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.

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 40 cm, 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 42.3 Bq/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 1 mSv.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.

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

Article information

Received: 07-June-2023
Revised: 04-Oct-2023
Accepted: 18-Oct-2023
Available online: 01-Jan-2024

Correspondence:
Name: Genan Nassir Hawas
Email: scph20m020@uokirkuk.edu.iq
DOI: 10.33899/earth.2023.140762.1092, ©Authors, 2024, College of Science, University of Mosul.
This is an open access article under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).
تقييم تركيزات الرادون في تربة مدينة كركوك

جنان ناصر هواس 1، أحمد عبد ابراهيم 2، عمر صباح التميمي 3

قسم علوم الفيزياء، كلية العلوم، جامعة كركوك، كركوك، العراق.
قسم علوم الأرض، كلية العلوم، جامعة كركوك، كركوك، العراق.

الملخص

في الدراسة الحالية، تم قياس تركيز نشاط الرادون في غاز التربة في 22 موقعًا مختلفًا في مدينة كركوك، العراق باستخدام مقياس الرادون الكهربائي (Rad-7) لثلاثة أعمق مختلفة (20 و40 و60 سم). تظهر النتائج أن معدل انبعاث غاز الرادون يختلف من موقع إلى آخر، اعتمادًا على التكوين الجيولوجي. وجد أن أعلى تركيز للرادون هو 1463 Bq/m3 في الموقع (عينة S16) وأقلها هو 0 Bq/m3 في الموقع (عينة S20 & S22) لعمق 20 سم. لعمق 40 سم، أعلى تركيز هو 33303 Bq/m3 في الموقع (عينة S12) وأقلها هو 168 Bq/m3 في الموقع (عينة S5). لعمق 60 سم، أعلى تركيز هو 12005 Bq/m3 في الموقع (عينة S20 & S22) وأقلها هو 0 Bq/m3 في الموقع (عينة S20 & S22).

تم تقدير الجرعة الفعالة السنوية (AED) بسبب استنشاق من تركيز الرادون 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 وهو أقل بكثير من المستوى المرجعي الذي أقترحه ICRP (0.1 mSv.y-1). يشير ذلك أن تركيز الرادون والجرعة الفعالة السنوية المرتبطة به لا يشكل أي نوع من المخاطر الصحية على السكان والسياح في منطقة الدراسة.

الممارسات الإرشادية

تاريخ الاستلام: 07-يونيو-2023
تاريخ المراجعة: 04-اكتوبر-2023
تاريخ القبول: 18-اكتوبر-2023
تاريخ النشر الإلكتروني: 01-يناير-2024

الكلمات المفتاحية:
غاز الرادون
Rad7
كافش
التكوين الجيولوجي
انحلال الأقا العلامة
كركوك

المراسلة:
الاسم: جنان ناصر هواس
Email: scph20m020@uokirkuk.edu.iq
DOI: 10.33899/earth.2023.140762.1092
©Authors, 2024, College of Science, University of Mosul.
This is an open access article under the CC BY 4.0 license (http://creativecommons.org/licenses/by/4.0/).

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 ± 9.7 and 355.6 ± 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.

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.**

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

**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.

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Cycle</th>
<th>Recycle</th>
<th>Mode</th>
<th>Thoron</th>
<th>Pump</th>
</tr>
</thead>
<tbody>
<tr>
<td>Grab</td>
<td>00.05</td>
<td>04</td>
<td>Sniff</td>
<td>Off</td>
<td>Auto</td>
</tr>
</tbody>
</table>

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:

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

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$^{-3}$)]

