to some of its progenies and sufficiently enough for detecting and measuring. The major source of radon gas in the atmosphere is the soil surface, although secondary contributions come from ground and surface water, natural and volcanic gases, and others (Prasad et al., 2008). The distribution of radon in soils has been related to geological controls in terms of its production and migration, uranium content in bedrocks and soil influence production. The soil moisture and permeability control the transportation of radon (Hatif et al., 2016). The radium and uranium contents of the soil, generally, reflect that of the bedrock from which the soil materials have originated due to weathering processes (Huy et al., 2006). Radon gas escapes easily from the surface soils and rocks into the air through a process called exhalation. The factors that influence the exhalation of radon from the soil into the air are : The concentration of uranium , thorium and radium in the bedrock and soil materials , the emanation capacity of the ground , the porosity of the soil or rock , barometric pressure gradient between the interfaces , soil moisture and water saturation grade of the medium and other variables such as micro-cracks of bedrocks , rainfall ,air temperature , and surface winds (Inceöz et al.,2006 ; Righi et al., 2006 ; Alharbi et al., 2013) . Due to its low mobility and its short half –life, radon obviously diffuses from a short distance below the measuring device (Jean-Paul et al., 1999). This distance is approximately (2)m under the soil surface in areas where slow diffusive flow present (Connor et al., 1996). Hence, the higher radon concentration is often to be due to convective movement in addition to diffusive processes. Generally, there is a direct proportion between radon activities and flows, and hence because of the increase of gas velocity, gas decay occurs faster with more extraction (Rodriguez et al., 2008). The estimation of radon in the soil-gas and atmosphere has been suggested as a tool for many investigations such as exploration for uranium, earthquake prediction, groundwater transport and geothermal resource assessments. Radon concentration levels are strongly affected by geological and geophysical conditions. Movement of radon through the Earth is strongly influenced by permeability of soil , porosity and degree of fracturing in rocks among other factors .As a result, the ease with which radon moves in pore spaces or fractures affects how much radon reaches the Earth's surface at any given location (Ramola et al., 1997; Al-Taj et al., 2004; Erees et al., 2006 ) .However, radon and its progeny are responsible for about 45% of the exposure of the world population to ionizing radiation from natural sources (UNSCEAR, 2000 ; Durrance , 1986 ; Mireles et al., 2007). Radon enters the water and dissolves in it due to hydrological cycle pores in rocks and soil; its movement in soil and rocks depends on the amount and location of uranium underground, grain size, moisture content, soil permeability, porosity, etc. In Jordan they investigated the Sahab area's highly radioactive anomalous zone, utilizing a GRS-500 differential gamma-ray spectrometer to measure gamma-ray activity in the field. Solid-state nuclear track detectors were used to determine uranium concentrations. The data revealed that gamma-ray activity ranged between 100 and 2500 counts per second, whereas uranium concentrations ranged between $88 \pm 9.7$ and $355.6 \pm 37.4$ ppm. (Kareem et al., 2020; Al-Taj et al., 2022). Radon is the second leading cause of lung cancer in the U.S, smoking being the first. The nature of building materials, soil, and water used for drinking and other domestic applications can make variable contributions to the radon level in indoor environment (Ibrahim et al., 2017). Soil is an important compartment receiving significant amount of pollutants from different sources every year. Generally, soil not only serves as sink for the chemical pollutants but also acts as a natural buffer by controlling the transport of chemical elements and substances to the environment (Al-Kahachi et al., 2022).

## Aim of study

1. Studying the concentration of radon in the soil samples irrigated of well water at different depths in several areas distributed within the city of Kirkuk.

2. Studying the behavior of radon concentrations with respect to soil depth in the study area.

3. Studying the annual effective dose in soil samples.

## Study area

The study area is located in Kirkuk city, northeast Iraq (Fig. 1) Kirkuk city is one of the richest cities with crude oil in the world. In addition to oil wealth, the region is rich with sulfur and natural gas, which is produced through the initial refining of oil.

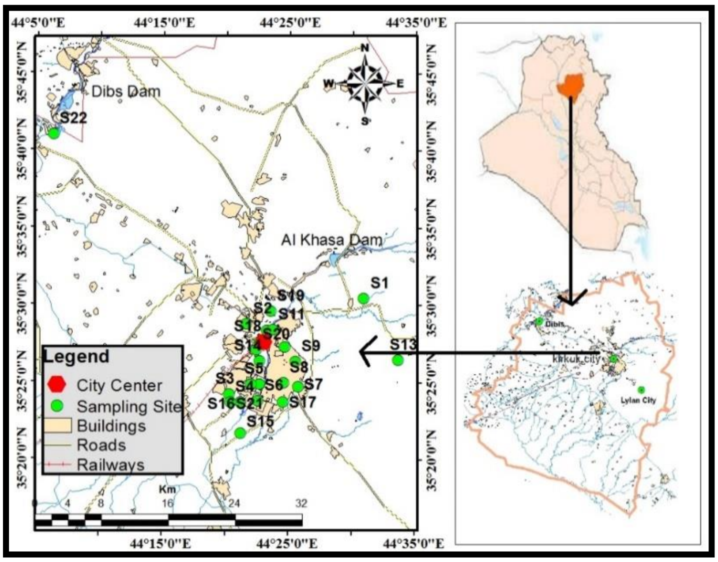
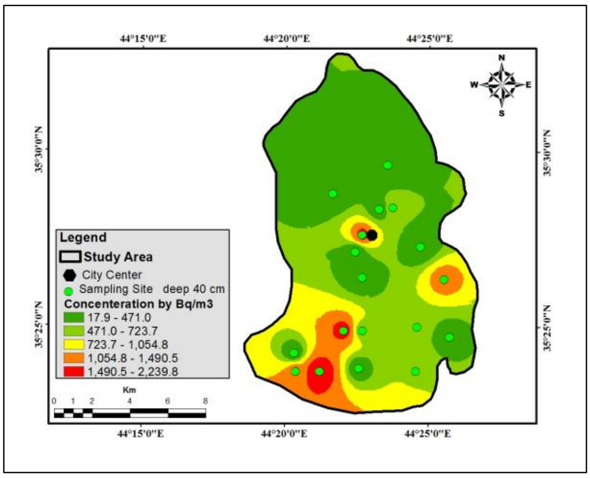
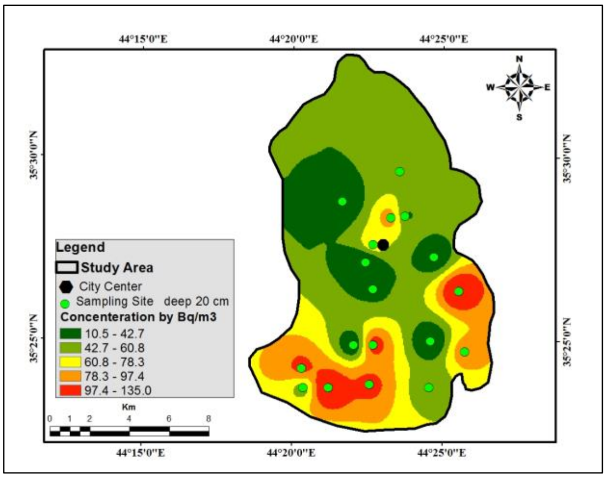


