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# Comparative Study Between Virgin and Agriculture Soil Radon Activity Concentration and Their Radiological Risks

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# Comparative Study Between Virgin and Agriculture Soil Radon Activity Concentration and Their Radiological Risks


## Abstract

The present study is to compare the radon activity concentration in agricultural and virgin soils from various locations along the Little Zab River (LZR) in the Iraqi Kurdistan region. We conducted 24 measurements of soil samples using long tube techniques equipped with an electric radon detector called RAD7 in our research. The findings revealed that the radon activity concentrations ranged from 37.3 ± 7.52 Bq m-3 to 298.25 ± 50.09 Bq m-3 in virgin soil, and from 33.03 ± 10.85 Bq m-3 to 320.25 ± 34.62 Bq.m-3 in agriculture soil. The annual effective dose was also calculated to be from 0.94 ± 0.19 mSv.y-1 to 8.08 ± 0.87 mSv.y-1 for virgin soil, and from 0.83 ± 0.27 mSv.y-1 to 8.08 ± 0.87 mSv.y-1 for agriculture soil in the Iraqi Kurdistan Region. The field dose rates were measured using the RIIDEye Handheld Radiation Isotope Identifier and found to be within the range 56.8 nSv h-1 to 80.6 nSv h-1. It was observed that Agricultural soil has the highest radiation dose for humans compared to virgin soil.



## Keywords

Radon.; RAD7; Agriculture soil; Virgin soil; Radiological risks

## Cover Page Footnote

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ORIGINAL ARTICLE

# Comparative Study Between Virgin and Agriculture Soil Radon Activity Concentration and Their Radiological Risks

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**Abstract**

**This study aims to compare the levels of radon gas in agricultural and virgin soils from various locations along the Little Zab River (LZR) in the Kurdistan region - Iraq. We conducted 24 measurements of soil samples using long tube techniques equipped with an electric radon detector called RAD7 in our research. The findings revealed that the radon activity concentrations ranged from 37.3 ± 7.52 Bq m$^{-3}$ to 298.25 ± 50.09 Bq m$^{-3}$ in virgin soil, and from 33.03 ± 10.85 Bq m$^{-3}$ to 320.25 ± 34.62 Bq.m$^{-3}$ in agriculture soil. The annual effective dose was also calculated to be from 0.94 ± 0.19 mSv y$^{-1}$ to 7.52 ± 1.26 mSv y$^{-1}$ for virgin soil, and from 0.83 ± 0.27 mSv y$^{-1}$ to 8.08 ± 0.87 mSv y$^{-1}$ for agriculture soil in the Iraqi Kurdistan Region. The field dose rates were measured using the RIIDEye Handheld Radiation Isotope Identifier and found to be within the range 56.8 nSv h$^{-1}$ to 80.6 nSv h$^{-1}$. It was observed that Agricultural soil has the highest radiation dose for humans compared to virgin soil.**

*Keywords:* Radon, RAD7, Agriculture soil, Virgin soil, Radiological risks

## 1. Introduction

The primary origin of ionizing radiation, constantly affecting humans, stems from the Earth's crust, where uranium, thorium, and their by-products exist in the environment [1]. Studies conducted in the past few decades have demonstrated that, under typical circumstances, over 70 % of the overall yearly radioactive exposure received by individuals arises from natural sources of ionizing radiation. Specifically, 54 % of this exposure can be attributed to the inhalation and ingestion of the natural radioactive gas radon ($^{222}$Rn) and its subsequent decay products [2]. Natural radioactive materials, including radon gas, have become a major focus of the International Atomic Energy Agency (IAEA) and are frequently discussed in IAEA publications and reports, as well as in directives issued by the European Council [3].

Radon, an odourless and tasteless radioactive gas, occurs naturally and possesses a density approximately 7.5 times greater than that of air [4]. Radon gas and its radioactive isotopes are of particular concern because they are the most significant source of radiation exposure to humans [5]. Radon is a radioactive gas that is constantly being produced in the Earth's crust. It is created when naturally occurring radioactive elements, such as uranium and thorium, decay. Radon can be found in all types of soil and rock, and it can enter homes through cracks in the foundation or basement. Once inside a home, radon can build up to high levels and become a health hazard [6].