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

Where $C_{Rn}$ is the radon concentration in the air near the soil surface which is calculated using the relation (Kumar et al., 2018), $C_{SG}$ 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>
<thead>
<tr>
<th>Sample point ID</th>
<th>Depth 20 cm</th>
<th>Depth 40 cm</th>
<th>Depth 60 cm</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$C_{SG}$ (Bq/m$^3$)</td>
<td>$C_{Rn}$ (Bq/m$^3$)</td>
<td>Effective Dose (mSv/y)</td>
</tr>
<tr>
<td>S1</td>
<td>84.6</td>
<td>0.0846</td>
<td>0.000804</td>
</tr>
<tr>
<td>S2</td>
<td>8.43</td>
<td>0.00843</td>
<td>0.000801</td>
</tr>
<tr>
<td>S3</td>
<td>110</td>
<td>0.11</td>
<td>0.00104</td>
</tr>
<tr>
<td>S4</td>
<td>119</td>
<td>0.119</td>
<td>0.00113</td>
</tr>
<tr>
<td>S5</td>
<td>8.43</td>
<td>0.00843</td>
<td>0.000801</td>
</tr>
<tr>
<td>S6</td>
<td>111</td>
<td>0.111</td>
<td>0.00105</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>No.</th>
<th>Country</th>
<th>Region</th>
<th>Radon (Bq/m³)</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Iraq</td>
<td>Al Najaf City</td>
<td>9</td>
<td>9290          Hasan et al., 2011</td>
</tr>
<tr>
<td>2</td>
<td>Iraq</td>
<td>Karbala City</td>
<td>50</td>
<td>7800           Hashim et al., 2016</td>
</tr>
<tr>
<td>3</td>
<td>Iraq</td>
<td>Basra Province</td>
<td>61.18</td>
<td>2337.77        Alwan et al., 2017</td>
</tr>
<tr>
<td>4</td>
<td>Iraq</td>
<td>Amara City</td>
<td>53.18</td>
<td>2047.51        Abojassim et al., 2017</td>
</tr>
<tr>
<td>5</td>
<td>Iraq</td>
<td>AL Kufa City</td>
<td>41.45</td>
<td>12775          Al-Hamadawi et al., 2012</td>
</tr>
<tr>
<td>6</td>
<td>Iraq</td>
<td>Al Najaf Province</td>
<td>38.5</td>
<td>100            Hameed, 2015</td>
</tr>
<tr>
<td>7</td>
<td>Iraq</td>
<td>Salahaddin Province</td>
<td>45.25</td>
<td>100.75         Ridha et al., 2014</td>
</tr>
<tr>
<td>8</td>
<td>Iraq</td>
<td>Basra Sport City</td>
<td>1439</td>
<td>38765          Al-Mosawi et al., 2013</td>
</tr>
<tr>
<td>9</td>
<td>Iraq</td>
<td>Hilla City</td>
<td>25</td>
<td>12700          Hatif et al., 2016</td>
</tr>
<tr>
<td>10</td>
<td>Saudi Arabia</td>
<td>Al Qassim Area</td>
<td>26</td>
<td>340            Alharbi et al., 2013</td>
</tr>
<tr>
<td>11</td>
<td>Saudi Arabia</td>
<td>Jazan Region</td>
<td>896.81</td>
<td>302.91         Aseeri et al., 2018</td>
</tr>
<tr>
<td>12</td>
<td>Jordan</td>
<td>Irbud Province</td>
<td>697</td>
<td>6335           Ershadat et al., 2013</td>
</tr>
<tr>
<td>13</td>
<td>Turkey</td>
<td>Dikili Geothermal Area</td>
<td>98</td>
<td>8594           Tabar et al., 2013</td>
</tr>
<tr>
<td>14</td>
<td>Palestine</td>
<td>Gaza</td>
<td>23.48</td>
<td>584.15         Hamed, 2005</td>
</tr>
<tr>
<td>15</td>
<td>Egypt</td>
<td>Southwestern Sinai</td>
<td>648</td>
<td>21361          Korany et al., 2013</td>
</tr>
<tr>
<td>16</td>
<td>Italy</td>
<td>Bolena</td>
<td>7</td>
<td>176            Cimelli et al., 2015</td>
</tr>
<tr>
<td>17</td>
<td>Iraq</td>
<td>Kirkuk City</td>
<td>0</td>
<td>12005          Present study</td>
</tr>
</tbody>
</table>

**Results and Discussion**

The 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 Al 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.
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