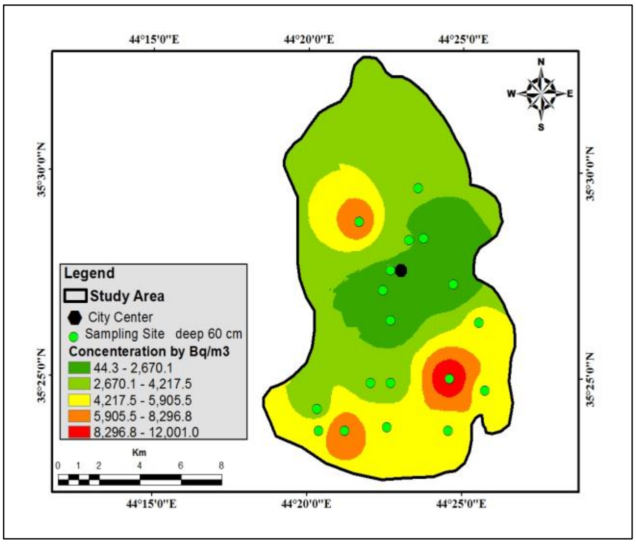

**Fig. 1. Location map of the study area in Kirkuk city and the distribution of the studied sites.**




(b)




(a)




(c)

**Fig. 2. Maps showing the spatial distribution of radon gas concentrations at depths (a) 20 cm, (b) 40 cm, (c) 60 cm.**

**Table 1: The locations and map symbols used in this study.**

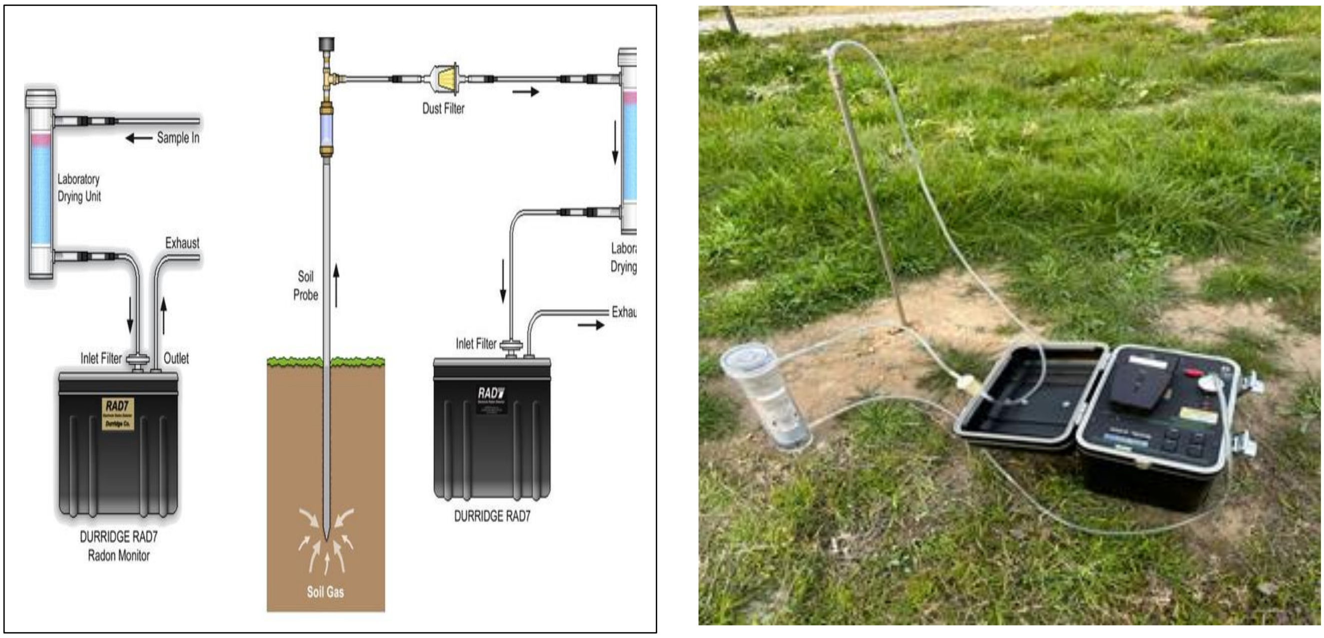
| No. | Sample ID | Name | Location | |
|---|---|---|---|---|
| | | | Longitude | Latitude |
| 1 | S1 | Rahimawa | 35°30′20″N | 44°23′56″E |
| 2 | S2 | Al-failaq | 35°28′48″N | 44°21′44″E |
| 3 | S3 | Huzairan Garden | 35°24′21″N | 44°20′23″E |
| 4 | S4 | Hay Adan | 35°24′48″N | 44°22′36″E |
| 5 | S5 | Al-saraf Mosque | 35°24′54″N | 44°22′01″E |
| 6 | S6 | Nidaa | 35°23′46″N | 44°22′31″E |
| 7 | S7 | Banja Ali Apartments | 35°24′33″N | 44°25′45″E |
| 8 | S8 | Qadisiyah( Al-Salam Garden ) | 35°25′01″N | 44°24′30″E |
| 9 | S9 | Ashti Mosque | 35°26′20″N | 44°25′31″E |
| 10 | S10 | Qishla | 35°28′19″N | 44°23′20″E |
| 11 | S11 | Castle | 35°28′19″N | 44°23′38″E |
| 12 | S12 | Shorja Park | 35°27′13″N | 44°24′46″E |
| 13 | S13 | Ashti Park | 35°26′24″N | 44°24′37″E |
| 14 | S14 | Al-mansor Mosque | 35°26′21″N | 44°22′39″E |
| 15 | S15 | Ras Domiz | 35°24′12″N | 44°21′30″E |
| 16 | S16 | Al-khasa River | 35°23′17″N | 44°21′44″E |
| 17 | S17 | Hay Al-Askari (Al-hijra Mosque) | 35°23′38″N | 44°24′34″E |
| 18 | S18 | Al-Baho | 35°27′31″N | 44°22′40″E |
| 19 | S19 | Ali Bin Abi Talib Mosque | 35°29′36″N | 44°23′35″E |
| 20 | S20 | Tisen Park | 35°27′10″N | 44°22′30″E |
| 21 | S21 | Kirkuk University | 35°23′41″N | 44°20′33″E |
| 22 | S22 | Al-Zab River | 35°41′06″N | 44°06′06″E |