Radon is a naturally occurring gas that breaks down quickly, with a half-life of 3.8 days. It is

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unique in that it remains a gas even though it is one of the densest substances known. Radon has been linked to lung cancer and is second only to smoking as a cause of this disease [7]. Long-term radon exposure through inhalation in closed rooms, caverns, or open-air saturated with Radon gas accounts for approximately 10 % of all lung cancer-related fatalities [8]. Several studies have documented the correlation between radon exposure and the occurrence of kidney and malignant melanoma cancers. Additionally, radon can be found dissolved in underground water in the soil. Studies have revealed that the ingestion of water contaminated with radon poses a significant risk of developing stomach and colon-rectal cancer [9].

Radioactive nuclides in soil can build up when they attach to soil particles and when rain falls on the soil. They can be removed from the soil by leaching and dilution. The behaviour of radioactive nuclides in soil is affected by the characteristics of the soil, the amount and rate of rainfall, and the drainage of the soil [10].

The amount of naturally occurring radioactive elements in soil can vary depending on where in the world you are. One of the main sources of radioactive materials in soil that are not naturally occurring is the use of chemical fertilizers in agriculture [11]. Farmers apply chemical fertilizers to their fields to boost crop yields [10].

Furthermore, substances used in fertilizers, including phosphates containing uranium-238 and thorium-232, as well as potassium used in plant fertilization, are recognized as significant contributors to soil pollution and the potential origin of radioactive elements [12]. This occurrence has the potential to give rise to radiological hazards, stemming from both external exposure when residing on farms for extended periods and internal exposure through the consumption of crops grown in soil enriched with phosphate fertilizers. Over time, the use of phosphate fertilizers may lead to an escalation in the levels of radium and uranium within the soil, ultimately leading to higher radiation doses. This, in turn, could result in an associated increase in radiation exposure and potentially lead to health issues in the human body [13]. Its direct precursor is $^{226}$Ra, and $^{222}$Rn undergoes alpha particle emission in a chain of relatively short-lived decay elements, primarily involving polonium, lead, and bismuth isotopes. This process leads to the formation of $^{210}$Pb and ultimately to the stable element $^{206}$Pb [14].

This research aims to evaluate the radon activity concentration in soils taken from different spots along the Little Zab River (LZR) in the Iraqi Kurdistan region. This analysis employs long tube techniques with the RAD7 semiconductor radon detector. Additionally, it offers a comparison of the findings between the virgin and agricultural soils.

## 2. Materials and Method

### 2.1. Description of the area

Numerous agricultural sectors are situated along the banks of the Little Zab River (LZR), serving as the primary origin of agricultural goods in the Kurdistan Region - Iraq. In these regions, farmers utilize fertilizers, potentially leading to higher levels of radioactive substances in the soil they cultivate. To gather soil samples for analysis, we selected 12 distinct locations along the Little Zab River (LZR) within the Kurdistan region of Iraq. You can find the coordinates for the sampling sites in Table 1. The locations where samples were taken are indicated in Fig. 1, displaying their geographical positions. These locations consist of 12 farms and 12 virgin fields. The study area falls within latitudes 36°13′18.0″ N and 35°47′23.3″ N and longitudes 45°13′58.2″ and 44°10′26.3″ E as shown in Fig. 1.

### 2.2. Sample collection and preparation

In the investigated region, a total of 24 soil samples were gathered. These samples were acquired through a core technique, utilizing a core measuring 15 cm in diameter and reaching a depth of 20 cm [15]. The significance of soil depth becomes particularly pronounced when there is a non-uniform distribution of radionuclides within the different layers of soil [16]. To mitigate the impact of this factor, the International Union of Radioecology (IUR) suggests using a standardized soil depth for root placement [17]. After eliminating stones and non-organic substances from the soil samples, the soil specimens were subjected to a 24-hour drying period at 110 °C in an electric oven to remove all moisture content [18]. Following this, the soil was crushed and passed through a 2 mm mesh sieve, enhancing the uniformity of particle size distribution. This procedure standardized the soil's particle sizes [15].

After drying, the powder of each soil sample was packed in a plastic container of volume 115.5 cm$^3$ and the sample surface area was 38.5 cm$^2$, as shown in Fig. 2. The samples in the long tube's lower container are 3 cm thick, which is the optimum thickness of the sample [19]. The mass of the samples is about 150 gm. The long-tube chamber was made of PVC (polyvinyl choired) which is an

*Table 1. Activity concentration of Radon in virgin and agricultural soil along LZR.*

| Name | Longitude | Latitude | Activity concentration of Radon ($Bq.m^{-3}$) | |
|---|---|---|---|---|
| | | | Virgin soil | Agriculture soil |
| Shexawdalan | 36°13′42.4″N | 45°13′19.7″E | 65.85 ± 12.95 | 92 ± 31.36 |
| Sndolan | 36°10′42.4″N | 45°03′10.5″E | 37.3 ± 7.52 | 134.75 ± 38.47 |
| Braymawa | 36°12′00.1″N | 45°03′29.5″E | 298.25 ± 50.09 | 312.75 ± 95.43 |
| Grdastera | 36°16′17.6″N | 45°07′18.9″E | 111.58 ± 26.14 | 86.18 ± 12.91 |
| Zarawa | 36°13′41.2″N | 45°04′21.3″E | 227.5 ± 7.55 | 247.75 ± 22.19 |
| Bastasten | 36°14′22.8″N | 45°03′10.8″E | 296.5 ± 41 | 320.25 ± 34.62 |
| Sangasar | 36°14′48.8″N | 45°01′00.4″E | 104 ± 22.88 | 179 ± 7.75 |
| Daraban | 36°24′07.3″N | 44°45′12.4″E | 237.75 ± 21.78 | 199.5 ± 22.01 |
| Saruchawa | 36°16′26.9″N | 44°45′02.2″E | 256.5 ± 53.69 | 200.75 ± 32.19 |
| Khdran | 36°07′56.7″N | 44°47′03.0″E | 115.75 ± 19.65 | 127.58 ± 38.1 |
| Goptapa | 35°50′58.8″N | 44°50′10.9″E | 119 ± 28.35 | 33.03 ± 10.85 |
| Taq Taq | 35°52′04.9″N | 44°26′08.5″E | 43.8 ± 5.3 | 59.08 ± 24.79 |

impermeable and tight container to prevent the escape of radon gas [20]. The sample has been kept at ambient temperature for a minimum of one month. During this period, the tube chamber has attained a state of secular equilibrium between radium, and it is decay products [21].

### 2.3. Radon gas measurements

The long tube techniques equipped with an electric radon detector called RAD7 were used to measure the radon gas in soil samples in our research. The RAD7 detector is a highly adaptable instrument