## Experimental Technique

In this study, measurements of radon concentration in soil gas were performed by using a portable electrostatic radon monitor RAD7 (Durridge Co. United States). The Durridge RAD7 uses a solid-state alpha detector. RAD7 detector has an internal sample cell of 0.7-liter hemisphere, coated on the inside with an electrical conductor. The high voltage range of the detector is 2000–2500 V, which creates an electric field throughout the volume of the cell. The electric field propels positively charged particles onto the detector. It detects only alpha particles. The major advantages of this detector are the distinguishing characteristics of old radon daughters from new radon daughters, radon from thoron based on the energy of the alpha particle released, and signals from noise. The RAD7 amplifies, filters, and sorts the signals according to the signal produced by the different isotopes having different energies. RAD7 uses only the 218Po signal to determine radon concentration. The most important accessories of RAD7 were the power cord, the Laboratory Drying Unit (the large tube of desiccant, with a screw cap at one end), an inlet filter (one of the six small filters supplied), and the piece of tubing with a 5/16″ ID segment at one end and a 1/8” ID segment at the other and an attached printer (Rad7 User Manual ,2012).

**Table 2: The RAD7 protocol used for measuring radon concentration in soil-gas in this study.**

| Protocol | Cycle | Recycle | Mode | Thoron | Pump |
|---|---|---|---|---|---|
| Grab | 00.05 | 04 | Sniff | Off | Auto |




**(a)** **(b)**

**Fig. 3. (a) Tubing concentration of stainless-steel Soil Gas probe, (b) Measuring Radon Gas in one of the locations.**

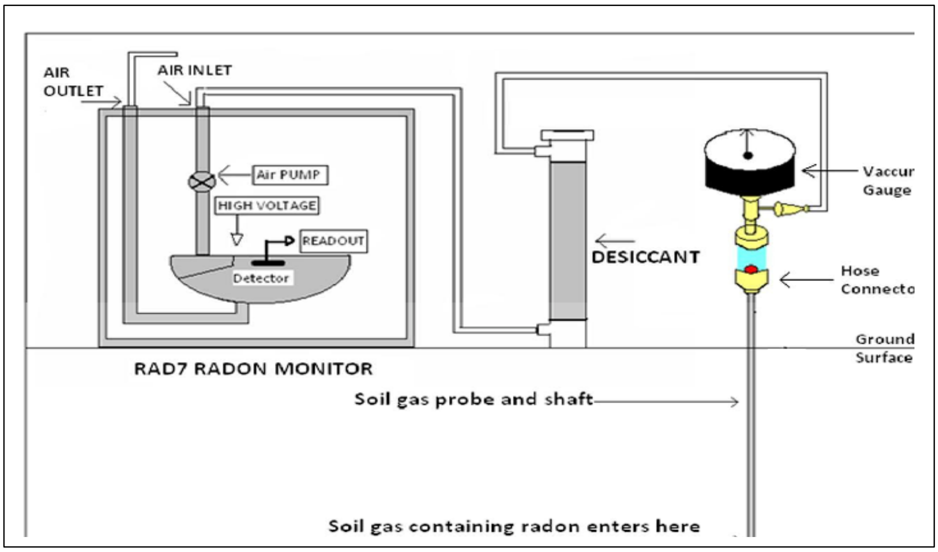



**Fig.4. Diagram of the RAD7 setup (Jean-paul et al.,1999).**

## Radon Activity Measurement in Soil Gas

Radon concentrations were measured for soil gas in the (22) different locations inside Kirkuk. They are carried out for a period of one month (February 2023) (i.e., during the winter season), by the stainless-steel soil gas probe, which is one of the accessories of the RAD7 equipment (Durridge Company, USA) which allows the determination of radon soil gas levels directly Fig. (3B), at three different depths 20, 40, and 60 cm. The soil was drilled by a hollow cylinder with a diameter of 2 cm and a length of 100 cm. The probe was then inserted into the hole and closed tightly to prevent the leakage of air into the hole. Fig. (3) shows the tubing connections of stainless-steel soil gas probe. Before connecting the probe to the device to start the measurement, the device was dried for 10 minutes to reduce the relative humidity to reach 6% where the device pumps the soil gas to the measuring section in the first five minutes of operation. The pumping was stopped for five minutes to reach equilibrium state (five minutes pump and five minutes waiting to complete 95% of equilibrium), and then the radon concentration was measured for four cycles (five minutes per cycle). Thus, the measurement duration takes 30 minutes and eventually the device will print a summary including the highest, lowest and the average radon concentrations, standard deviation, relative humidity, temperature within the device, the date and time perform the test, as well as the operating number and the number of cycles, it will then give the diagram of the four cycles, and the accumulated spectrum.