*Fig. 2. The schematic diagram for measuring radon in the soil samples.*

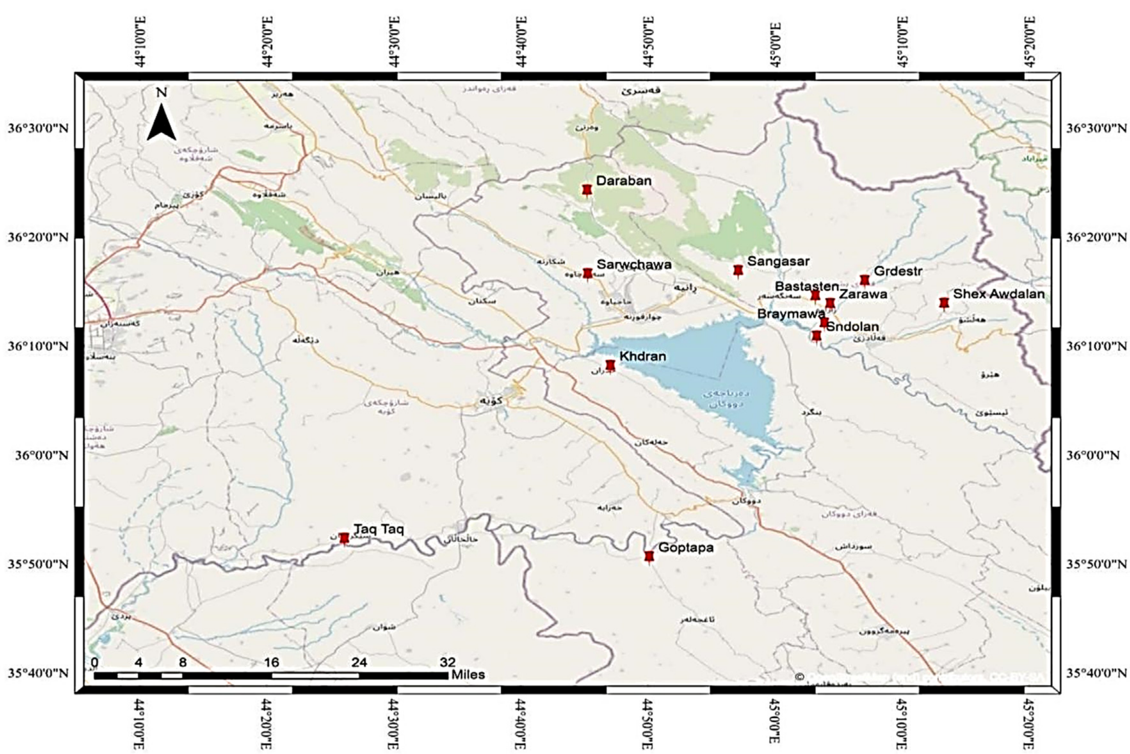


*Fig. 1. The latitude and longitude of soil collection points along LZR.*

that forms the core of a complete radon measurement system. The radon monitor can be used in a variety of ways to meet different needs. It can continuously monitor radon levels in the air, detect radon during air testing, collect air samples for analysis, measure radon in water, and assess radon levels in soil gas [22]. The RAD7 radon detector, made by DURRIDGE Company-USA, uses a solid-state alpha particle detector in a hemispherical chamber to measure radon levels. As shown in Fig. 3, the internal sample cell of the RAD7 instrument consists of a 0.7-litre hemisphere that has been coated internally with an electrical conductor [23]. It can create the energy spectrum for α-particles emitted from the decay products of radon-220 and radon-222 in the range of 0–10 MeV [24,25].

When a $^{222}$Rn nucleus undergoes decay inside the cell, it produces a positively charged ion known as Polonium ($^{218}$Po), which is the resulting nucleus of the transformation. The electric field in the cell pushes the positively charged ion towards the detector. When the short-lived polonium nucleus ($^{218}$Po) decays on the surface of the active detector, its alpha particle has a 50 % chance of entering the detector and creating an electrical signal [26]. The strength of this signal is directly proportional to the energy of the alpha particle. Various isotopes possess different alpha energies, resulting in distinct signal strengths within the detector [27].

### 2.4. The annual effective dose of radon gas inhalation

The amount of radiation exposure to the lungs from breathing in radon gas from the soil can be estimated using the following mathematical models [2]:

$$AED\,(mSv/y) = C_{Rn}\,.\,F\,.\,T\,.\,O\,.\,D$$

The equilibrium factor, or F, is a measure of how well the concentration of radon daughters in

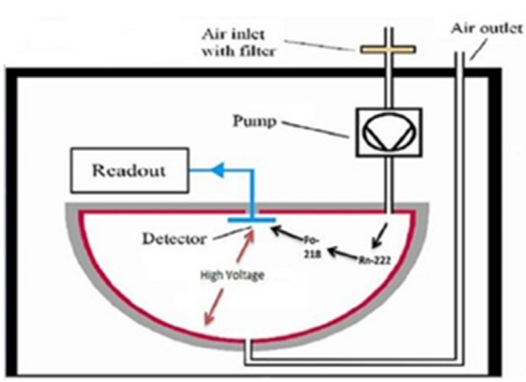


*Fig. 3. The internal sample cell unit of the RAD7 detector.*

the air matches the concentration of radon gas and is equal to 0.4. Radon daughters are radioactive particles that are created when radon gas decays. T is the amount of time people spend annually, and it is 8760 h per year. O is a factor that accounts for how much time people spend indoors. To calculate the total dose of radiation people receive, the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) uses 0.8 as an indoor occupancy factor (O). This means that people spend 18% of their time indoors on average. The amount of radiation dose received by the lungs of adults per unit of radon concentration in the air is measured by dose conversion coefficient D. In this case, the dose conversion coefficient is $9 \times 10^{-6}$ mSv per Bq.m$^{-3}$, which means that for every becquerel of radon per cubic meter of air, adults receive an effective dose of $9 \times 10^{-6}$ mSv to their lungs [25]. The global average annual exposure dose (AED) resulting from inhaling radon gas is determined to be 1.2 millisieverts per year, as indicated in the findings presented in the report [29–31].

## 3. Results and Discussion

Table 1 displays the radon activity concentrations measured in soil samples obtained from 12 different locations, along with their corresponding geographical coordinates. The measured radon concentration values in virgin (they do not receive any kind of fertilizer) and agriculture soil (they use fertilizers for agricultural growth) vary from 37.3 ± 7.52 Bq.m$^{-3}$ to 298.25 ± 50.09 Bq.m$^{-3}$ and 33.03 ± 10.85 Bq.m$^{-3}$ to 320.25 ± 34.62 Bq.m$^{-3}$ with average values of 159.48 ± 24.74 Bq.m$^{-3}$ and 166.05 ± 30.88 Bq.m$^{-3}$, respectively. It is generally observed that agricultural soil contains higher levels of radon compared to undisturbed soil. This is due to human activities such as irrigation, water usage, decomposition of organic matter, and the application of fertilizers, contributing to the elevated levels of radon in agricultural soil [10]. It's crucial to understand that the concentration of radon in agricultural soil can differ due to several factors, including geographical location, soil composition, agricultural practices, and local sources of radon.

### 3.1. Radon health risk assessment

According to the results presented in Table 2, the annual effective doses resulting from inhalation of radon in virgin and agricultural soil gas varied from 0.94 ± 0.19 to 7.52 ± 1.26 mSv. y$^{-1}$ for virgin soil, and from 0.83 ± 0.27 to 8.08 ± 0.87 mSv. y$^{-1}$ for agriculture soil. The mean values for virgin and

*Table 2. AED from the inhalation of radon in virgin and agricultural soil along LZR.*

| Name | AED Inhalation of Radon in soil ($mSv.y^{-1}$) | |
|---|---|---|
| | Virgin soil | Agriculture soil |
| Shexawdalan | 1.66 ± 0.33 | 2.32 ± 0.79 |
| Sndolan | 0.94 ± 0.19 | 3.4 ± 0.97 |
| Braymawa | 7.52 ± 1.26 | 7.89 ± 2.41 |
| Grdastera | 2.81 ± 0.66 | 2.17 ± 0.33 |
| Zarawa | 5.74 ± 0.19 | 6.25 ± 0.56 |
| Bastasten | 7.48 ± 1.03 | 8.08 ± 0.87 |
| Sangasar | 2.62 ± 0.58 | 4.52 ± 0.2 |
| Daraban | 6.00 ± 0.55 | 5.03 ± 0.56 |
| Saruchawa | 6.47 ± 1.35 | 5.06 ± 0.81 |
| Khdran | 2.92 ± 0.5 | 3.22 ± 0.96 |
| Goptapa | 3.00 ± 0.72 | 0.83 ± 0.27 |
| Taq Taq | 1.11 ± 0.13 | 1.49 ± 0.63 |
| Mean values | 4.02 ± 0.62 | 4.18 ± 0.78 |

agricultural soil were determined to be 4.02 ± 0.62 mSv. $y^{-1}$ and 4.18 ± 0.78 mSv. $y^{-1}$, respectively. It was observed that agricultural soil has the highest radiation dose for humans compared to virgin soil.

Importantly, the study findings indicated that the annual effective doses received by the population from these two soil types, except virgin soil from Sndolan and agricultural soil from Goptapa, were higher than the recommended annual effective dose limit of 1 mSv. $y^{-1}$ for the general public, as suggested by the International Commission on Radiological Protection (ICRP) and UNSCEAR [28].