Geographical coordinates of all locations were documented using the GPS portable device table (1). These coordinates were used later to draw a map showing the location of each sampling point using GIS (Geographic Information System) fig. (1).

The annual effective dose (AED, mSv/y) that received by the public due to inhalation has been calculated using the relation proposed by the UNSCEAR 2000 (United Nations Scientific Committee on the Effects of Atomic Radiation,2000), which is:

$$\mathbf{D_{inh} = C_{Rn} \times F \times I \times (DCF)} \text{ ----------------- } \mathbf{(1)}$$

Where $D_{inh}$ is the annual effective dose received by the public, F is the equilibrium factor between radon and its products (=0.6), I mean outdoor occupancy time per individual (=1760 h/y), and DCF is the dose conversion factor for radon exposure [9 nSv (Bq h m $^{-3})^{-1}$].

$$\mathbf{C_{Rn} = C_{SG}\sqrt{\frac{d}{D}}} \text{ -------------------- } \mathbf{(2)}$$

Where $\mathbf{C_{Rn}}$ is the radon concentration in the air near the soil surface which is calculated using the relation (Kumar et al., 2018), $\mathbf{C_{SG}}$ is the radon activity in the soil gas, **d** is the exhalation diffusion constant (=0.05 cm$^2$/s) and **D** is the eddy diffusion coefficient (=5× 10 $^4$ cm$^2$/s).

**Table 3: Radon activity concentration in soil using the RAD7 radon monitor with a soil probe and corresponding effective dose.**

| Sample point ID | Depth 20 cm | | | Depth 40 cm | | | Depth 60 cm | | |
|---|---|---|---|---|---|---|---|---|---|
| | $C_{SG}$ (Bq/m$^3$) | $C_{Rn}$ (Bq/m$^3$) | Effective Dose (mSv/y) | $C_{SG}$ (Bq/m$^3$) | $C_{Rn}$ (Bq/m$^3$) | Effective Dose (mSv/y) | $C_{SG}$ (Bq/m$^3$) | $C_{Rn}$ (Bq/m$^3$) | Effective Dose (mSv/y) |
| S1 | 84.6 | 0.0846 | 0.000804 | 1440 | 1.44 | 0.0136 | 5720 | 5.72 | 0.0543 |
| S2 | 8.43 | 0.00843 | 0.0000801 | 42.1 | 0.0421 | 0.000400 | 7970 | 7.97 | 0.0757 |
| S3 | 110 | 0.11 | 0.00104 | 431 | 0.431 | 0.00409 | 2820 | 2.82 | 0.0268 |
| S4 | 119 | 0.119 | 0.00113 | 468 | 0.468 | 0.00447 | 2620 | 2.62 | 0.0249 |
| S5 | 8.43 | 0.00843 | 0.0000801 | 1840 | 1.84 | 0.0174 | 3330 | 3.33 | 0.0316 |
| S6 | 111 | 0.111 | 0.00105 | 119 | 0.119 | 0.00113 | 5600 | 5.6 | 0.0532 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| S7 | 94.2 | 0.0942 | 0.000895 | 194 | 0.194 | 0.00184 | 5060 | 5.06 | 0.0480 |
| S8 | 8.52 | 0.00852 | 0.0000809 | 564 | 0.564 | 0.00536 | 12005 | 12.005 | 0.114 |
| S9 | 137 | 0.137 | 0.00130 | 1420 | 1.42 | 0.0134 | 4900 | 4.9 | 0.0465 |
| S10 | 101 | 0.101 | 0.000959 | 186 | 0.186 | 0.00176 | 2920 | 2.92 | 0.0277 |
| S11 | 33.9 | 0.0339 | 0.000322 | 721 | 0.721 | 0.00685 | 1370 | 1.37 | 0.0130 |
| S12 | 17 | 0.017 | 0.000161 | 33.9 | 0.0339 | 0.000322 | 42.3 | 0.0423 | 0.000402 |
| S13 | 8.34 | 0.00834 | 0.0000792 | 1730 | 1.73 | 0.0130 | 2830 | 2.83 | 0.0268 |
| S14 | 33.7 | 0.0337 | 0.000320 | 67.2 | 0.0672 | 0.000638 | 372 | 0.372 | 0.00353 |
| S15 | 8.38 | 0.00838 | 0.0000796 | 2390 | 2.39 | 0.0227 | 4350 | 4.35 | 0.0413 |
| S16 | 146 | 0.146 | 0.00138 | 2240 | 2.24 | 0.0212 | 8100 | 8.1 | 0.0769 |
| S17 | 42.4 | 0.0424 | 0.000402 | 711 | 0.711 | 0.00675 | 4620 | 4.62 | 0.0439 |
| S18 | 84.7 | 0.0847 | 0.000804 | 1750 | 1.75 | 0.0166 | 2720 | 2.72 | 0.0258 |
| S19 | 59.3 | 0.0593 | 0.000563 | 110 | 0.11 | 0.00104 | 2730 | 2.73 | 0.0259 |
| S20 | 0 | 0 | 0 | 16.8 | 0.0168 | 0.000159 | 913 | 0.913 | 0.00867 |
| S21 | 43.7 | 0.0437 | 0.000415 | 1310 | 1.31 | 0.0124 | 5880 | 5.88 | 0.0558 |
| S22 | 0 | 0 | 0 | 901 | 0.901 | 0.00856 | 3720 | 3.72 | 0.0353 |
| Mean value | 57.2545 | 0.0572 | 0.000544 | 849.318 | 0.849 | 0.00791 | 4117.8318 | 4.117 | 0.0391 |

**Table 4: Values of radon concentration in the soil for some studies compared to the present work.**

| No. | Country | Region | Radon (Bq/m$^3$) | | Reference |
|---|---|---|---|---|---|
| | | | Low | High | |
| 1 | Iraq | AI Najaf City | 9 | 9290 | Hasan et al., 2011 |
| 2 | Iraq | Karbala City | 50 | 7800 | Hashim et al., 2016 |
| 3 | Iraq | Basra Province | 61.18 | 2237.77 | Alwan et al., 2017 |
| 4 | Iraq | Amara City | 53.18 | 2047.51 | Abojassim et al.,2017 |
| 5 | Iraq | AL Kufa City | 41.45 | 12775 | Al-Hamidawi et al ., 2012 |
| 6 | Iraq | Al Najaf Province | 38.5 | 100 | Hameed, 2015 |
| 7 | Iraq | Salahaddin Province | 45.25 | 100.75 | Ridha et al., 2014 |
| 8 | Iraq | Basra Sport City | 1439 | 38765 | Al-Mosuwi et al., 2013 |
| 9 | Iraq | Hilla City | 25 | 12700 | Hatif et al., 2016 |
| 10 | Saudi Arabia | Al Qassim Area | 26 | 340 | Alharbi et al., 2013 |
| 11 | Saudi Arabia | Jazan Region | 896.81 | 302.91 | Aseeri et al., 2018 |
| 12 | Jordan | Irbid Province | 697 | 6335 | Ershaidat et al., 2013 |
| 13 | Turkey | Dikli Geothermal Area | 98 | 8594 | Tabar et al.,2013 |
| 14 | Palestine | Gaza | 23.48 | 584.15 | Hamed ,2005 |
| 15 | Egypt | Southwestern Sinai | 648 | 21361 | korany et al.,2013 |
| 16 | Italy | Bolsena | 7 | 176 | Cinelli et al,.2015 |
| 17 | Iraq | Kirkuk City | 0 | 12005 | Present study |

## Results and Discussion

Radon concentration in soil gas was measured at twenty-two locations in Kirkuk City and its surrounding areas using the RAD7 radon monitoring system, and the data is shown in Table (3), and Fig. (5), three different depths (20, 40, and 60 cm) were taken for soil gas radon measurement using a soil probe. The obtained results show that soil gas radon concentrations were varied 0 Bq.m-3 to 0.146 kBq.m-3 with an average value of 0.0572 for 20 cm depths, 0.0168 Bq.m-3 to 1.31 kBq.m-3 with the average value of 0.849 Bq.m-3 for 40 cm depth, and 0.0423 Bq.m-3 to 12.005 kBq.m-3 with an average value of 4.117 kBq.m-3 for 60 cm depth. The maximum allowed concentration level of radon in the soil is between 0.4–40 kBq/m3. It was found that the obtained average values were within the maximum allowed concentration level of radon in soil. The variation of soil gas radon concentrations among three depths is shown in Fig. (6). It shows that radon gas in soil was found high at 60 cm depth and minimum at 20 cm depth. Therefore, it is clear that the radon level was variable at different depths and the soil gas radon activity concentration was increased with increasing the depth. Radon activity concentration in soil gas usually increases with increasing depth due to some facts such as moisture content increasing with the depth of the soil and increasing water content in the pores. The result of the present study Radon concentration in soil gas was measured at twenty-two locations in Kirkuk City and its surrounding areas using the RAD7 radon monitoring system, and the data is shown in Table (3), and Fig. (5), three different depths (20, 40, and 60 cm) were taken for soil gas radon measurement using a soil probe. The obtained results show that soil gas radon concentrations were varied 0 Bq.m-3 to 0.146 kBq.m-3 with an average value of 0.0572 for 20 cm depths, 0.0168 Bq.m-3 to 1.31 kBq.m-3 with the average value of 0.849 Bq.m-3 for 40 cm depth, and 0.0423 Bq.m-3 to 12.005 kBq.m-3 with an average value of 4.117 kBq.m-3 for 60 cm depth. The maximum allowed concentration level of radon in the soil is between 0.4–40 kBq/m3. It was found that the obtained average values were within the maximum allowed concentration level of radon in soil. The variation of soil gas radon concentrations among three depths is shown in Fig. (6). It shows that radon gas in soil was found high at 60 cm depth and minimum at 20 cm depth. Therefore, it is clear that the radon level was variable at different depths and the soil gas radon activity concentration was increased with increasing the depth. Radon activity concentration in soil gas usually increases with increasing depth due to some facts such as moisture content increasing with the depth of the soil and increasing water content in the pores. The result of the present study agrees with the findings of some reported values (Duggal et al., 2014; Mittal et al., 2015). It is also reported that high radon concentration depends on high uranium content rocks (Cevik et al., 2011). A comparison of measured radon activity concentration in soil gas with the results of different studies carried out around the world at different depths is given in Table (4).

From Table (4), it is clearly seen that the radon concentration in the soil of the present study was lower than AL Kufa City in Iraq, Basra Sport City in Iraq, Southwestern Sinai in Egypt and Hilla City in Iraq. On the other hand, this study shows higher data than AI Najaf City in Iraq, Karbala City in Iraq, Bolsena in Italy, Basra Province in Iraq, Gaza in Palestine, Amara City in Iraq, Al Qassim Area in Saudi Arabia, Irbid Province in Jordan, Dikli Geothermal Area in Turkey, Jazan Region in Saudi Arabia and Salahaddin Province in Iraq. Such a variation in data might be attributed to the variation in soil depth, detection techniques as well as geological characteristics.