### 3.2. Descriptive statistics and distribution of measured data

The measured radon concentrations, their descriptive statistics and distributions in both soil types are shown in Fig. 4. The lower panel compares the radon density between the two soils. One can easily see that in most areas the densities of the gas in the soils are fairly close, which is further confirmed by the strong positive Pearson Correlation (r = 0.855), and they fluctuated simultaneously except for Goptapa, Sangasar and Sndolan, where the residuals between the virgin and agriculture soils radon concentration are 86 Bq $m^{-3}$, 75 Bq $m^{-3}$ and 97 Bq $m^{-3}$, respectively. In these regions, the difference between gas densities is very noticeable among all the other places. The middle panel shows the descriptive statistics of the measured data using box plots. Each box plot, alternatively called a box and whisker plot is a prevalent chart in exploratory data analysis within descriptive statistics. It depicts the distribution and skewness of numerical data by displaying quartiles (or percentiles) and means. Box

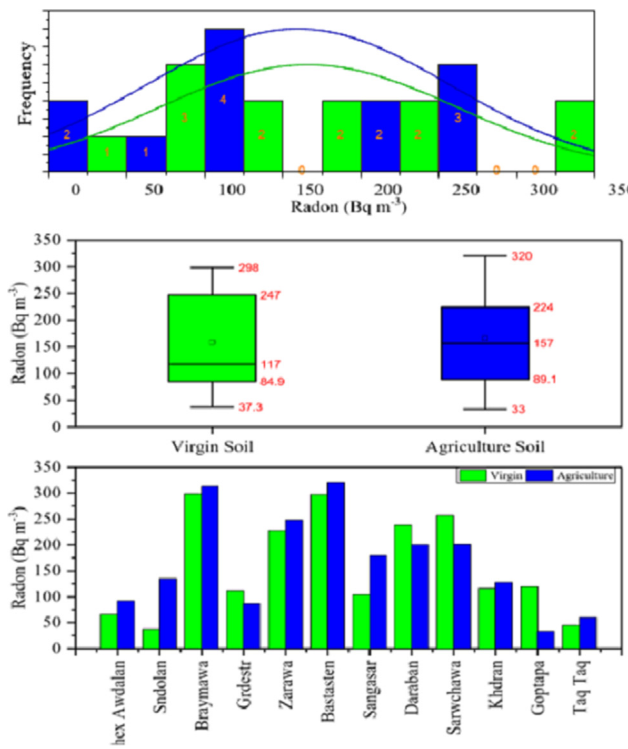


*Fig. 4. The descriptive statistics and distribution of measured data.*

plots provide a comprehensive summary of the measured concentrations by exhibiting the five number summary, which are the minimum value 37.3 Bq $m^{-3}$, first quartile 84.9 Bq $m^{-3}$, median 117 Bq $m^{-3}$, third quartile 247 Bq $m^{-3}$, and maximum value 298 Bq $m^{-3}$ for virgin soil, and which are the minimum value 33 Bq $m^{-3}$, first quartile 89.1 Bq $m^{-3}$, median 157 Bq $m^{-3}$, third quartile 224 Bq $m^{-3}$, and maximum value 320 Bq $m^{-3}$ for the agriculture soil.

## 4. Conclusions

This study focused on comparing radon levels on agricultural and virgin lands using long-tube techniques equipped with the RAD7 electronic radon detector. The annual effective dose resulting from most of the soil samples collected from both virgin and agricultural areas was found to be higher than acceptable limits. The average radon concentration in virgin soil gas was determined to be 159.43 Bq $m^{-3}$, while in agricultural soil; it was measured to be 166.05 Bq $m^{-3}$. The activity concentration of radon in agricultural soil is generally greater than in virgin soil due to several factors: Human activities, irrigation and water usage, organic matter decomposition, and fertilizer usage. It's important to note that the specific radon concentrations in agricultural soil can vary depending on various factors, including geographical location, soil composition, agricultural practices, and local radon sources [10,32,33]. Therefore, while it is generally observed that agricultural soil has higher radon concentrations compared to virgin soil, local conditions and practices can influence the actual levels.