The annual effective dose due to radon inhalation has been determined to all studied locations and it was found to be in the range of ( 0 – 0.00138 ) mSv.y-1 with a mean value of ( 0.000544 mSv.y-1 ) for 20 cm depth , the range of (0.000159 – 0.0227) mSv.y-1 with a mean value of (0.007917 mSv.y-1 ) for 40 cm depth and , the range of (0.000402 –0.1140 ) mSv.y-1 with a mean value of (0.0391 mSv.y-1 ) for 60 cm depth , which were found to be well within the safe limit of 0.1 mS.y-1 as recommended by World Health Organization ( WHO,2004 ) and European Council( EU,1998 ) (WHO. Guidelines for Drinking-water Quality, 2004), and far below from the reference levels proposed by ICRP of 1 mSv.y-1 (Streffer ,2007). The sites in the study area were modeled homogeneously to be representative of all areas, but for each site more than one depth was taken. With the difference in depth, there is a difference in concentration. We note from the Fig. (2) for all depths that the green-colored areas, that is, the north of the region, there is a small percentage of radon concentrations, while the red-colored areas, that is, the south of the region, there is a high percentage of radon concentrations.

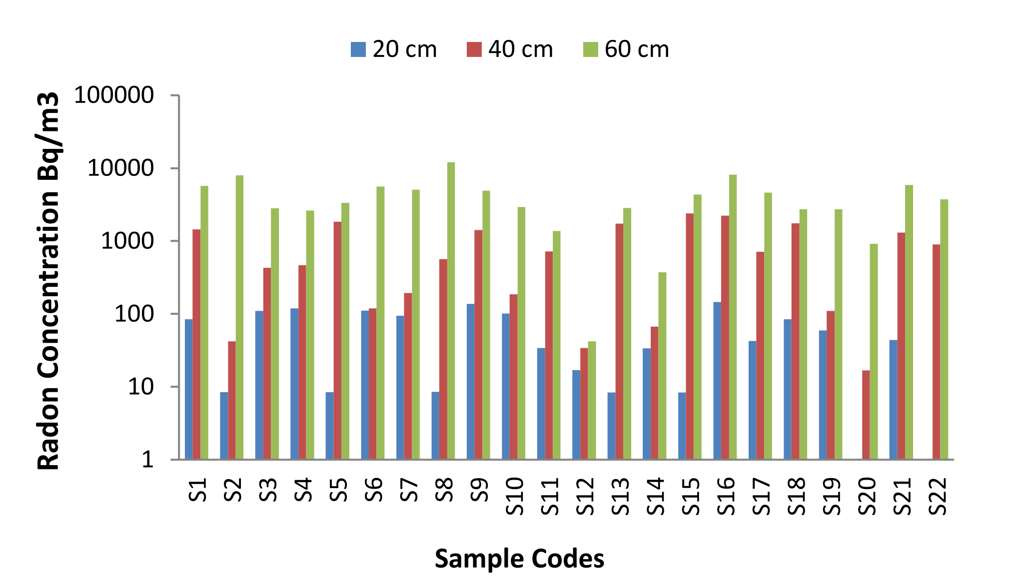



**Fig.5. Radon concentration as a function of the sample codes at all depths.**

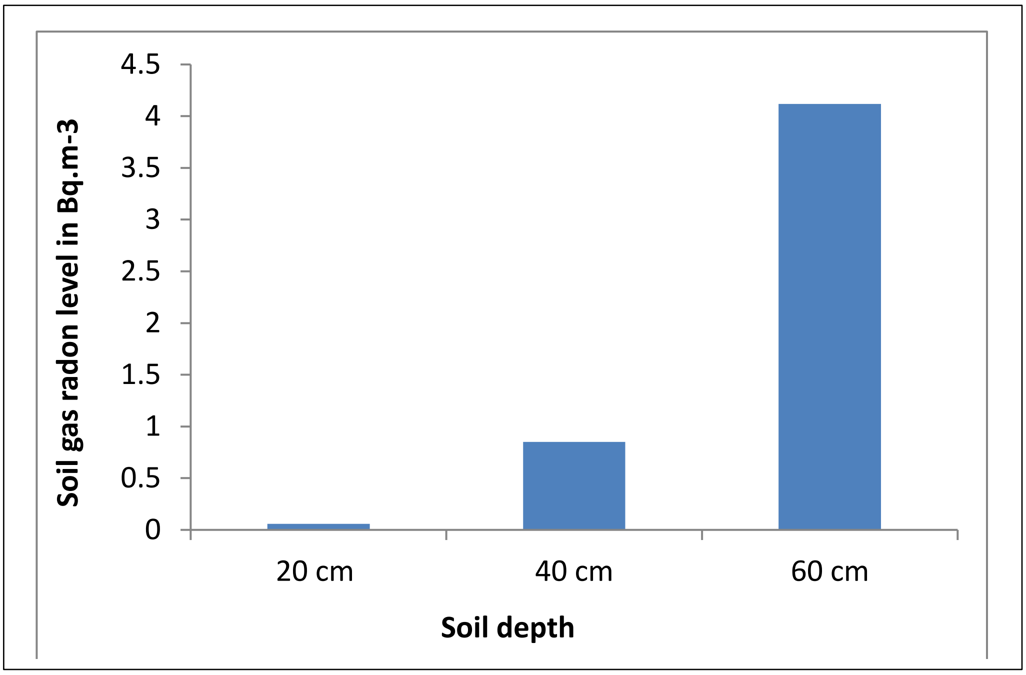



**Fig. 6. The variations of radon activity concentration in soil among three depths using radon monitor RAD7 with soil probe accessories.**