The average annual effective dose in virgin soil gas was determined to be 4.02 mSv $y^{-1}$, while in agriculture soil; it was measured to be 4.18 mSv $y^{-1}$. These measurements are highly valuable for assessing the health hazard index associated with radon exposure along LZR (presumably a specific location or parameter). They provide important information for estimating the potential risks and evaluating the level of health hazards posed by radon exposure in that particular area.

## Author contributions

Hiwa H. Azeez, Jahfer M. Smail, and Hemn Salh designed and performed the experiments. All the authors have analyzed data and assisted in. Habeeb H. Mansour, Sahdon T. Ahmed, and Hawbash H Karim reviewed and edited the manuscript.

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## Conflict of interest

There were no disclosed conflicts of interest about the research or writing of this work.

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## References

[1] Aswood MS, Jaafar MS, Salih N. Estimation of Radon Concentration in Soil Samples from Cameron Highlands, Malaysia. Int J Sci Technol Soc 2017;5(1):9–12.
[2] UNSCEAR. Sources and effects of ionizing radiation, ANNEX B, Exposures from natural radiation sources. Vol. 1, United Nations Publications. New York: Scientific Committee on the Effects of Atomic Radiation; 2000.
[3] Kant K, Upadhyay SB, Sonkawade RG, Chakarvarti SK. Radiological risk assessment of use of phosphate fertilizers in soil. Iran J Radiat Res 2006;4(2):63–70.
[4] Hussein ZA, Ismail AH, Battawy AA, Karim HH&SJM. Indoor radon levels in apartments of Erbil city by using long and short term techniques. Tikrit J Pure 2018;21(3): 150–4.
[5] Ujić P, Čeliković I, Kandić A, Žunić Z. Standardization and difficulties of the thoron exhalation rate measurements using an accumulation chamber. Radiat Meas 2008;43(8):1396–401.
[6] Haji S O, Ahmed A H, Azeez H H. Radon concentration Measurements in Qaysare of Erbil City. Kirkuk Univ Journal-Scientific Stud. 2015;10(3):332–44.
[7] Handbook of parameter values for the prediction of radionuclide transfer in temperate environments. Int At Energy Agency 1994:364.
[8] BO G, OO D, IM O. Measurement of Radon Concentration and Radioactivity in Soil Samples of Aramoko , Ekiti State , Nigeria. Int J Public Heal Res 2016;4(5):37–41.
[9] Oni OM, Yusuff IM, Adagunodo TA. Measurement of Radon-222 Concentration in Soil-Gas of Ogbomoso Southwestern Nigeria using RAD7. Int J Hist Sci Stud Res 2019; 1(3):26–33.
[10] Azeez HH, Mansour HH, Ahmad ST. Effect of using chemical fertilizers on natural radioactivity levels in agricultural soil in the Iraqi Kurdistan Region. Pol J Environ Stud 2020 Jan;29(2):1059–68.
[11] Abbady A, El-Arabi AM, Abbady AGE, Taha S. Gamma-ray measurements of natural radioactivity in cultivated and reclaimed soil , Upper Egypt. Int Conf Radioecol Environ Radioact 2008:15–20.
[12] Azeez HH, Ahmad ST, Hanna H. Assessment of radioactivity levels and radiological-hazard indices in plant fertilizers used in Iraqi Kurdistan Region. J Radioanal Nucl Chem [Internet] 2018;317(3):1273–83. https://doi.org/10.1007/s10967-018-6001-3.
[13] Righi S, Lucialli P, Bruzzi L. Health and environmental impacts of a fertilizer plant - Part I: Assessment of radioactive pollution. J Environ Radioact 2005;82(2):167–82.
[14] Esan DT, Sridhar MKC, Obed R, Ajiboye Y, Afolabi O, Olubodun B, et al. Determination of Residential Soil Gas Radon Risk Indices Over the Lithological Units of a Southwestern Nigeria University. Sci Rep 2020;10(1):1–10.
[15] Smail JM, Ahmad ST, Mansour HH. Estimation of the natural radioactivity levels in the soil along the Little Zab River, Kurdistan Region in Iraq. J Radioanal Nucl Chem 2021: 0123456789.
[16] Guillen J, Baeza A, Salas A, Muñoz-Muñoz JG, Muñoz-Serrano A. Factors Influencing the Soil to Plant Transfer of Radiocaesium. Impact Cesium Plants Environ [Internet] 2017:19–33. Available from: https://link.springer.com/chapter/10.1007/978-3-319-41525-3_2.
[17] Protocol IUR. developed by the working group on soil to plant transfer, 1982-1992. France: Saint-Paul-lez-Durance; 1992.
[18] Smail JM, Mansour HH, Ahmad ST, Smail JM, Mansour HH, Ahmad ST. Evaluation of radiological hazards in lower zab river sediments. Radiat Eff Defects Solids 2023;178(10): 1252–68.
[19] Csige I, Szabo Z, Szab0 C. Experimental technique to measure thoron generation rate of building material samples using RAD7 detector. Radiat Meas [Internet] 2013;59:201–4. https://doi.org/10.1016/j.radmeas.2013.07.003.
[20] Mansour HH. Design of long- tube techniques for discrimination of radon (Rn-222) in building materials and soil using CN-85 nuclear track detector. Iraq: Mustansiriyah University; 2000.
[21] Babakr DA, Ahmad ST, Taha AH. Assessment of radioactivity levels in soil of Koya district in Kurdistan Region-Iraq using high-purity germanium detector. Jordan J Phys 2022; 15(3):259–77.
[22] Ridha AA, Karim MS, Kadhim NF. Measurement of Radon Gas Concentration in Soil and Water Samples in Salahaddin Governorate-Iraq Using Nuclear Track Detector (CR-39). Civ Environ Res 2014;6(1):24–30.
[23] Durridge. Rad7 radon detector user manual. DURRIDGE Co Inc; 2015. p. 1–81 (978).
[24] Durridge Company. Rad7 radon detector [Internet]. USA: Durridge Company Inc.; 2014. p. 1–81. Available from: www.durridge.com.