## Conclusion

The radon concentrations in soil gas in Kirkuk City northeast Iraq, were measured using the continuous radon monitoring device RAD7. The measured radon concentration in soil varied from location to another. This may be due to the geological changes in the locations. The high radon concentration in a few locations may be due to the presence of parent materials and soil type in that area. The minimum radon activity concentration was found at 20 cm depth and the maximum concentration was found at 60 cm. The average soil gas radon concentrations at a depth of 20, 40, and 60 cm were found 0.0572 Bq.m-3, 0.849 Bq.m-3, and 4.117 Bq.m-3, respectively. Which is well within the world average of 4kBq/m3 as reported in UNSCEAR. It is found that the radon concentrations of the most soil samples are less than the recommended levels reported by UNSCEAR (2000). The mean value of AED has been calculated depending on the radon concentration in air near the soil surface for depth 20, 40, and 60 cm were found (0.000544, 0.007917, and 0.0391 mSv.y-1), respectively, which shows that the dose received by the public is lower than that of the suggested value of (1 mSv.y-1). Hence, the present study has revealed that radon soil gas concentration and associated annual effective dose are within referenced levels and the study area does not pose any kind of health hazard that tourist and population possibly received.

A previous environmental study dealing with the aspect of measuring the levels of exclusively radioactive and chemical pollution of water resources in the city of Kirkuk in particular has been conducted only some studies that dealt with the aspect of assessing the level of chemical pollution, one of which is nearly six years old. Therefore, especially in cities, there is a need to conduct periodic studies dealing with the aspect of environmental assessment to know the pollution in them, including radiological.

## Acknowledgements

The authors are grateful to the residents of the study area for their cooperation during the field work and I would like to thank everyone who supported me to finish this fruitful project especially my supervisors.

## References

Abojassim A., Kadhim S., Alasadi A., Ali A., 2017. Radon, Radium Concentrations and Radiological Parameters in Soil Samples of Amara at Maysan, Iraq. Asian Journal of Earth Sciences, pp. 44-49. DOI: 10.17311/ajes.2017.44.49.

Al-Hamidawi A., Jabar Q., AL. Mashhadani A., AL. Bayati A., 2012. Measurement of radon and thoron concentrations of soil- gas in Al-Kufa city using RAD-7 detector. Iraqi Journal of Physics, Vol. 10, No, 19, pp. 110–116.

Alharbi W., Abbady A., 2013. Measurement of radon concentrations in soil and the extent of their impact on the environment from Al-Qassim, Saudi Arabia. Natural Science, Vol. 5, No. 1, pp. 93-98. DOI:10.4236/ns.2013.51015.

Al-Kahachi sh., Al-Tawash B., Al-Tamimi O., 2022. Distribution and Enrichments of Abundant and Trace Elements in Al-Khasa Sub Basin Soil, Kirkuk, Northeastern of Iraq. Iraqi Journal of Science, Vol. 63, No. 12, pp. 5338-5352. DOI: 10.24996/ijs.2022.63.12.22.

Al-Mosuwi W., Subber A., 2013. Radon concentration: The cases of study are Shut - Al-Basra, river banks and Basra Sport City, Basra, Iraq. Archives of Physics Research, Vol. 4, No. 6, pp. 16-23.

Al-Taj, M., Al-Bataina, B., Al-Qawasmeh, A., Al-Bataina, Bataine, B., 2022. The impact of geologic and structural settings on radioactivity: a case study from Sahab area, Jordan. Environmental Earth Sciences, 82:9. https://doi.org/10.1007/s12665-022-10689-y.

Al-Taj, M., Al-Batainah, B. and Atallah, M., 2004. Evaluation of geodynamic activity of the Dead Sea transform fault by radon gas concentrations. Environmental Geology, Vol. 46, No. 5, pp. 574-583.

Alwan A., Al-Obiady A., Amin S., 2017. Radon Level Measurements in Soil and Sediments at Oil Field Area and Its Impact on the Environment. Engineering and Technology Journal, Vol. 35, pp. 1-7. DOI: https://doi.org/10.30684/etj.35.1B.1.

Aseeri R., Arishi A., Elaraby E., 2018. Estimation of primeval radio nuclei concentration in soil in Jazan region. AIP Conference Proceedings; 1976(June).

Cevik U., Kara A., Celik N., Karabidak M., Celik A., 2011. Radon Survey and Exposure Assessment in Karaca and Çal Caves, Turkey. Water Air Soil Pollution, pp. 461–469. DOI:10.1007/s11270-010- 0437-6.

Cinelli G., Tositti L., Mostacci D., 2015. soil gas radon assessment and development of a radon risk map in Bolsena, Central Italy. Environmental Geochemistry and Health, pp. 305-319. DOI 10.1007/s10653-014-9649-9.

Connor C., Hill B., LaFemina P., Navarro M., Conway M., 1996. Soil 222Rn pulse during the initial phase of the June-August 1995 eruption of Cerro Negro, Nicaragua. Journal of Volcanology and Geothermal Research, Vol.73, pp. 119-127. https://doi.org/10.1016/0377-0273(96)00020-0.

Duggal V., Rani A., Mehra R., 2014. Measurement of Soil-Gas Radon in Some areas of Northern Rajasthan, India. Journal of Earth System Science, No. 6, pp. 1241–1247. DOI:10.1007/s12040-014- 0473-5.

Durrance E., 1986. Radioactivity in Geology: Principles and Applications in England. p. 441.

Erees F., Yener G., Salk M., Özbal Ö., 2006. Measurement of radon content in soil gas in the thermal waters Western Turkey. Radiation Measurements, pp. 354–361. DOI: 10.1016/j.radmeas.2005.06.030.

Ershaidat N., Almomani R., Bataina B., Al-Rayashi W., 2013. Periodicity of Diurnal Variation of Soil Radon Concentration Levels and temperature. Jordan Journal of Physics, Vol. 6, No. 2, pp. 47-54.

Hamed N., 2005. Measurement of Radon Concentration in Soil at North Gaza. Islamic University of Gaza; MSc Thesis. DOI: 10.12691/ijp-4-6-1.