[25] Azeez HH, Mohammed MA, Abdullah GM. Measurement of radon concentrations in rock samples from the Iraqi Kurdistan Region using passive and active methods. Arabian J Geosci 2021;14(7):1−9.
[26] Smail JM, Azeez HH, Mansour HH, Ahmad ST. Radon Activity Concentration Measurements in the Water Collected from the Lower Zab River in the Kurdistan Region of Iraq. Aro-the Sci J Koya Univ. 2023;11(2):51−8.
[27] Ezzulddin SK, Mansour HH. Radon and radium activity concentration measurement in drinking water resources in Kurdistan Region-Iraq. J Radioanal Nucl Chem 2020;324(3): 963−76.
[28] UNSCEAR. Sources and effects of ionising radiation. New York: United Nations Publications; 1993.
[29] WHO. Guidelines for drinking-water quality. Third. Vol. 1, world health organisation. Geneva, Switzerland: WHO Press; 2008. p. 564.
[30] International Commission on Radiological Protection. Publication 63: Principles for Intervention for Protection of the Public in a Radiological EmergencyVol. 63. Elsevier Health Sciences; 1993.
[31] International Commission on Radiological Protection. Publication 119: Compendium of Dose Coefficients based on ICRP Publication 60Vol. 41. Elsevier Health Sciences; 2012.
[32] Jakhu R, Mehra R, Bangotra P, Kaur K, Mittal HM. Estimation of terrestrial radionuclide concentration and effect of soil parameters on exhalation and emanation rate of radon. J Geochemical Explor [Internet] 2018;184(September): 296−303. https://doi.org/10.1016/j.gexplo.2017.03.002.
[33] Mittal S, Rani A, Mehra R. Estimation of radon concentration in soil and groundwater samples of Northern Rajasthan, India. J Radiat Res Appl Sci [Internet] 2016;9(2):125−30. Available from: http://linkinghub.elsevier.com/retrieve/pii/S168785071500117X.