Hameed T., 2015. Measurement of radon gas concentration in water and soil samples in Al-Najaf governorate by using nuclear track detector (CR-39). Baghdad Science Journal, Vol. 12, No. 3, pp. 603-609. DOI: https://doi.org/10.21123/bsj.2015.12.3.603-610.

Hasan A., Subbar A., Shaltakh A., 2011. Measurement of Radon Concentration in Soil Gas us RAD7 in the Environs of Al-Najaf Al-Ashraf City-Iraq. Advances in Applied Science Research, pp. 273-278.

Hashim A., Mohammed E., 2016. Measurement of Radon Concentration and the Effective Dose Rate in the Soil of the City of Karbala, Iraq. Journal of Radiation and Nuclear Applications, No. 1, pp. 17-23. DOI: https://doi.org/10.2478/pjmpe-2021-0028.

Hatif K., Muttaleb M., 2016. Determination of Natural Radioactivity and Radon, Thoron Concentrations of Soil in Hilla City – Iraq. Journal of University of Babylon Vol. 24, pp. 1295-1309.

Huy N., Luyen T., 2006. Study on external exposure doses from terrestrial radioactivity in Southern Vietnam. Radiation Prot. Dosimetry. 118(3):331–6. doi: 10.1093/rpd/nci341. Epub 2005 Sep 5.

Ibrahim A., Hassan I., moklofe S., 2017. Radon Concentrations in Tap and Ground Water in Kirkuk Governorate Using Active Detecting Method RAD7. Int. J. of Phys., vol.5, no.2, pp.37-42. Doi:10.12691/ijp-5-2-1.

Inceöz M., Baykara O., Aksoy E., Doğru M., 2006. Measurements of soil gas radon in activefault: A case study along the North and East anatolian fault systems in Turkey.Radiation Measurements; 41(3):349–53. DOI:10.1016/j.radmeas.2005.07.024.

Jean-Paul T., Jean-Claude B., 1999. Gas geochemistry and seismotectonics: A review. Tectonophysics, Vol. 304, pp. 1-27. https://doi:10.1016/S0040-1951(98)00295-9.

Kareem D., Ibrahim A., Ibrahiem O., 2020. Heavy metal and radon gas concentration levels in Khasa River in Kirkuk City (NE Iraq) and the associated health effects. Arabian Journal of Geoscience, pp.1-11. https://doi.org/10.1007/s12517-020-06037-8

korany K., Shata A., Hassan S., Nagdy M., 2013. Depth and Seasonal Variations for the Soil Radon-Gas Concentration Levels at Wadi Naseib Area, Southwestern Sinai, Egypt. Journal of Physical Chemistry & Biophysics, Vol. 3, pp. 1-6. DOI:10.4172/2161-0398.1000123.

Kumar M., Nagaiah N., Mathews G., Ambika M., 2018. Assessment of annual effective dose due to outdoor radon activity in the environment of Bengaluru. Radiation Protection and Environment, Vol. 41, pp. 115-118. DOI: 10.4103/rpe.RPE_40_18.

Mireles F., García M., Quirino L., Dávila J., Pinedo J., Ríos C., 2007. Radon survey related to construction materials and soils in Zacatecas, México using LR-115. Radiation Measurements, Vol. 42, pp. 1397–1403. DOI 10.1007/s13753-014-0029-y.

Mittal S., Rani A., Mehra R., 2015. Estimation of Radon Concentration in Soil and Groundwater Samples of Northern Rajasthan, India. Journal of Radiation Research and Applied Science, pp. 1–6. https://doi.org/10.1016/j.jrras.2015.10.006.

Prasad G., Prasad Y., Gusain G., Ramola R., 2008. Measurement of radon and thoron levels in soil, water and indoor atmosphere of Budhakedar in Garhwal Himalaya, India. RadiationMeasurement;43(SUPPL.1):S375–S379. DOI:10.1016/j.radmeas.2008.04.050.

Rad7 User Manual, 2012. Durridge Radon Instrumentation, RAD7 Radon Detector. USA: Durridge Co.

Ramola R., Kandari M., Rawat R., 1997. Assessment of health risk due to exposure of radon and its daughter products in the lower atmosphere. Current Science Vol. 73, No. 9, pp. 771-774. https://www.jstor.org/stable/24100423.

Ridha A., Karim M., Kadhim N., 2014. Measurement of Radon Gas Concentration in Soil and Water Samples in Salahaddin Governorate-Iraq Using Nuclear Track Detector (CR-39). Civil and Environmental Research, Vol. 6, No. 1, pp. 24-30.

Righi S., Bruzzi L., 2006. Natural radioactivity and radon exhalation in building materials used in Italian dwellings. Journal of Environmental Radioactivity ;88(2):158–70. DOI:10.1016/j.jenvrad.2006.01.009.

Rodriguez A., Torres Y., Chavarria L., Molina F., 2008. soil gas radon measurements as a tool to identify permeable zones at las pailas geothermal area, Costarica. Geothermal Training Programme , pp. 1–7.

Streffer C., 2007. The ICRP 2007 recommendations. Radiation Protection Dosimetry ;127 (1–4), pp. 2–7. DOI:10.1093/rpd/ncm246.

Tabar E., Kumru M., içhedef M., Saç M., 2013. Radioactivity level and the measurement of soil gas radon concentration in Dikili geothermal area, Turkey. International Journal of Radiation Research, Vol. 11, No. 4, pp. 253–261. DOI: http://ijrr.com/article-1-1105-en.html.

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) Report to the General Assembly with Scientific Annexes, United Nations, Annexure B 97 (2000).

United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR). 2000-Sources and Effects of Ionizing Radiation: Vol. 1, 2000, pp. 1–17.

WHO. Guidelines for Drinking-water Quality. Third Edition. Volume 1. Recommendations. Who. 2004; 1:540.